UNIVERSITAS INDONESIA

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Oleh :

ESTU PRAYOGI

NPM : 700503023X

PROGRAM STUDI

MAGISTER KESELAMATAN DAN KESEHATAN KERJA

FAKULTAS KESEHATAN MASYARAKAT

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Tesis ini diajukan sebagai salah satu persyaratan untuk memperoleh gelar

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Universitas Indonesia
Fakultas Kesehatan Masyarakat
Program Studi Magister Keselamatan dan Kesehatan Kerja

Tesis, Juli 2008
Estu Prayogi,NPM 700503023X

KAJIAN KESELAMATAN KOREK API GAS *CHILD RESISTANT* PRODUKSI PT. TOKAI DHARMA INDONESIA DENGAN UJI EKSPERIMENTAL BEBAN IBU JARI ANAK DAN UJI BEBAN UNTUK MENYALAKAN API

ix + 100 halaman, 18 tabel, 22 gambar, 18 lampiran

ABSTRAK

Dilandasi tingginya angka kecelakaan kebakaran yang diakibatkan oleh anak bermain dengan korek api gas,bertumbuhnya perokok di Indonesia menimbulkan implikasi negatif tidak saja terhadap kualitas kesehatan tetapi menyangkut kehidupan sosial dan ekonomi, berdampak pula pada peningkatan penggunaan korek api, salah satunya adalah korek api gas. Korek api gas dengan bentuk yang kecil merupakan produk konsumtif yang mengandung potensi bahaya tersendiri. Apalagi bila diletakkan di sembarang tempat yang bisa dijangkau oleh anak-anak. Akan menjadi sangat beresiko apabila disalahgunakan oleh anak-anak untuk bermain-main dan secara tidak sengaja menyebabkan kebakaran, cedera serius bahkan kematian.

Korek api gas child resistant produksi PT. Tokai Dharma Indonesia, sejak Maret 2007 telah dipasarkan, sebagai produk yang dinyatakan aman bagi anak. Untuk menyakinkan kegunaan child resistant tersebut penelitian ini adalah untuk mengkaji keselamatan korek api gas child resistant apakah betul aman tidak bisa dioperasikan oleh anak hingga usia lima tahun.

Menggunakan metoda uji eksperimental meneliti kekuatan ibu jari anak berdasarkan usia hingga 9 tahun dengan menekan beban uji dan melakukan uji eksperimental beban yang diperlukan untuk menyalakan api di mesin load test terhadap korek api gas child resistant. Kemudian dengan membandingkan berapa gaya yang diperlukan untuk menyalakan api dan berapa gaya yang mampu dihasilkan oleh ibu jari anak. Tingkat keamanan akan dicapai bila gaya yang mampu dihasilkan anak lebih kecil daripada gaya yang dicapai oleh mesin load test untuk menyalakan api.

Hasil dari 93 responden beban gaya terendah 10 Newton dapat dicapai hingga katagori usia 84 bulan, beban tertinggi hingga 40 Newton dicapai hingga usia 108 bulan, semakin tinggi usia semakin tinggi gaya yang sanggup dihasilkan.
Dari 50 sample korek uji di mesin load test beban terendah untuk menyalakan api tercapai pada 15,5 Newton dan tertinggi pada 27 Newton.
Hasil perhitungan dan distribusi gaya sesungguhnya untuk 15,5 Newton gaya yang diperlukan untuk menyalakan korek api adalah sebesar 52,245 Newton. Kemampuan ibu jari anak hingga usia 60 bulan(5tahun) adalah 20 Newton dan lebih kecil dari gaya yang diperlukan untuk menyalakan sebesar 52,245 Newton.

Kesimpulan dari penelitian ini korek api gas child resistant mempunyai tingkat keamanan hingga 2,61 kali dari kemampuan beban kekuatan ibu jari anak hingga batasan usia 5 tahun. Sehingga betul aman untuk tidak bisa dioperasikan anak hingga usia 5 tahun dan dikatagorikan dalam tingkatan resiko yang rendah untuk fungsi child resistant.

Kata Kunci : Child Resistant, Korek api gas, kebakaran, anak usia 5 tahun.

References : 22 (1980 – 2007)

University of Indonesia
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Master of Occupational Health and Safety Program.

Thesis,July 2008
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STUDY OF EFFECTIVENESS OF THE CHILD RESISTANT CIGARETTE LIGHTER PRODUCE OF PT.TOKAI DHARMA INDONESIA WITH EXPERIMENTAL FORCE OF THE CHILD'S THUMB AND FORCE TO SPARK THE LIGHTER.

ix + 100 pages, 18 tables, 22 pictures, 18 appendices

ABSTRACT

Fire accident are a leading which is caused by children playing with gas lighter and the increasing of smoker in Indonesia not only cause negative effects to the quality of public health and public social and economic, but also cause the increase of using lighter, one of the example cigarette gas lighter. The small gas lighter is a consumptive product which can cause danger to the user itself. Moreover, if it is placed not in proper place so the child can use it. This can be a high risk if children use it not in proper way or for playing only, which are accidentally cause of gas lighter, serious injury, the worst is causing death.

The child resistant cigarette lighter produce of PT. Tokai Dharma Indonesia, has launched since March 2007, as a child resistant product. To convince the using of this product, the aim of this research is to study the effectiveness of the child resistant cigarette lighter, and child resistant mechanism is it really safe to the children under five years.

Methods: Test experimental by research force of child's thumb under 9 years old to pushed the push gauge test and on load test machine experimental to spark the child resistant lighter. Comparing forced of the child's respondent and force which can ignited spark of child resistant lighter. The safety factor was result if the child force less than force to ignited spark of child resistant lighter.

Result the minimum force from 93 respondents, the minimum force 10 Newton can be achieved by child under 84 months, the maximum force is 40 Newton is achieved by child under 108 months, the more high the age is the more high the force can be produced.

From 50 child resistant lighter samples in load test machine, the minimum force to spark is result on 15.5 Newton, and the maximum is 27 Newton.

The calculating and distributing result of the real force for 15.5 Newton, needs 52.245 Newton to spark on. Whereas, the ability of child's thumb under 60 months (5 years) is only 20 Newton, it is less than the needed force which is 52.245 Newton.

The conclusion: child resistant cigarette lighter has a effectiveness up to 2.61 times from child's thumb force under 5 years old. Thus, it really safe for not being used by children under 5 years old and categorized in lowest risk to child resistant function.

Key words : Child Resistant, Gas lighter, fire, Children under 5 years.

References : 22 (1980 – 2007)

PERNYATAAN PERSETUJUAN

Tesis dengan judul

KAJIAN KESELAMATAN KOREK API GAS *CHILD RESISTANT* PRODUKSI PT. TOKAI DHARMA INDONESIA DENGAN UJI EKSPERIMENTAL BEBAN IBU JARI ANAK DAN UJI BEBAN UNTUK MENYALAKAN API

Telah disetujui, diperiksa dan dipertahankan dihadapan Tim Penguji Tesis Program Pascasarjana Magister Keselamatan dan Kesehatan Kerja Fakultas Kesehatan Masyarakat Universitas Indonesia

Depok, 12 Juli 2008

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Apabila suatu saat nanti terbukti saya melakukan tindakan plagiat, maka saya akan menerima sanksi yang telah ditetapkan.

Demikian surat pernyataan ini saya buat dengan sebenar-benarnya.

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8. **PT. Tokai Dharma Indonesia, Depok 1995- saat ini.**

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Tesis dengan judul "KAJIAN KESELAMATAN KOREK API GAS *CHILD RESISTANT* PRODUKSI PT. TOKAI DHARMA INDONESIA DENGAN UJI EKSPERIMENTAL BEBAN IBU JARI ANAK DAN UJI BEBAN UNTUK MENYALAKAN API" masih jauh dari harapan sempurna, akan tetapi diharapkan dapat menambah khasanah ilmu pengetahuan, pengenalan produk yang berorientasi keselamatan serta menjadikan motivasi kepada pembaca untuk lebih mendalami dan melakukan penelitian lebih lanjut.

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Depok, Juli 2008

DAFTAR ISI

DAFTAR TABEL

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DAFTAR LAMPIRAN

Nomor lampiran

BAB 1

PENDAHULUAN

1.1. Latar Belakang Masalah

Korek api gas pada saat ini sangat mudah ditemukan dimana-mana, fungsinya sebagai alat yang dapat menghasilkan nyala api secara manual membantu kita dalam kebutuhan terhadap api sehari-hari, baik untuk menyalakan rokok, lilin, kompor dan banyak lagi kegunaannya.

Para perokok merupakan pihak yang paling merasakan manfaat dari korek api gas, ukurannya yang relatif kecil dan berat yang juga relatif ringan menjadikannya sebagai penghasil api yang praktis dan mudah dibawa kemana saja.

Dikemukakan dalam peringatan Hari Anti Tembakau Internasional Maret 2003, bahwa Indonesia termasuk dalam lima besar konsumsi rokok di seluruh dunia. Konsumsi rokok di Indonesia mengalami peningkatan 44,1% dalam sepuluh tahun terakhir dan jumlah perokok di Indonesia mencapai 70% jumlah penduduk, diperkirakan jumlah konsumsi rokok mencapai 199 milliar batang pertahunnya.

Bertumbuhnya perokok di Indonesia akan menimbulkan implikasi negatif yang sangat luas, tidak saja terhadap kualitas kesehatan, tetapi menyangkut kehidupan sosial dan ekonomi, berdampak pula pada peningkatan penggunaan korek api, salah satunya adalah korek api gas.

Sebagai salah satu alat penghasil / pemantik api, seperti halnya dengan semua penghasil api, korek api gas juga mempunyai potensi bahaya tersendiri.

Karena kecil dan ringannya korek api gas ini, para penggunanya sering kali lalai dalam menaruhnya di sembarang tempat. Peletakan yang tidak benar dapat meningkatkan potensi bahaya tersendiri, peletakan yang berbahaya tersebut seperti meletakkan di tempat yang terkena matahari langsung, di dekat sumber panas dan lainnya, yang lebih mengkhawatirkan lagi apabila seseorang lalai meletakkan di tempat yang dapat dijangkau oleh anak kecil yang belum mengerti tentang bahayanya bermain api.

Korek api gas untuk rokok memang merupakan produk konsumsi yang memang mengandung bahaya tersendiri yang dimulai sejak menghasilkan api atau nyala api dan menghasilkan panas dan juga mengandung bahan bakar. Akan menjadi sangat beresiko apabila disalahgunakan oleh anak-anak. Ini biasanya terjadi pada korek api habis buang (*disposable lighter*) yang dijual dengan jumlah yang sangat banyak dan seringkali dalam bentuk multipack dan digunakan dalam nilai ekonomis yang relatif rendah atau biasa diletakkan atau dibuang pada sembarang tempat. Maka anak-anak sangat mungkin bermain-main dengan korek api tersebut dan secara tidak sengaja menyebabkan kebakaran, cidera serius bahkan kematian.

U.S Safety Commision pada tahun 1991 mempublikasikan bahwa setiap tahunnya di Amerika Serikat sekitar 180 orang meninggal akibat kebakaran yang diawali oleh anak balita yang bermain korek api, sebagian besar melibatkan korek api gas habis buang (*disposable gas lighters*) bukan korek api batang (*matches*). Walaupun telah ada regulasi yang mewajibkan bahwa pada setiap korek api gas harus mencantumkan peringatan agar dijauhkan dari anak kecil namun, Studi yang dilakukan oleh New York

Federal menunjukkan bahwa 50 % dari anak kecil berumur di bawah 5 tahun cukup cerdas dan cukup kuat untuk menyalakan korek api gas, bahkan hanya dengan satu tangan.

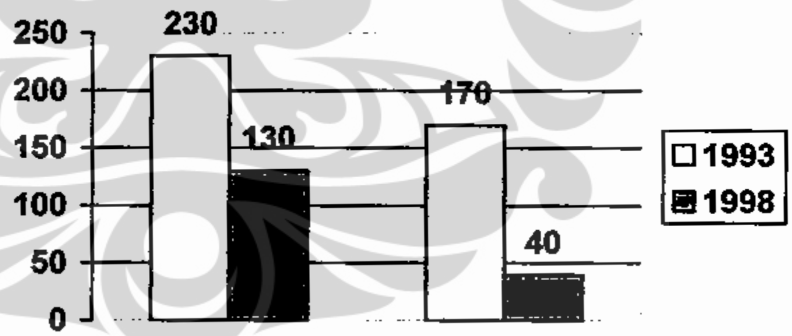
Angka statistik kecelakaan yang diakibatkan oleh penggunaan korek api di Indonesia memang masih belum tersedia namun di Amerika Serikat dimana diperkirakan hampir 1 juta korek api terjual setiap harinya dan lebih dari 700 juta korek diimport pertahunnya, dimana sekitar 400 jutanya berasal dari China. Pada periode 1997 - 2002 *U.S Consumer Product Safety Commission (CPSC)* mengestimasikan lebih dari 3000 orang dibawa ke unit gawat darurat rumah sakit karena cidera yang dihasilkan oleh kesalahan dalam menggunakan korek api (*lighter malfunction*). Kebanyakan dari cidera ini termasuk dalam terbakar / terpapar panas pada muka, tangan dan jari jemari. Dalam periode yang sama , *CPSC* menerima 256 laporan kecelakaan yang disebabkan oleh kesalahan dalam penggunaan maupun kegagalan mekanik korek api itu sendiri, 65% dari laporan tersebut sampai menyebabkan kebakaran. Dengan korban jiwa 3 orang dan 6 orang luka serius.

Berdasarkan Laporan dari Departemen Perdagangan dan Industri Inggris pada tahun 1997 kecelakaan yang berhubungan dengan anak-anak berumur dibawah 5 tahun yang bermain korek api menyebabkan 1200 kebakaran 260 cidera dan 20 kematian. Data statistik di Inggris juga menyebutkan bahwa antara tahun 1999 – 2003 terdapat rata-rata 5 meninggal dan 220 angka cidera yang disebabkan oleh anak-anak berusia di bawah 9 tahun bermain korek api. (*UK Fire Statistik – ODPM, 2004*).

Korban jiwa akibat kebakaran yang berhubungan dengan aktifitas anak bermain korek api, menurun drastis sejak ditetapkannya secara efektif ketentuan tentang standar korek api *child resistant* pada Juli 1994. Hasil statistiknya adalah sebagai berikut :

- Dari keseluruhan korban tewas sebanyak 230 orang pada tahun 1994 menjadi 130 orang pada 1998.
- Anak-anak berusia di bawah 5 tahun (balita) yang menjadi korban jiwa sebanyak 170 pada 1994 turun menjadi 40 korban jiwa pada tahun 1998.
- Sebanyak 11.100 tempat tinggal terbakar yang berhubungan dengan aktifitas anak bermain korek api, pada tahun 1994 dan turun menjadi 6.100 kebakaran pada tahun 1998.

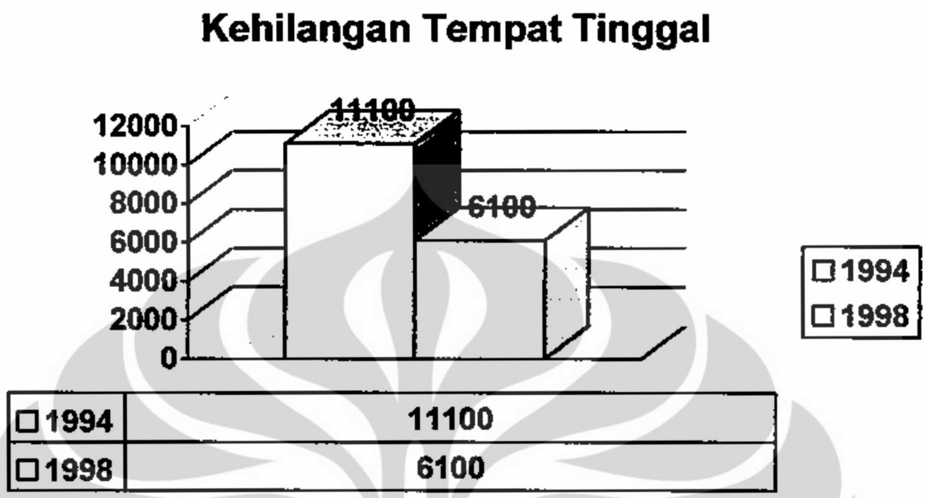
(U.S. Consumer Product Safety Commission,April6, 2005)



	korban tewas	balita meninggal
1993	230	170
1998	130	40

Sumber: *U.S. Consumer Product Safety Commission,April6, 2005)*

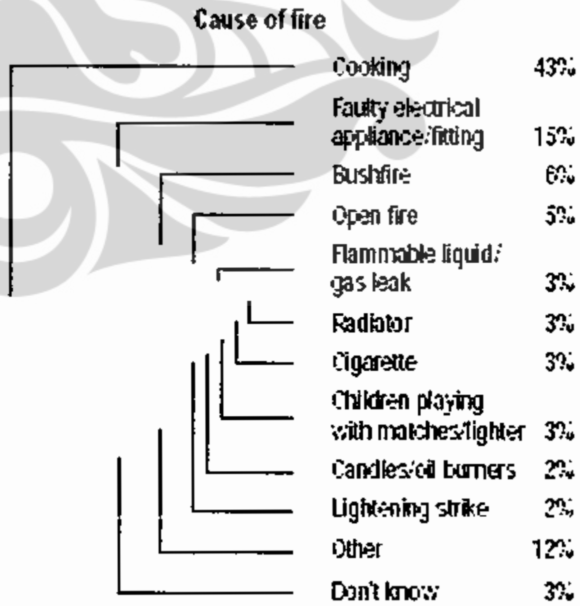
Gambar 1.1Grafik Insiden Akibat Aktifitas Balita Bermain Korek Api Gas



Sumber : *US Consumer Product Safety Commission,April6, 2005)*

Gambar 1.2 Grafik Kehilangan tempat tinggal.

Berdasarkan data penelitian di Australia (AAMI Fire Screen Index, 2004) asal mula kebakaran di dalam rumah disebabkan oleh hal – hal sebagai berikut :



Sumber : *Sweeney Research Survey, 2004*

Gambar 1.3. diagram fire started in home

Di Indonesia sendiri dimana jumlah perokok dan pengguna korek apinya relatif sangat tinggi, namun regulasi tentang kewajiban memproduksi korek api gas *child resistant* belum tersedia. Regulasi yang tersedia hanya mengenai keselamatan korek api gas yang dikeluarkan oleh Badan Standarisasi Nasional (BSN) pada tahun 2004.

Tingginya laporan tentang kecelakaan yang berhubungan dangan aktifitas anak bermain korek api terjadi di Amerika Serikat dan Inggris serta banyak lagi laporan serupa yang terjadi di negara lain, khususnya uni Eropa. Di Indonesia sendiri ditengarai sering kali kebakaran disebabkan oleh sebab yang sama, namun belum diketahui angka secara spesifiknya.

PT. Tokai Dharma Indonesia (PT. TDI) pada tahun bulan Maret 2007 mencoba menjawab masalah tersebut dengan mengeluarkan produk korek api gas dengan konsep *child resistant*. Sejak dikeluarkannya produk tersebut belum pernah dikaji keselamatannya dari segi beban untuk menyalakan api dibandingkan dengan uji eksperimental untuk mengetahui beban ibu jari anak secara langsung terhadap anak-anak yang sebenarnya menjadi perhatian utama dalam produk baru ini.

1.2. Rumusan Masalah

Banyaknya penelitian yang menyatakan tingginya tingkat kecelakaan (insiden) yang diawali oleh aktifitas anak bermain korek api gas, menyumbangkan angka kebakaran, kecelakaan bahkan kematian yang cukup signifikan. Konsep tentang korek api yang tidak bisa dioperasikan oleh anak (*child resistant*) merupakan salah satu solusi untuk mengatasi hal tersebut, di Amerika Serikat dan negara-negara Eropa sudah lama mewajibkan bagi korek api yang beredar di negaranya untuk menerapkan konsep tersebut dan terbukti hasilnya sangat efektif menurunkan tingginya tingkat kebakaran.

Indonesia, dengan jumlah perokok yang sangat besar namun masih belum mewajibkan penggunaan korek api dengan konsep *child resistant*, peraturan yang ada hanya merupakan regulasi dari SNI mengenai standar keselamatan korek api gas biasa. Padahal ditengarai jumlah kebakaran karena kelalaian para orang tua terhadap anak-anak mereka yang bermain korek api ikut menyumbangkan angka kebakaran yang relatif tinggi.

PT. Tokai Dharma Indonesia pada Maret 2007 menjawab masalah tersebut dengan mengeluarkan produk korek api gas dengan konsep *child resistant*. Produk korek api *child resistant* PT. TDI diproduksi dengan mengikuti standard 16 CFR 1210.4. *American Standard Consumer Product Safety for cigarette Lighters*, dan untuk Pasar Eropa sesuai standard DIN EN ISO 9994:2006 EN 13869. Sejak dikeluarkannya produk tersebut belum pernah dikaji keamanannya baik dari segi beban untuk memantik api dan uji eksperimental untuk mengetahui beban ibu jari anak secara langsung terhadap anak-anak yang sebenarnya menjadi perhatian utama dalam produk baru ini.

Sebagai kewajiban produk yang dinyatakan aman untuk dipergunakan masyarakat. Produk harus secara sistematis dan secara seksama telah melalui tahapan-tahapan pemeriksaan yang teliti. Produsen mempunyai tanggung jawab bila terjadi kemungkinan terjadinya kerusakan, kerugian atau luka-luka atas produk tersebut kepada orang atau property. Dengan demikian produsen harus terlebih dahulu membuktikan keamanan dan keselamatan dari produk yang dibuatnya.

Pertimbangan di atas yang melandasi penulis dalam melakukan penelitian tentang keamanannya baik dari segi beban untuk memantik api yang dilakukan dengan mesin load test dan uji eksperimental untuk mengetahui beban ibu jari anak secara langsung terhadap anak-anak usia dibawah 9 tahun, dilihat dari beban yang sanggup dihasilkan dan hubungannya dengan umur. Kemudian membandingkan antara beban yang mampu dihasilkan ibu jari anak dengan beban yang diperlukan untuk menyalakan korek api *child resistant* di load test. Dengan demikian bisa diketahui berapa tingkat keselamatan dari produk tersebut. Tingkat keselamatan adalah perbandingan antara beban desain dan beban pemakaian. Dengan diketahui tingkat keselamatan produk dapat pula ditentukan kemungkinan tingkat resiko bila produk tersebut terjadi kegagalan dalam pengoperasiannya.

1.3. Pertanyaan Penelitian

a. Berapakah beban gaya menekan yang mampu dihasilkan oleh ibu jari anak hingga umur 9 tahun.

b. Bagaimanakah hubungan antara umur dengan kemampuan menghasilkan gaya untuk menekan suatu beban dengan ibu jari ?

c. Berapakah tingkat keselamatan korek api *child resistant* berdasarkan uji laboratorium dilihat dari beban yang dibutuhkan untuk menyalakan api dibandingkan dengan kemampuan beban gaya ibu jari anak?

1.4. Hipotesis Penelitian

Berdasarkan pertanyaan penelitian di atas maka hipotesis penelitian ini adalah :

Ho : Ada hubungan antara umur anak dengan kemampuan menghasilkan gaya untuk menekan suatu beban dengan ibu jari

Ha : Tidak ada hubungan antara umur anak dengan kemampuan menghasilkan gaya untuk menekan suatu beban dengan ibu jari

1.5. Tujuan Penelitian

1.5.1. Tujuan Umum

Mengetahui tingkat keselamatan korek api *child resistant* dari segi beban untuk menyalakan api yang dilakukan dengan mesin load test dan membandingkan dengan hasil uji eksperimental beban ibu jari anak secara langsung terhadap anak-anak usia di bawah 108 bulan (9 tahun). Hingga dapat diyakinkan fungsi *child resistant* aman untuk anak di bawah 60 bulan (5 tahun).

1.5.2 Tujuan Khusus

a. Mengetahui beban yang dibutuhkan untuk menyalakan api korek api *child resistant*.

b. Mengetahui kemampuan gaya tekan yang dapat dihasilkan ibu jari anak hingga usia dibawah 108 bulan (9 tahun).

c. Mengetahui hubungan antara umur dengan kemampuan menghasilkan gaya untuk menekan suatu beban dengan ibu jari

1.6. Manfaat Penelitian

1.6.1. Manfaat Akademis

a. Diharapkan penelitian ini akan menggali lebih dalam khasanah ilmu dan menghasilkan masukan dan sumbangan terhadap perkembangan ilmu pengetahuan, khususnya kesehatan dan keselamatan produk.

b. Bagi peneliti diharapkan dapat menambah pengalaman dan pengetahuan baru yang bermanfaat.

1.6.2. Manfaat Aplikatif

a. Perusahaan dapat mengetahui tingkat keselamatan produk yang telah dikeluarkan, sehingga yakin layak dan aman untuk dipasarkan dan mengetahui tingkat resiko bila terjadi kegagalan.

b. Masyarakat pengguna korek api dapat mengetahui dan memilih menggunakan korek api yang aman.

c. Menjadi bahan evaluasi dan masukan yang berguna dalam pengembangan suatu produk yang berorientasi pada keselamatan

d. Bagi masyarakat sebagai informasi agar memperhatikan kegiatan anak-anak yang berpotensi menimbulkan bahaya terhadap keselamatan.

1.7. Ruang Lingkup Penelitian

Penelitian observasi dan eksperimental uji beban ibu jari anak melibatkan murid Play Group & Taman Kanak-kanak Tadika Puri Depok dan SD Yaspen Tugu Ibu

Depok, laki-laki dan perempuan dengan katagori usia hingga 108 bulan, dilakukan pada bulan Desember 2007.

Sedangkan untuk korek api *child resistant* produksi PT. TDI Depok, pada bulan Mei 2008 dilakukan uji laboratorium untuk mengukur beban yang diperlukan untuk menyalakan api.

BAB 2

TINJAUAN PUSTAKA

2.1. Api

Diperkirakan api telah ditemukan sejak 500.000 tahun lalu, tetapi walaupun demikian tidak seorangpun tahu bagaimana permulaan ditemukannya api. Sangat mungkin api masyarakat prasejarah mendapatkan ide dari melihat gejala alam seperti lahar dan hutan yang terbakar karena sambaran petir. Masyarakat pada waktu itu mempergunakan api untuk menghangatkan badan, memasak makanan dan menakuti predator. Seiring berkembangnya zaman, mereka dapat menggunakannya untuk menghasilkan cahaya, senjata dan menciptakan peralatan yang lebih baik untuk berperang (Microsof Encarta, 1995).

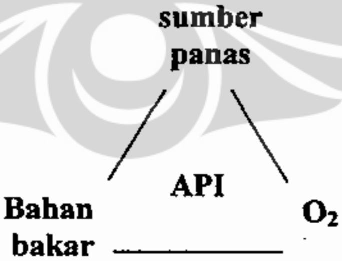
2.1.1. Deskripsi

Api adalah zat panas yang ditimbulkan dari benda yang terbakar, berasal dari proses oksidasi sehingga berupa energi berintensitas yang bervariasi dan memiliki bentuk cahaya (dengan panjang gelombang juga di luar spektrum visual sehingga dapat tidak terlihat oleh mata manusia) dan panas yang juga dapat menimbulkan asap.

Lidah api (*flame*) adalah partikel yang berpendar (*glowing*) dari subtansi yang terbakar, biasanya berwarna kuning atau oranye, tetapi kadang-kadang dapat berwarna hijau dan biru. Warna yang dihasilkan lidah api tergantung dari subtansi yang terbakar .

Gambar 2.1. - Lidah Api

Api merupakan suatu kondisi bahan bakar yg temperaturnya dinaikkan, dengan cara apapun, seperti gesekan dan lainnya. Akan berubah *state of matter*-nya menjadi plasma dengan bantuan oksigen yang akan bereaksi secara kimia dengan bahan bakar dan melepas panas (juga cahaya tampak sesuai temperatur bahan bakar tersebut). Proses terciptanya api itu digambarkan oleh segitiga api (*fire triangle*), yg terdiri dari panas, udara (oksigen), dan bahan bakar apabila salah satu bagian tidak dapat terpenuhi, maka api tidak dapat tercipta



Gambar 2.2.Segitiga Api

Gambar di atas memperlihatkan bagaimana ketiga unsur tersebut bereaksi secara kimia, yaitu reaksi eksothermis yang terjadi dalam suatu kondisi yang memungkinkan.

Ketiga unsur tersebut adalah :

1. Bahan Bakar

Bahan bakar adalah semua bahan yang dapat terbakar pada kondisi tertentu, umumnya adalah senyawa yang mengandung unsur carbon dan hydrogen, magnesium, titanium dan sulfur. Secara garis besar bahan bakar dikatagorikan atas : - *Combustibles*, yaitu zat-zat padat organik- *Flammables*, yaitu bahan-bahan bakar cair dan gas Sedangkan klasifikasi berdasarkan phasenya adalah bahan bakar padat, cair dan gas.

2. Oksigen

Oksigen di udara secara kasar untuk perhitungan teknik estimasi di udara tediri dari 21% O_2 dan 75% Nitrogen. Untuk mendukung terjadinya proses pembakaran diperlukan kandungan oksigen di udara di atas 10%. Sebagaiman diketahui bahwa api merupakan reaksi oksidasi cepat yang mengeluarkan energi panas dan menyala, semakin tinggi kandungan oksigen makin besar energi yang dihasilkan

Selain terdapat di udara, oksigen juga terdapat dalam zat kimia yang disebut zat pengoksida (*oxidizing agents*), seperti : hidrogen peroksid, ozone, nitrat, chlorat, permanganat dan lainnya.

3. Sumber Panas

Sumber panas dapat dibagi atas 5 katagori, yaitu :

a. Sumber api terbuka (*open flame*)

   Adalaah panas atau nyala api/sumber api terbuka seperti : korek api, kompor, flare, api rokok, dan lain-lain

b. Sumber panas mekanis

Ditimbulkan oleh gesekan/benturan mekanis, misalnya : gesekan antara 2 buah benda keras seperti logam besi atau lainnya. Dapat dilihat seperti pada aktifitas menggerinda, mengebor besi dan sebagainya.

c. Sumber panas kimia

Ditimbulkan oleh adanya reaksi kimia yang disebut pemanasan spontan dari zat pengoksida dengan bahan bakar, misalnya : kalium permanganat dengan gliserine, logam natrium yang terkena air, dan lainnya.

d. Sumber panas listrik dinamis

Ditimbulkan karena adanya hubungan singkat (*korsluiting*) atau panas lebih (*over heating*) pada suatu aliran listrik.

e. Sumber panas listrik statis

Ditimbulkan karena adanya loncatan listrik dari ion negatif dan ion positif misalnya terjadi pada petir, juga pada produk-produk minyak bumi tertentu yang bisa menghasilkan penumpukan listrik statis dan menghasilkan bunga api.

2.1.2. Istilah – Istilah

a. *Flash Point* (Titik Nyala)

Merupakan suhu terendah dimana cairan suatu bahan bakar memberikan cukup uap yang bercampur dengan udara membentuk campuran dapat terbakar yang akan langsung menyala bila diberi api.

Titik nyala suatu zat / bahan bakar berbeda, contoh :

Bensin : 50^{o} C

Karosine : 40° C s/d 70° C

b. *Fire Point* (Titik Bakar)

Merupakan suhu terendah suatu cairan bahan bakar memberikan cukup uap yang bercampur dengan udara membentuk campuran yang dapat terbakar secara terus menerus setelah diberikan nyala api (pembakaran yang kontinyu). Titik bakar biasanya hanya beberapa derajat lebih tinggi di atas titik api.

c. Suhu Penyalaan Sendiri (*Auto Ignition Temperature*)

Merupakan penyalaan spontan / otomatis, dimana uap yang ditimbulkan oleh bahan bakar telah bercampur dengan udara dengan sendirinya dan terbakar tanpa adanya sumber panas dari luar.

b. *Flammable Condition*

Merupakan percampuran bahan bakar dan udara pada rasio perbandingan tertentu sehingga menghasilkan suatu kondisi yang mudah terbakar.

2.1.3 Metode Dalam Menghasilkan Api

Ada dua metode utama dalam menyalakan api. Cara pertama adalah dengan menggunakan friksi (pergesekan) Menggesekan dua benda bersama-sama dengan suatu kecepatan dan lama yang diperlukan untuk menghasilkan panas yang selanjutnya menyalakan bahan bakar. Cara kedua adalah dengan metode perkusi, metode ini adalah menghasilkan api dengan menggunakan energi alam, seperti matahari.

Titik nyala api adalah apabila sesuatu dapat menyala akibat panas. Untuk suatu benda solid temperatur yang dibutuhkan untuk dapat menyalakan api adalah antara

260° C sampai 428,2° C, sedangkan untuk bahan bakar minyak atau gas (*gasoline*) titik nyala apinya dapat terjadi dalam temperatur -37,78° C.

2.2. Korek Api

2.2.1. Pengertian

Korek api adalah sebuah alat untuk menyalakan api secara terkendali. Korek api dijual bebas di toko-toko dalam bentuk paket sekotak korek api. Sebatang korek api terdiri dari batang kayu yang salah satu ujungnya ditutupi dengan suatu bahan yang umumnya fosfor yang akan menghasilkan nyala api karena gesekan ketika digesekkan terhadap satu permukaan khusus. Walaupun ada tipe korek api yang dapat dinyalakan pada sembarang permukaan kasar. Korek api yang menggunakan cairan seperti naphtha atau butana disebut korek api gas.

2.2.2. Sejarah

Bangsa Tiongkok sejak 577 telah mengembangkan korek api sederhana yang terbuat dari batang kayu yang mengandung belerang. Korek api modern pertama ditemukan tahun 1805 oleh K. Chancel, asisten Profesor L. J. Thénard di Paris. Kepala korek api merupakan campuran potasium klorat, belerang, gula dan karet. Korek api ini dinyalakan dengan menyelupkannya ke dalam botol asbes yang berisi asam sulfat. Korek api ini tergolong mahal pada saat itu dan penggunaannya berbahaya sehingga tidak mendapatkan popularitas. (www.wikipedia.com).

Korek api yang dinyalakan dengan digesek pertama kali ditemukan oleh kimiawan Inggris John Walker seorang ahli obat-obatan Inggris pada 31 Desember 1827. Walker menyebut penemuannya itu dengan nama *Friction Light*. Ia menjual korek api buatannya itu dalam sebuah kaleng silinder.(www.republikaonline.com / 30 Agustus 2005) Penemuan tersebut diawali oleh Robert Boyle tahun 1680-an dengan campuran fosfor dan belerang, tetapi usahanya pada waktu itu belum mencapai hasil yang memuaskan. Walker menemukan campuran antimon (III) sulfida, potasium klorat, *natural gum*, dan pati dapat dinyalakan dengan menggesekkannya pada permukaan kasar.

2.2.3 Bebarapa jenis korek api menurut SNI

1. Jenis korek api berdasarkan bahan bakar yang digunakan :

- korek api minyak

  korek api dengan sumbu yang tampak dan bahan bakarnya menggunakan hidrokarbon cair seperti heksanan yang tekanan gas pada 24°C tidak melebihi 34,5 kPa

- korek api gas

  korek api yang menggunakan hidrokarban cair seperti n-butana, isobutana dan propana yang mempunyai tekanan pada 24°C melebihi 104 kPa

- korek api *postmixing burner*

  korek api gas yang bahan bakar untuk pembakar dan udara disuplai pada titik/tempat pembakaran

- korek api *premixing burner*

  korek api gas yang bahan bakar dan udara dicampur sebelum disuplai untuk pembakaran

2. Berdasarkan pemakaiannya

- korek api habis buang (*disposable lighter*)

  korek api dengan bahan bakar yang utuh/lengkap dan tidak untuk diisi ulang

- korek api isi ulang (*refillable lighter*)

  korek api yang dimaksudkan untuk dapat diisi ulang dengan pengisian bahan bakar dari sebuah tabung luar atau dengan menyiapkan sebuah tabung bahan bakar yang sudah diisi

3. Berdasarkan nyala apinya

- korek api yang dapat disetel (*adjustable lighter*)

  korek api yang dilengkapi dengan mekanik bagi pemakainya untuk dapat memperoleh tinggi api yang beragam

- korek api yang tidak dapat disetel (*non adjustable lighter*)

  korek api yang tidak dilengkapi dengan mekanik yang dapat diperoleh pemakainya untuk menyetel tinggi api orek api canklong penyetelan otomatis (*automatically adjusting pipe lighter*)

  korek api yang ditandai dengan peningkatan tinggi api secara otomatis ketika dimiringkan dari posisi tegak lurus, dirancang khusus untuk penyalaan cangklong

- korek api yang tidak padam dengan sendirinya (*non self-extinguishing lighter*)

  korek api yang sekali dinyalakan tidak membutuhkan aksi tegas dan disengaja oleh pemakainya untuk menjaga api dan dibutuhkan tindakan yang disengaja untuk memadamkan api

- korek api yang padam dengan sendirinya (*self-extinguishing lighter*)

  korek api yang sekali dinyalakan, membutuhkan aksi tegas yang disengaja dan terus menerus untuk menjaga api dan kemudian padam dengan mengakhiri aksi tegas tersebut

2.3. Korek Api Gas

Salah satu jenis korek yang populer di kalangan perokok adalah korek api gas. Korek jenis ini mudah untuk dinyalakan, pengguna tak perlu menggesek batang korek dengan bagian samping korek untuk menghasilkan api seperti pada korek api konvensional. Biasanya, untuk menyalakan korek api gas, pengguna tinggal menggerakkan roda pemantik api ke arah bawah dengan ibu jari tangan. Api pun langsung bisa didapatkan. Namun, seiring perkembangan teknologi yang sudah semakin canggih, ada korek yang sudah langsung menyala ketika penutupnya dibuka.

Sumber : PT. Tokai Dharma Indonesia

Gambar 2.3. Korek Api *Child Resistant*

Menurut definisi yang digunakan oleh Standar Nasional Indonesia (SNI) korek api merupakan peralatan penghasil api secara manual ,menggunakan turunan petrokimia sebagai bahan bakar, biasanya digunakan untuk menyalakan cerutu, rokok dan cangklong, juga dapat diduga digunakan untuk menyalakan material seperti kertas, sumbu, lilin dan lentera.

Korek api gas adalah korek api yang menggunakan cairan seperti naphtha atau butana. Untuk dapat menghasilkan percikan dan menyulut terjadinya bunga api digunakan batu api yang digesekan pada permukaan yang sangat kasar, sehingga bunga api ini menyulut cairan atau gas sehingga terbakar. Besarnya api dapat diatur sehingga tidak membahayakan.

Nafta atau naphtha adalah suatu kelompok yang terdiri dari beberapa jenis hidrokarbon cair produk antara kilang minyak yang digunakan terutama sebagai bahan baku produksi komponen bensin oktan tinggi melalui proses reformasi katalitik. Nafta juga digunakan dalam industri petrokimia untuk memproduksi olefin dalam perengkah uap (*steam cracker*) serta digunakan sebagai pelarut atau solven dalam industri kimia.

Butana, juga disebut *n*-butana, adalah alkana rantai lurus dengan empat atom karbon $CH_3CH_2CH_2CH_3$. Butana juga digunakan sebagai istilah kolektif untuk n-butana dan satu-satunya isomernya, isobutana (disebut juga metilpropana), $CH(CH_3)_3$. Butana sangat mudah terbakar, tidak berwarna, dan merupakan gas yang mudah dicairkan. Nama butana diturunkan dari nama asam butirat.

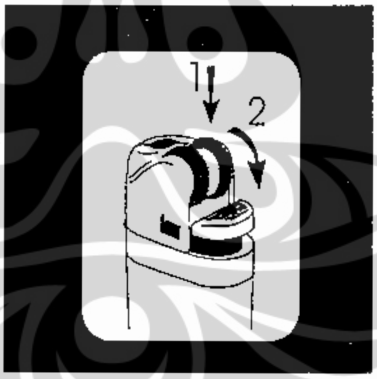
Gas adalah suatu fase benda. Seperti cairan, gas mempunyai kemampuan untuk mengalir dan dapat berubah bentuk. Namun berbeda dari cairan, gas yang tak tertahan tidak mengisi suatu volume yang telah ditentukan, sebaliknya mereka mengembang dan mengisi ruang apapun di mana mereka berada.

Tenaga gerak/energi kinetis dalam suatu gas adalah bentuk zat terhebat kedua (setelah plasma). Karena penambahan energi kinetis ini, atom-atom gas dan molekul sering memantul antara satu sama lain, apalagi jika energi kinetis ini semakin bertambah. Kata "gas" kemungkinan diciptakan oleh seorang kimiawan Flandria sebagai pengejaan ulang dari pelafalannya untuk kata Yunani, *chaos* (kekacauan). (*www.wikipedia.com*)

2.3.1. Korek Api *Child Resistant*

Merupakan korek api yang didisain secara khusus untuk mengurangi dampak yang terjadi akibat cedera dan kecelakaan akibat korek api yang ada selama ini. Korek api *child resistant* tidak dapat digunakan / sangat sulit oleh anak dibawah 5 tahun untuk dapat menghasilkan api. Untuk di Amerika korek api gas yang telah lolos uji sesuai 16 CFR 1210.4. *American Standard Consumer Product Safety for cigarette Lighters.* Dan mempunyai ketentuan sebagai berikut:

1. Setidaknya 85% anak tidak dapat mempergunakan atau mengalami kesulitan untuk menyalakan.
2. Secara otomatis me-reset sendiri setelah setiap digunakan untuk menyalakan .
3. Tidak merusakkan fungsi pengaman korek selama digunakan secara normal maupun kenyamanannya.
4. Pengguna tidak dapat dengan mudah merusakkan fungsi child-resistantnya.
5. Berfungsi secara efektif sebagai korek api.



Sumber : PT. Tokai Dharma Indonesia

Gambar 2.4. Korek Api *Child Resistant* **Gambar 2.5. Tanda *Child Resistant***

Keterangan :

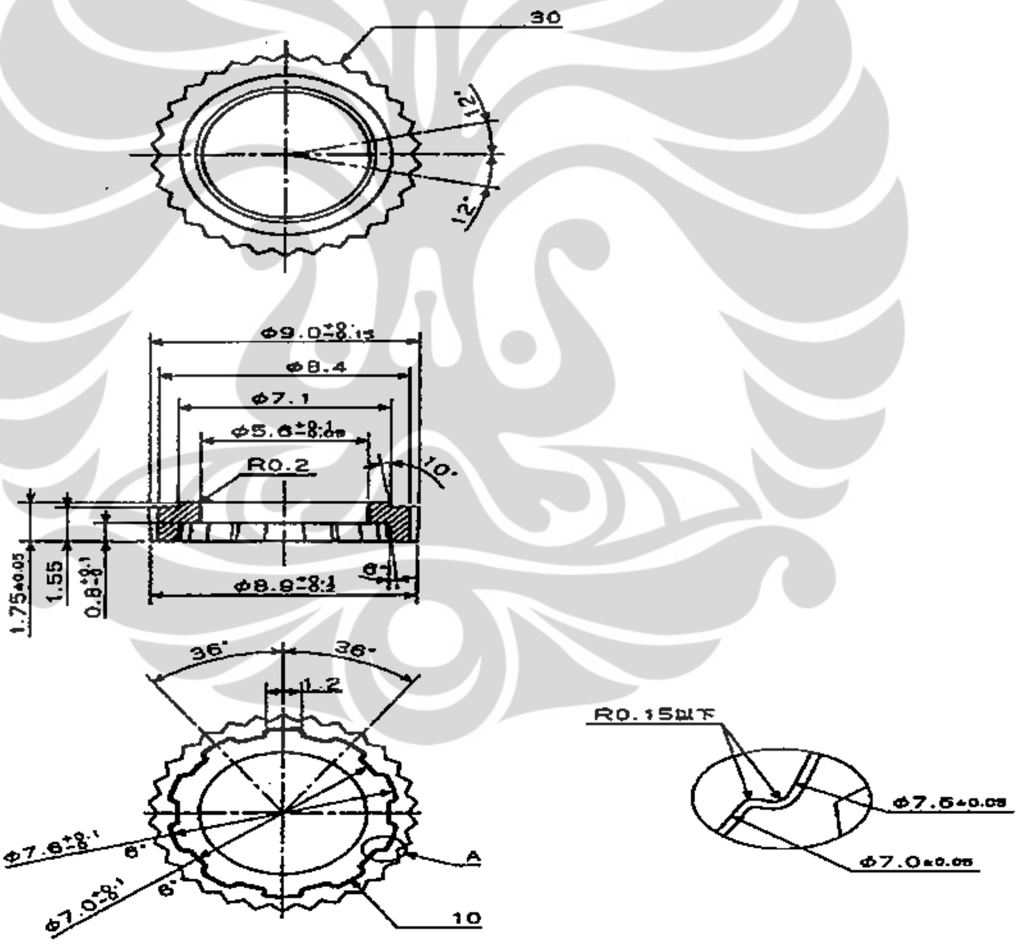
Roda penggerak sisi luar (*milled edge wheel*) harus ditekan terlebih dahulu [1] dan kemudian diputar [2] agar roda pemantik (friction wheel) dapat berputar dan menghasilkan percikan api. Gaya / beban yang diperlukan untuk memutar roda penggerak sisi dalam ini sulit dicapai oleh anak kecil khususnya yang berusia dibawah 5 tahun. Roda penggerak sisi luar terdapat tambahan mekanisme baru yaitu "roda bebas", roda ini sebagai pengaman untuk tidak menggerakkan roda pemantik. Sehingga saat diputar oleh anak hanya akan berputar bebas. Untuk menggerakkan roda pemantik, roda penggerak harus ditekan terlebih dahulu. Kekuatan daya tekan diperlukan agar roda penggerak sisi luar menekan penghubung plastik (*cushion ring*) dan menempel pada roda pemantik, dengan demikian roda pemantik akan sama-sama berputar untuk menghasilkan api.

Sehingga hal ini merupakan pencegah agar sulit dilakukan oleh anak, selain diperlukan tenaga untuk menekan juga diperlukan pemahaman cara penggunaannya.

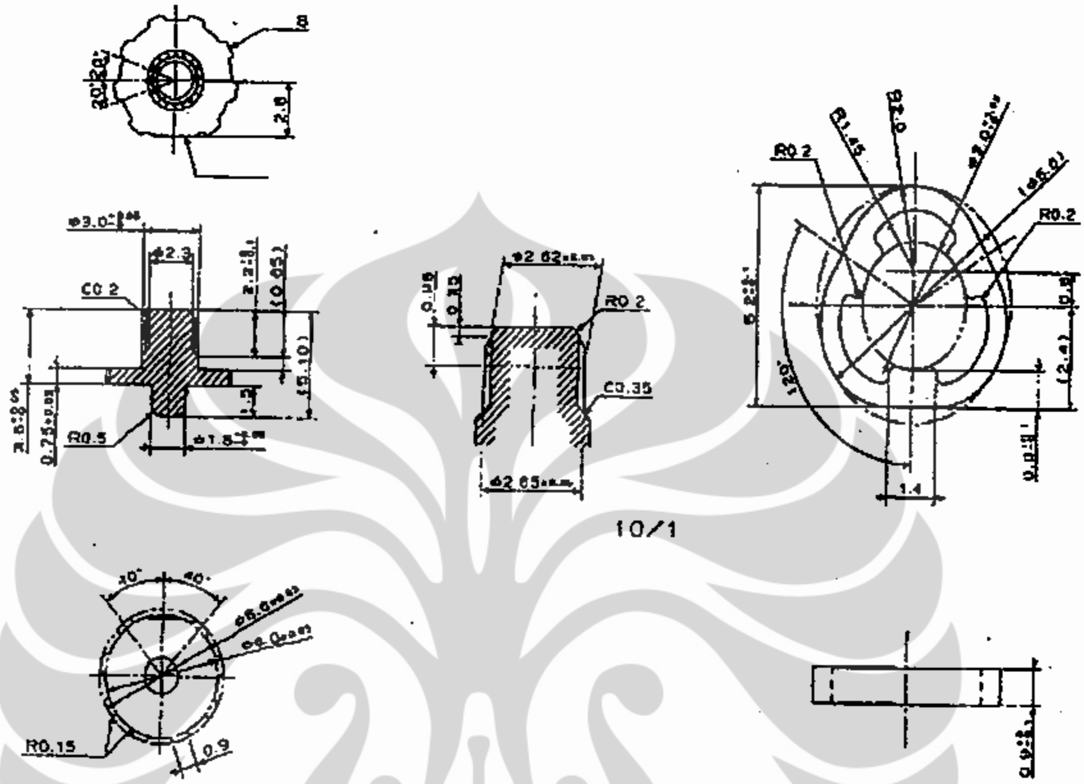
Deskripsi teknis korek api *child resistant* :

Korek api gas dengan batu api atau geretan, komponen yang digunakan sebagai mekanisme agar korek dapat berfungsi secara aman dan nyaman dipakai adalah *file assy child resistant* yaitu terdiri dari roda penggerak sisi luar (*milled edge wheel*) sebagi roda penggerak, roda pemantik *(friction wheel)* dengan poros bebas berputar (*point shaft*). Antara poros bebas dan roda penggerak dihubungkan dengan plastik penghubung (*cushion ring*). Roda penggerak akan terhubung dengan roda pemantik dan akan sama-sama berputar bila tekanan yang menekan sisi dalam dari roda penggerak menempel plastik penghubung (*cushion ring*) dan akan terhubung roda pemantik. *File assy* bertumpu pada kerangka tengah (*middle case*), roda pemantik akan menggesek batu api (*flint*) yang didorong oleh per (*spring*) agar batu api selalu menempel pada roda pemantiknya. Setelah roda pemantik mampu diputar dan menggesek batu api akan timbul percikan api selanjutnya ibu jari akan menekan tuas pengungkit (*lever*) untuk membuka katup gas (*valve assy*) dan gas akan keluar dan terbakar. Tinggi api yang dikehendaki bisa diatur ketinggiannya dengan memutar ring pengatur (*adjusting ring*). Lidah api akan otomatis padam apabila pengungkit api dilepas dan korek api akan kembali padam.

Struktur Korek Api *Child Resistant*:

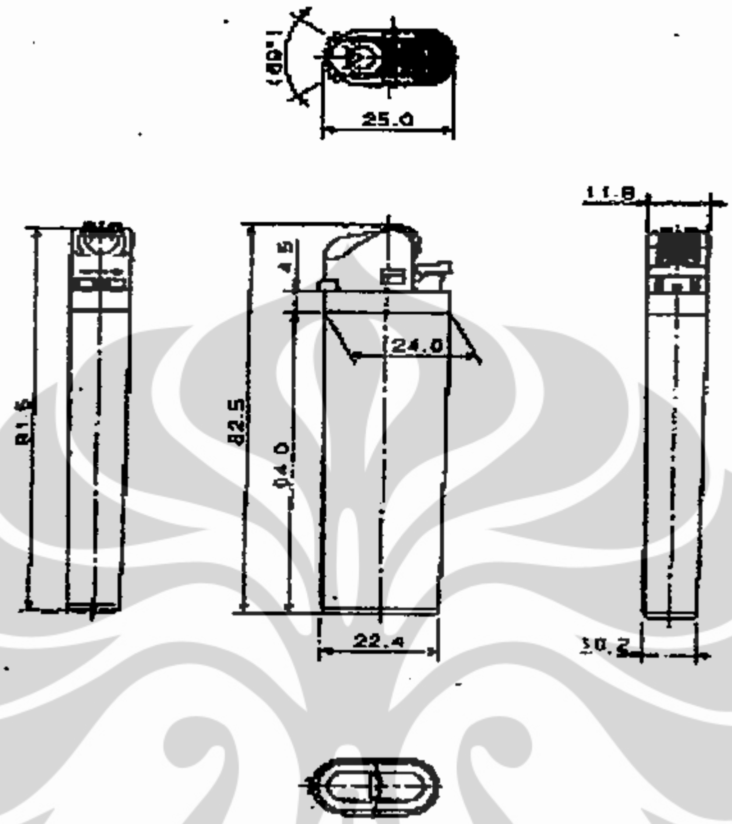


Sumber : Spec sheet PT. Tokai Dharma Indonesia.
Gambar 2.6.Struktur *Striker Wheel* Korek Api *Child Resistant*



Sumber : Spec sheet PT. Tokai Dharma Indonesia.

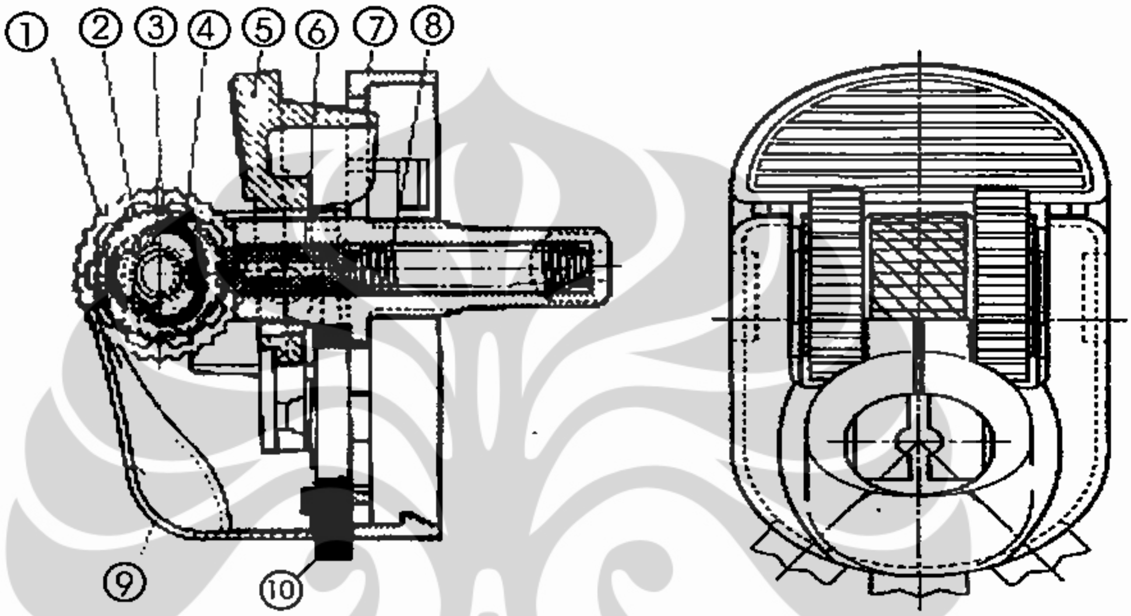
Gambar 2.7.Struktur *Flint Wheel* Korek Api *Child Resistant*



Sumber : Spec sheet PT. Tokai Dharma Indonesia.

Gambar 2.8 Ukuran Batang Korek Api *Child Resistant*

Perbedaan korek api *Child Resistant* dan NON-*Child Resistant* :

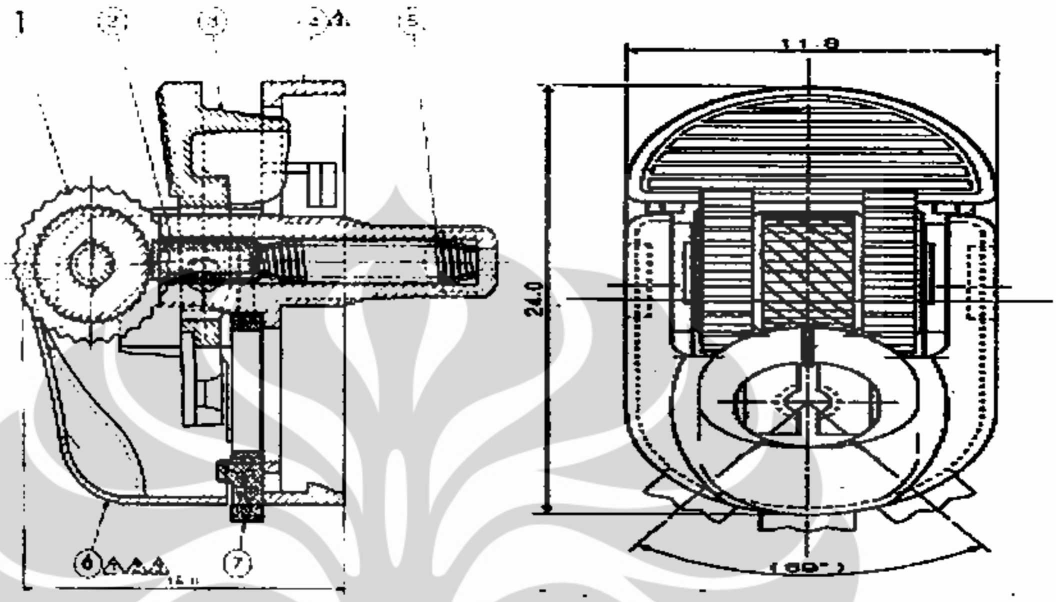


Keterangan:

1. *Milled edged wheel*
2. *friction wheel*
3. *point shaft*
4. *chusion ring*
5. *lever*
6. *flint*
7. *middle case*
8. *spring*
9. *outer casing*
10. *adjusting ring*

Sumber : Spec sheet PT. Tokai Dharma Indonesia.

Gambar 2.9.Struktur Kepala Korek Api *Child Resistant*



Keterangan :

1. *File assy*
2. *Flint*
3. *Lever*
4. *Middle case*
5. *Spring*
6. *Outer casing*
7. *Adjusting ring.*

Sumber : Spec sheet PT. Tokai Dharma Indonesia.

Gambar 2.10.Struktur Kepala Korek Api Non - Chid Resistant

2.4. Kecelakaan

Kecelakaan adalah suatu kejadian yang tidak diharapkan, tidak direncanakan, dan dapat mengakibatkan cidera *(Encyclopedia Health & Safety,ILO, Geneva).*

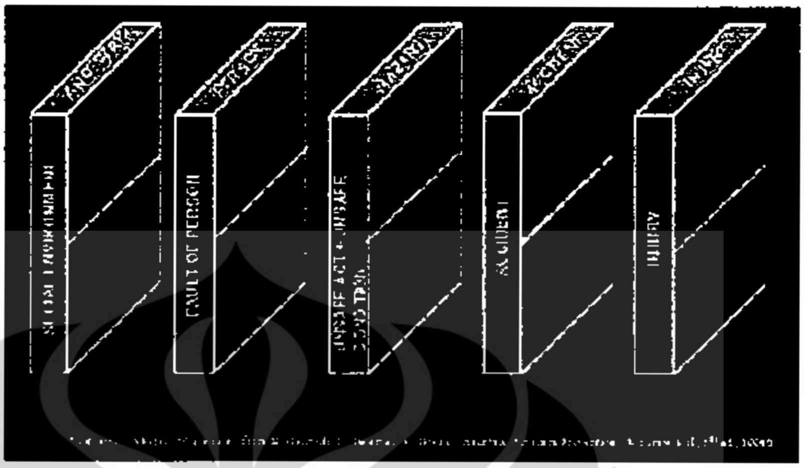
Sedangkan menurut Frank.E.Bird kecelakaan diartikan sebagai suatu kejadian yang tidak diinginkan, yang dapat mengakibatkan cidera pada manusia atau kerusakan pada harta. Kecelakaan dapat terjadi sebagai akibat kontak antara energi yang berlebihan dengan tubuh sehingga berakibat rusaknya jaringan oragan atau faal.

Kecelakaan merupakan suatu kejadian, yang dapat menimbulkan kerugian fisik bagi manusia atau kerusakan harta. Umumnya disebabkan karena hubungan dengan suatu sumber tenaga

2.4.1. Teori Penyebab Kecelakaan

1. Teori Domino Heinrich

Menurut H.W Heinrich, kejadian sebuah cidera disebabkan oleh bermacam-macam faktor yang terangkai, dimana pada akhir dari rangkain itu adalah cidera (*loss*). Kecelakaan yang menimbulkan cidera disebabkan secara langsung oleh perilkau yang tidak aman dan atau potensi bahaya mekanik atau fisik. Prinsip dasar tersebut kemudian dikenal dengan dengan "*Teori Domino*", dimana Heinrich menggambarkan seri rangkaian terjadinya kecelakaan.



Sumber: H.W, Heinrich and Petersen and Nestor Roos, Industrial Accident Prevention, 5 th,ed, McGraw-hill,1980 hal 22

Gambar 2.11 Teori Domino Heinrich

Dari gambar di atas maka masing-masing domino berlabel :

1. Lingkungan sosial atau keturunan
2. Kesalahan orang (*Faultry person*)
3. Kondisi dan atau tindakan tidak aman (*unsafe condition and or unsafe acts*)
4. Kecelakaan (*accident*)
5. Cidera (*Injury/ loss*)

Penggunaan teori domino ini digunakan sebagai petunjuk pertama, satu domino dapat menghancurkan empat domino yang lain, kecuali pada titik tertentu sebuah domino diangkat untuk menghentikan rangkaian. Domino yang paling mudah dan paling paling efektif dihilangkan adalah domino yang tengah, yang berlabel "tindakan dan atau kondisi tidak aman". Teori ini cukup jelas, praktis dan pragmatis sebagai pendekatan control terhadap kerugian. Dengan kata lain, jika kita ingin mencegah kerugian, pindahkan "tindakan dan atau kondisi tidak aman"tersebut.

Salah satu kerugian dari penggunaan teori Heinrich adalah model ini masih terlalu luas dan dapat diartikan dalam banyak cara. Model ini tidak menyediakan gambaran umum atau klasifikasi yang dapat dijadikandasar penelitian ilmiah. Model ini juga melibatkan faktor perilaku manusia, dan faktor mekanik dalam satu domino yang sama.

2. Gordon

Pada tahun 1949 mengemukakan kotribusinya dalam pencegahan kecelakaan menjadi sangat terkenal dengan pendahuluan mengenai apa yang biasa disebut sebagai teori penyebab berganda (*Multiple causation model*).

Teori penyebab berganda memiliki dasar epidemiologi. Gordon menjelaskan bahwa cidera kareana kecelakaan dapat diselidiki dengan metode epidemiologi. Ia percaya apabila karakteristik korban kecelakaan beserta *agent* (penyebab cidera) dan lingkungan pendukungnya daapt diuraikan dengan jelas maka pemahaman tentang penyebab kecelakaan akan daapat diketahui, dibandingkan dengan mengikuti teori domino yang hanya melihat satu penyebab saja. Pada intinya, teori Gordon mengatakan kecelakaan adalah interaksi yang komples adan acak antara korban, a*gent*, dan lingkungan.

3. Haddon

Pada tahun 1967 Haddon memperoleh reputasi dalam bidang pencegahan kecelakaan dengan memperkenalkan model perubahan energi (*Energy Exchange Model*). Pendekatan lain untuk menjelaskan kecelakaan adalah dengan memperhatikan energi yang dibawa dan menyebabkan cidera. Obyek yang membawa energi tersebut merupakan hal penting yang kedua, sebab sulit untuk dijelaskan obyek itu sendiri, melainkan dalam bentuk perubahan energi yang menyebabkan cidera. Inilah konsep "Model Perubahan Energi"yang diciptakan Haddon.

2.5. Bahaya Api (*Fire Hazards*)

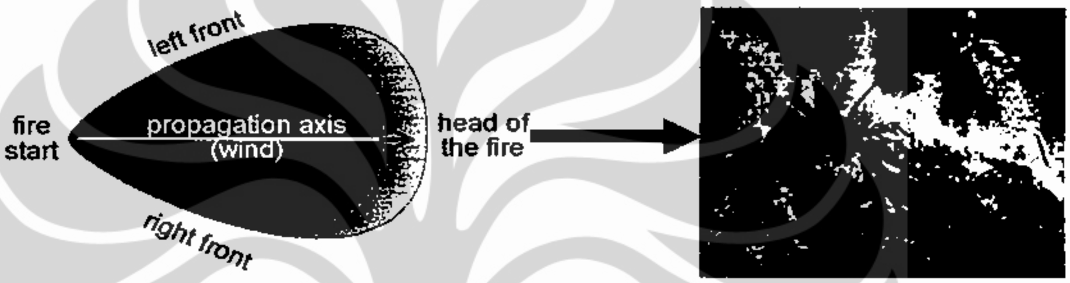
Api seringkali sangat membantu tetapi dapat sekaligus juga sangat berbahaya. Api yang terkontrol dapat digunakan untuk memasak, membakar sampah sampai menghasilkan energi untuk menjalanakan mesin kendaraan, api juga dapat digunakan untuk menciptakan senjata yang sangat mematikan.

Namun apabila tidak terkontrol api bisa sangat berbahaya, seperti merusak bahkan menghancurkan bangunan, hutan dan lainnya. Fakta membuktikan bahwa akibat dari kebakaran akan menghabiskan miliaran rupiah pertahunnya dan juga membunuh ribuan manusia dan binatang dalam setiap tahunnya.

2.5.1. Kebakaran

Kebakaran merupakan proses pembakaran yang ditandai oleh timbulnya panas, asap atau lidah api atau kombinasi atas ketiganya. Besarnya panas, lidah api atau asap tergantung pada jumlah dan konsentrasi bahan bakar dan oksigen yang secara simultan akan menimbulkan proses pembakaran selanjutnya. Akan terhenti apabila salah satu dari ketiga unsur yang terlibat dapat dipisahkan atau habis.

Proses terjadinya kebakaran :



Gambar 2.12. Proses Terjadinya kebakaran

Sumber : Baghdad Fire Department
Gambar 2.13. kebakaran

Kerusakan terhadap struktur ataupun cidera yang dialami manusia kebanyakan merupakan akibat dari panas yang dipancarkan, baik secara konveksi maupun radiasi.

Kebakaran dapat dibagi menjadi beberapa tipe, antara lain :

- *Pool fire*

  Kebakaran dalam bak penampung terbuka

- *Jet fire*

  Bahan yang terbakar bertekanan

- *Flash fire*

  Kebakaran yang bergerak dalam awan campuran gas dan oksigen

- *Fire ball*

  Sejumlah bahan bakar yang terlepas mendadak dan menyala

- *Fire storm*

  Kebakaran yang meluas dan menimbulkan suatu gelombang panas

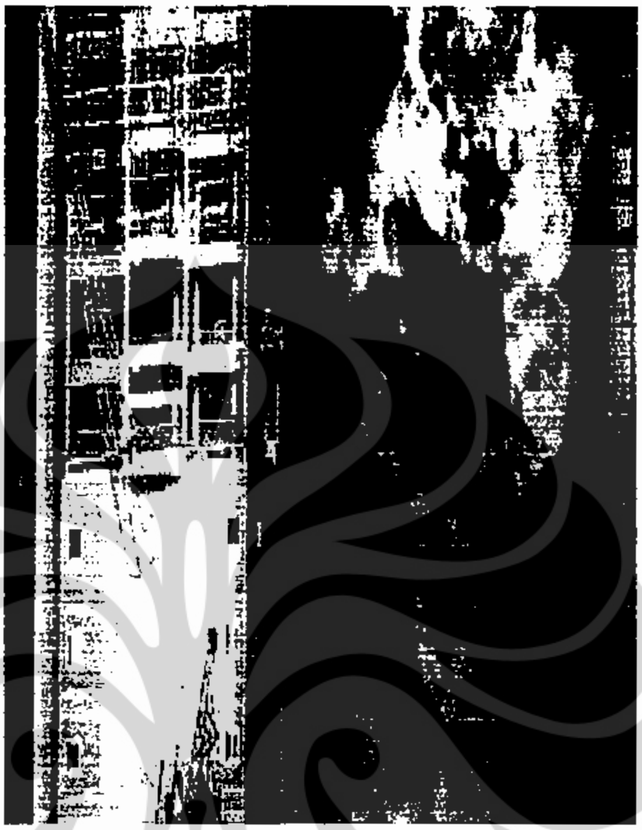
- *Dust fire*

  Kebakaran pada material yang berbentuk powder

2.5.2. Ledakan

Sedangkan ledakan didefinisikan sebagai pelepasan energi yang menimbulkan tekanan yang tidak kontinyu atau dalam bentuk gelombang kejut (*blastwave*). Meknisme terjadinya ledakan dibedakan menjadi 2, yaitu deflagrasi dan detonasi.

1. Deflagrasi terjadi apabila reaksi yang terbentuk untuk mengawali ledakan berada pada kecepatan yang lebih rendah dari kecepatan suara (331,4 m/s, 0° C, 1 atm).
2. Detonasi terjadi apabila reaksi yang mendahului pada *unreacted* material lebih besar dari kecepatan suara, tekanan yang tinggi dan bahan bakar bergerak searah dengan arah gelombang ledakan.



Gambar 2.14. Ledakan

Ledakan dapat dibedakan menjadi beberapa tipe, antara lain :

- *Vapour cloud explosion*

  Ledakan yang terjadi dalam awan gas atau uap

- *Boiling liquid expanding vapour exposure (BLEVE)*

  Bejana berisi fuida *flammable* pecah tiba-tiba akibat panas

- *Dust explosion*

  Kerusakan besar akibat secondary explosion

- *Mist explosion*

  Biasa terjadi pada marine diesel engine yang besar

- *Overpressure*

  Disebabkan penambahan fluida atau kenaikan tempratur dan atau tekanan

- *Pressure pilling*

  Biasanya terjadi pada dua vessel yang terhubung

2.6. Ergonomi

2.6.1. Pengertian Ergonomi

Ergonomi berasal dari bahasa Yunani yang secara harfiah berarti hukum kerja.

Terdiri dari 2 kata, yaitu :

Ergo : Kerja

Nomos : Hukum

Beberapa pengertian ergonomi :

1. Ergonomi merupakan sebuah studi mengenai aspek anatomis, fisiologis dan psikologis manusia dan lingkungan kerjanya. Fokus studi adalah pada efisiensi, kesehatan, keselamatan dan kenyamanan manusia di tempat kerja. (*International Ergonomic Association*).
2. Ergonomi merupakan penerapan ilmu biologis sejalan dengan ilmu rekayasa(*engineering*) untuk mencapai penyesuaian yang optimal antara manusia dan pekerjaannya, dengan tujuan dapat bermanfaat pada efisiensi dan kesejahteraan. (*International Labour Organization*).
3. Ergonomi adalah ilmu terapan yang berusaha untuk menyesuaikan pekerjaan dan lingkungan terhadap orang atau sebaliknya dengan tujuan tercapainya

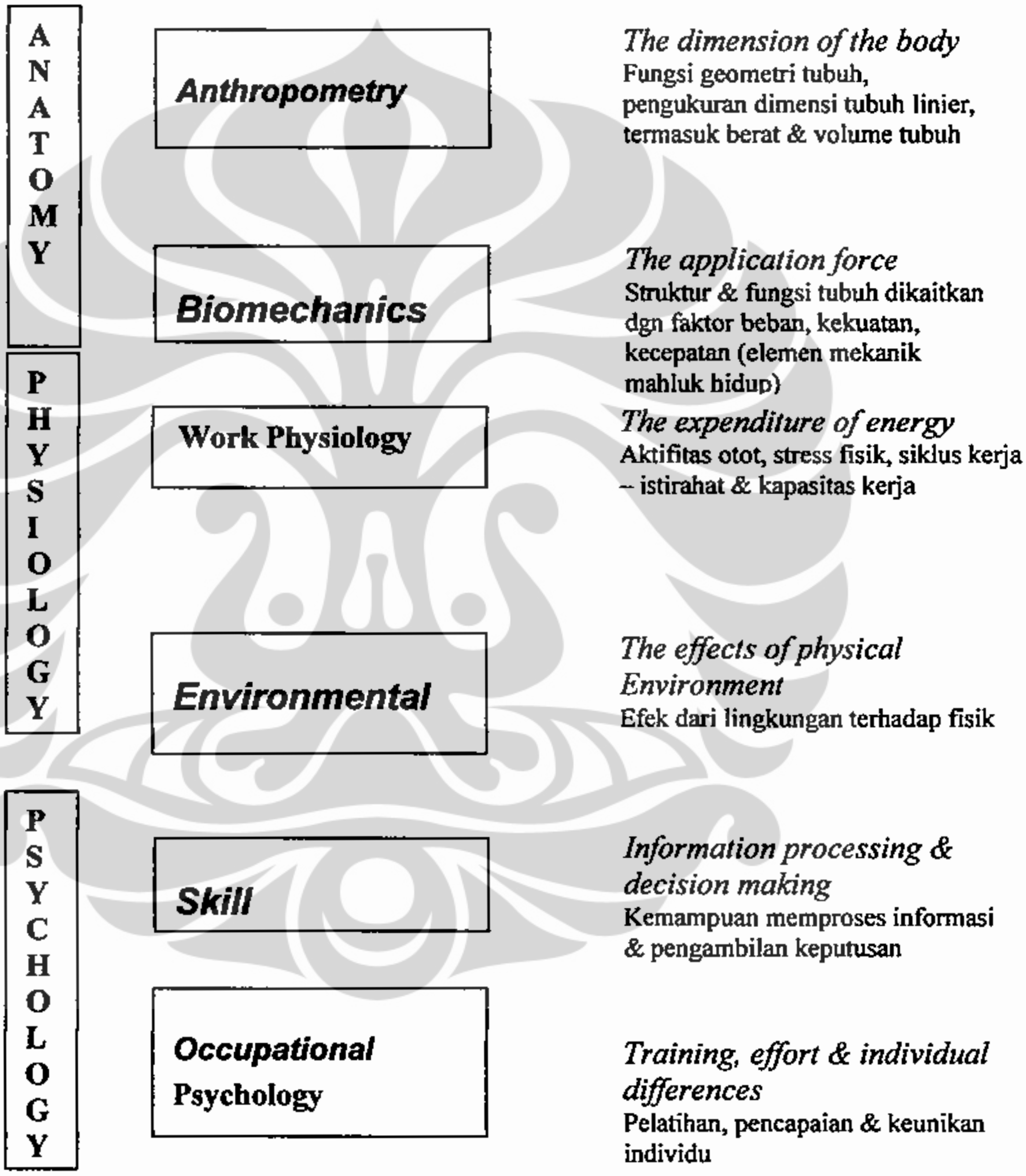
produktifitas dan efisiensi setinggi-tingginya bagi pemanfaatan manusia secara optimal. (Suma'mur, 1989).

Berdasarkan uraian diatas dapat disimpulkan bahwa elemen – elemen dalam ergonomi terdiri dari :

- Manusia
- Objek (tools)
- Lingkungan
- Interaksi antara diantara ketiganya.

2.6.2 Komponen – Komponen Dalam Ergonomi :

Secara sederhana komponen – komponen dalam ergonomi dapat kita lihat dari bagan berikut :



Gambar 2.15 Bagan Komponen – Komponen Ergonomi

2.7. Fungsi Otot

Sekitar 40 % dari total berat tubuh manusia merupakan berat dari otot. Fungsi otot antara lain :

- Menggerakan bagian badan
- Mempertahankan postur tubuh
- Menghasilkan panas

Kontraksi otot adalah peristiwa memendeknya otot. Kekuatan kontraksi otot bergantung pada besar kecilnya penampang otot, semakin besar penampang otot maka akan semakin besar kemampuan otot berkontraksi. Kekuatan otot dari karakteristik seseorang dipengaruhi antara lain oleh :

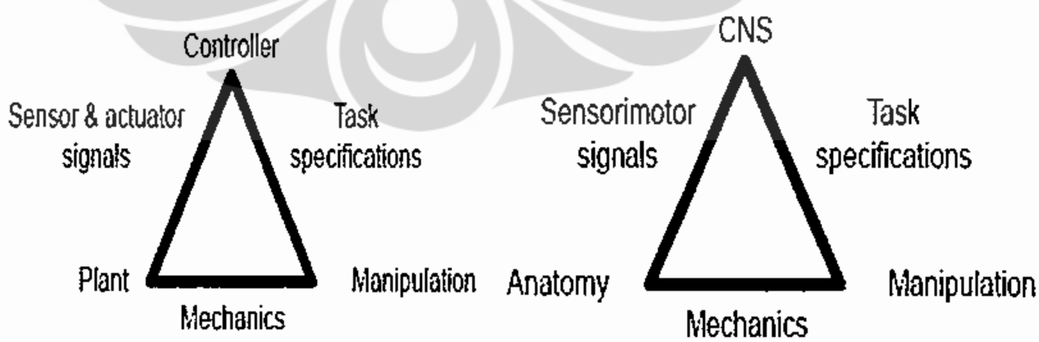
- Umur
- Jenis kelamin
- Massa tubuh
- Tinggi

Sedangkan ketahanan otot adalah kemampuan seseorang untuk mempertahankan kontraksi otot, pada umumnya semakin besar gaya yang diperlukan maka akan semakin lama otot bertahan pada kondisi kontraksi dan begitu juga sebaliknya. Ketahanan otot mengalami peningkatan yang signifikan selama masa pertumbuhan dan setelah usia pertengahan ketahanan otot berangsur mengalami penurunan.

2.8. Biomekanik Pada Jari Tangan

Manipulasi gerak statis dan dinamis dari suatu objek pada jari-jari tangan merupakan sesuatu yang sangat esensial pada kehidupan sehari-hari. Kemampuan manipulasi merupakan sesuatu yang sangat rapuh terhadap penyakit orthopedi/ saraf dan penuaan karena pada saat itu terbuka interaksi yang luar biasa pada anatomi yang kompleks diantara tangan dan sistem saraf. (valero, cuevas, 2000)

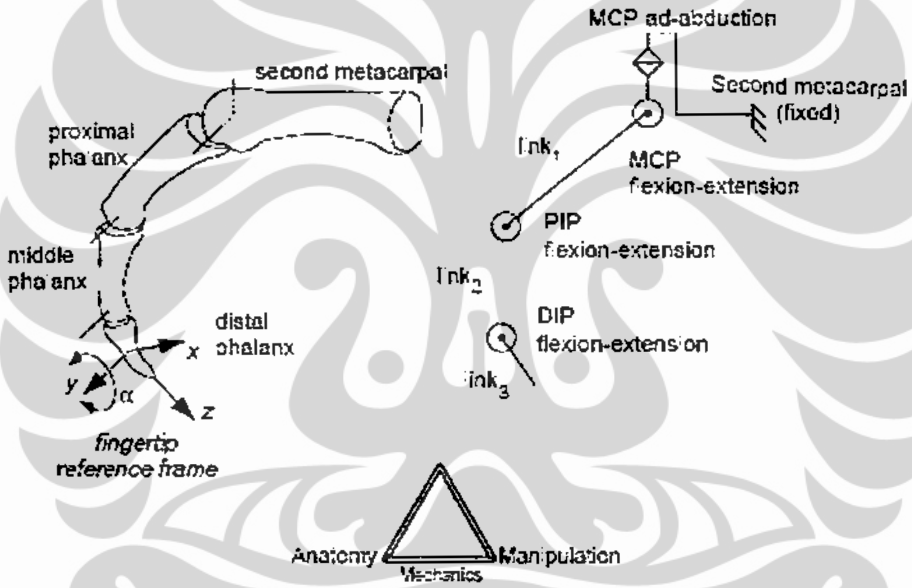
Kemampuan manipulasi merupakan suatu subjek dari keseluruhan bidang medis (tubiana, 1981; MacKenzie and Iberall, 1994; Brand and Hollister, 1999; Green atal., 1999). Kompleksnya sistem pada tangan menyebabkan tertundanya pemahaman yang komprehensif terhadap fungsi biomekanik dan kontrol neuromoscular pada tangan. Kompleksitas dari neuro-musculo-skeletal tangan yang tidak terlalu baik dipahami membuat Valero dan Cuevas mencoba membuat paradigma tentang interaksi pada komponen neuro-muculo-skeletal yang lebih mudah untuk dipahami, seperti terilustrasi pada gambar berikut ini :



Sumber : Francisco J. Valero-Cuevas / Journal of Biomechanics 38 (2005) 673-684
Gambar 2.16 Interaksi sistem saraf dan fungsi organ

Pemahaman yang mendasar tentang keperluan manipulasi, merupakan integritas dari paradigma yang didasari oleh fungsi mekanis dari jari-jari, tetapi berimbang dengan ditail anatomy dan karakteristik meticulous dari aktifitas otot. Paradigma ini akan memotivasi untuk membuat suatu kolaborasi studi antara mekanis, anatomy dan fisiologi saraf.

Berikut ini merupakan analogi dari fungsi manipulasi aktifitas pada jari tangan :



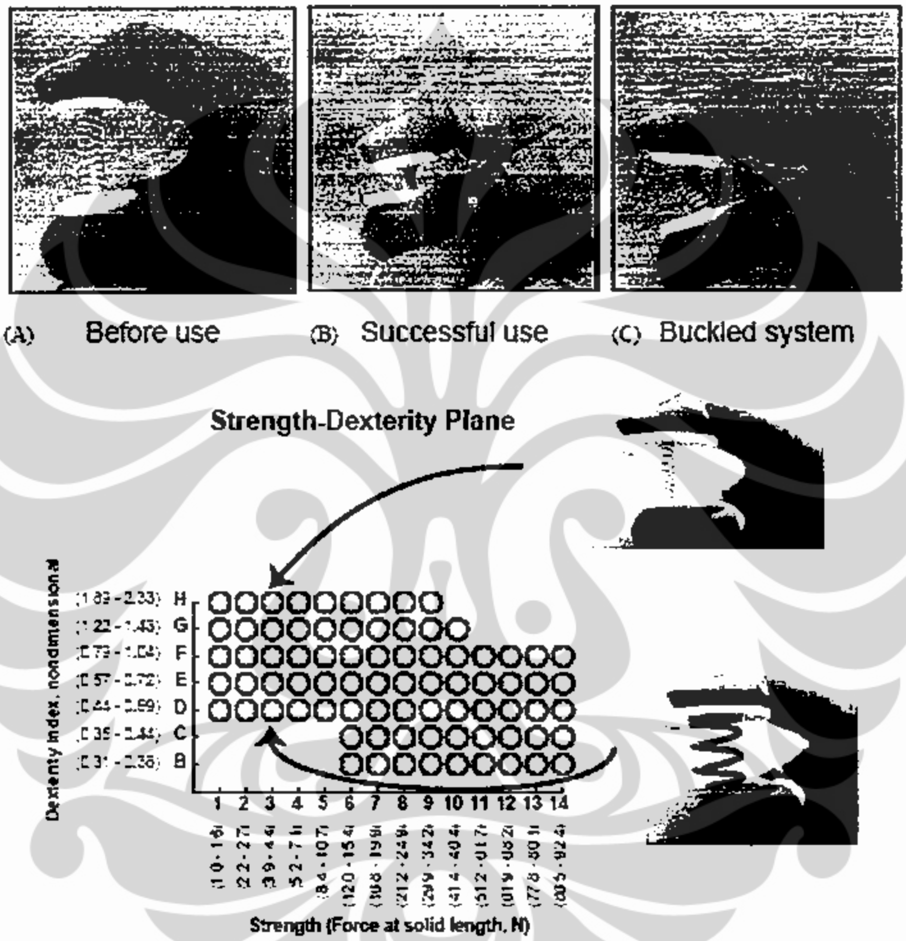
Sumber : Francisco J. Valero-Cuevas / Journal of Biomechanics 38 (2005) 673-684

Gambar 2.17 Analisa dan uraian mekanika yang didasarkan dari jari manusia.

Pengujian kekuatan dan ketrampilan ibu jari.

Ibu jari yang kuat dan selaras dengan kontrol yang sempurna akan mampu mengatasi resistensi per yang ditekan. (B).

Hanya mengandalkan kekuatan ibu jari tapi tidak selaras dengan kontrol yang mengarahkan arah gerakan, per tidak tertekan dengan sempurna (C)

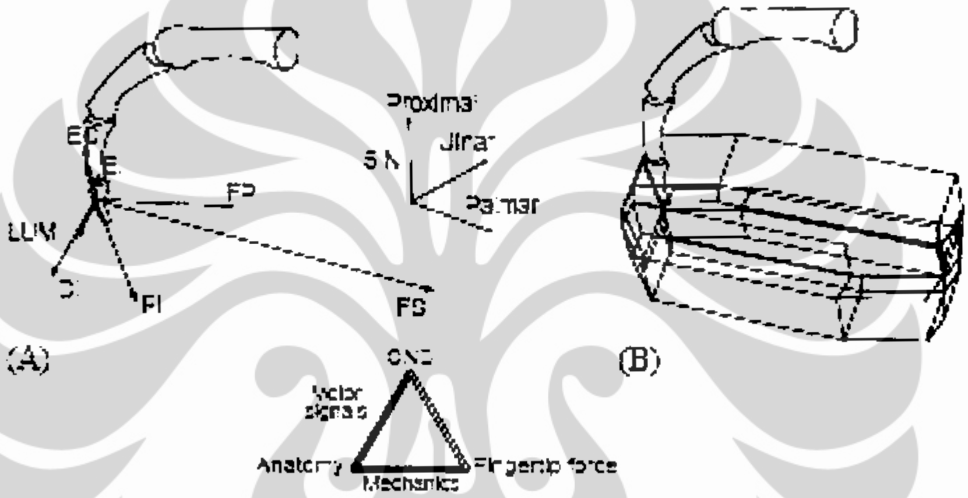


Sumber : Francisco J. Valero-Cuevas / Journal of Biomechanics 38 (2005) 673-684

Gambar 2.18 Pengujian ibu jari.

2.8.1. Kemampuan dan Gaya Pada Jari Tangan

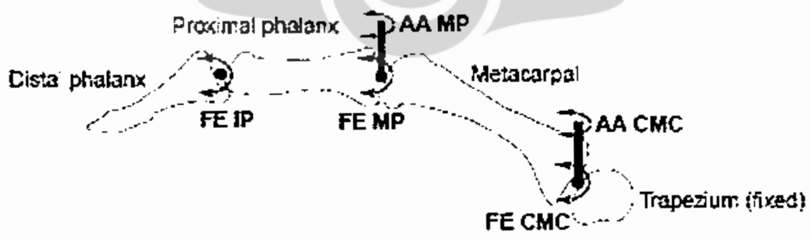
Kemampuan tekanan yang sanggup dilakukan oleh jari-jari tangan terdapat pada indeks jari, yang berisi : kemampuan biomekanis maksimal tekanan oleh jari-jari dan pola koordinasi yang unik untuk mencapai tekanan tersebut. Hal tersebut didapatkan dengan mengkalkulasi "feasibility force set" pada jari-jari, ruang 3D vector merepresentasikan tekanan maksimal yang dihasilkan kesemua arah pada ruang tekan (Lee & Rim, 1990). Setiap otot memproduksi vektor tekan pada jari-jari (Valero & Cuevas et al, 2000; pearlman et al, 2004).



Sumber : Francisco J. Valero-Cuevas / Journal of Biomechanics 38 (2005) 673-684

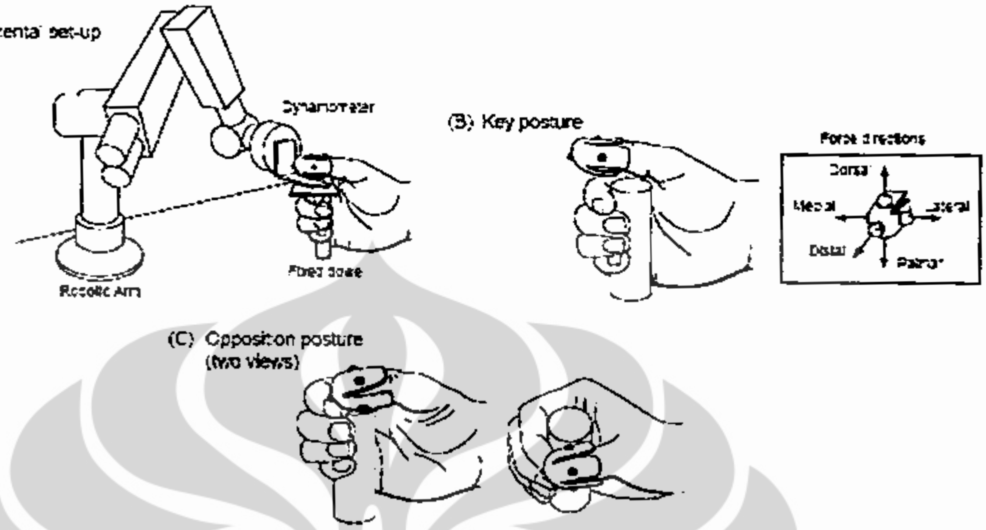
Gambar 2.19. kekuatan yang dimungkinkan dari jari telunjuk.

2.8.2 Biomekanik Pada Ibu Jari



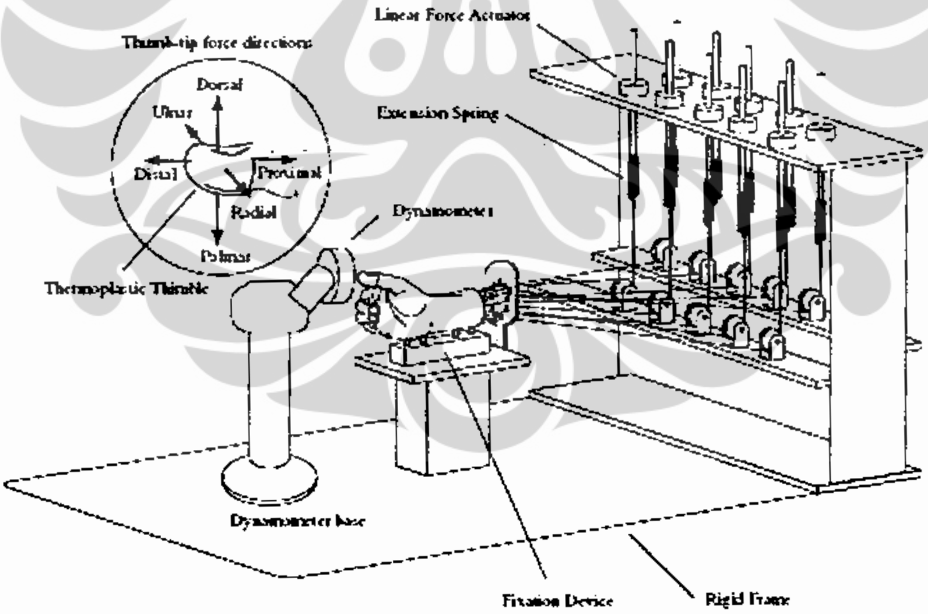
Sumber : Francisco J. Valero-Cuevas et al / Journal of Biomechanics 36 (2003) 1019-1030

Gambar 2.20 Kinematika gerakan dari sebuah ibu jari.



Sumber : Francisco J. Valero-Cuevas et al / Journal of Biomechanics 36 (2003) 1019-1030

Gambar 2.21. Metodologi untuk mempelajari gaya yang dihasilkan dari gerakan ibu jari.



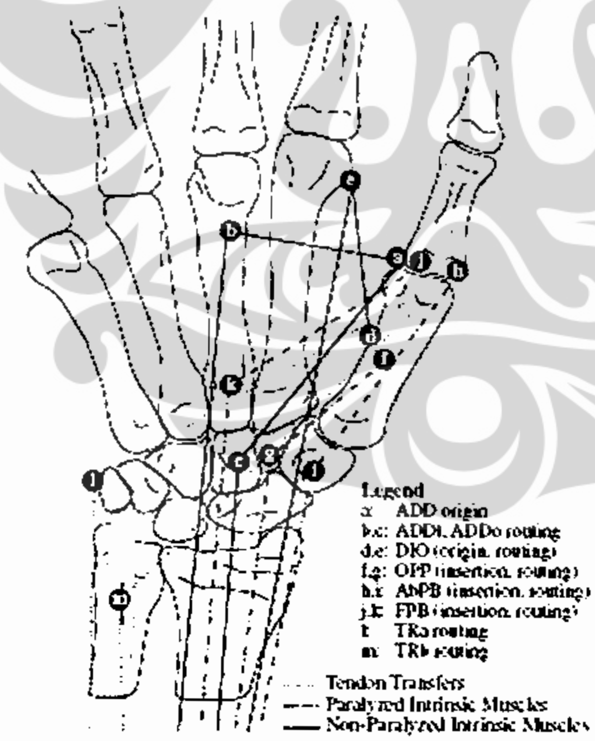
Sumber : J.L. Pearlman et al / Journal of Orthopaedic Research 22 (2004) 306-312

Gambar 2.22 perangkat perekam kontrol gerakan ibu jari.

Tabel 2.1. kekuatan ibu jari sesuai arah gerakan

Direction	Key posture			Opposition posture		
		Mean	SD		Mean	SD
Dorsal	Experiment	11.0	2.2	Experiment	11.5	2.7
	Model	4.7	2.6	Model	7.7	2.1
ratio Exp:Model		2.3			1.5	
Palmar	Experiment	51.9	20.4	Experiment	47.5	27.2
	Model	16.9	3.7	Model	14.1	4.1
ratio Exp:Model		3.1			3.4	
Distal	Experiment	65.0	27.9	Experiment	56.0	34.1
	Model	32.6	10.3	Model	15.1	4.8
ratio Exp:Model		2.0			3.7	
Medial	Experiment	21.3	7.8	Experiment	20.7	6.9
	Model	6.2	2.4	Model	6.1	2.2
ratio Exp:Model		3.4			3.4	
Lateral	Experiment	19.5	4.8	Experiment	36.6	21.5
	Model	3.0	1.4	Model	3.1	1.9
ratio Exp:Model		6.6			11.7	
Mean Exp:Model		3.5			4.7	

Sumber : J.L. Pearlman et al / Journal of Orthopaedic Research 22 (2004) 306-312



Sumber : J.L. Pearlman et al / Journal of Orthopaedic Research 22 (2004) 306-312

Gambar 2.23 penampang otot dan arah aksinya.

2.9. Psikologi Perkembangan Anak

J.Pieget mengemukakan perkembangan merupakan suatu proses yang panjang, dan membutuhkan dorongan atau stimulus untuk berlangsungnya suatu kehidupan. Perkembangan juga terjadi pada individu secara alami, karena di dalam dirinya telah terdapat komponen-komponen psikologis yang menunjang perkembangannya yaitu psiko-kognitif, psiko-motorik dan psiko-afektif.

2.9.1. Psiko- Kognitif.

Suatu proses psikologis yang terjadi dalam bentuk pengenalan, pengertian dan pemahaman dengan menggunakan pengamatan, pendengaran dan berfikir.

Kognitif adalah perilaku yang mengakibatkan individu memperoleh pengetahuan dan pemahaman atau sesuatu yang dibutuhkan untuk menggunakan pengetahuan.

Perkembangan kognitif ditentukan oleh perkembangan otak dan panca indra sebagai pengamatannya.

Kognitif merupakan suatu kemampuan-kemampuan individu untuk mengalami dan mengenali dirinya beserta lingkungannya secara berproses dan pengenalan individu untuk membuat atau mengatur dunianya dengan caranya sendiri. Dengan cara memasukkan informasi dari luar dirinya atau stimulus yangmasuk dalam reseptor-reseptor panca indra, pengamatan, pendengaran, perabaan, kemudian diproses dengan otak untuk dihantarkan ke dalam daerah pemahaman yang kemudian dianalisis, disusun dalam bentuk-bentuk simbolik dengan membandingkan dengan informasi atau pengalaman sebelumnya. Akhirnya semua informasi tersebut disimpan dalam memori yang sewaktu-waktu dapat digunakan apabila diperlukan. Kognisi akan berbentuk perilaku yang nyata dari proses analisis yaitu berkomunikasi, menulis, berinteraksi sosial, berkarya dan sebagainya.

Tokoh kognitif J. Pieget berpendapat bahwa perkembangan individu lebih banyak dipengaruhi oleh kognitif yaitu mengenal, mengerti, dan memahami dengan menggunakan berpikir dan pengamatan. Perkembangan kognitif dibagi dalam 4 tahapan yang harus dijalankan anak sesuai dengan usianya yaitu :

1. Tahapan Kognitif Sensor Motorik.

Dimulai usia 0-2 tahun, pada usia ini anak berkembang kognitifnya dengan sentuhan fisik, motorik atau disebut dengan aktifitas motorik

2. Tahapan Kognitif Pra-Operasional.

Dimulai usia 2-7 tahun, pada tahapan usia ini anak baru mau mulai berfikir dalam melihat sesuatu benda dan untuk memahami obyek lingkungannya anak menggunakan simbol-simbol. Dengan mampu melakukan tingkah laku simbolis anak tidak langsung bereaksi terhadap suatu obyek yang berhubungan dengannya, tetapi berusaha beraktifitas secara internal, yaitu mulai mengikuti dan menanggapi apa yang dilakukan orang lain maupun untuk dirinya. Pada tahapan ini anak mulai menggunakan bahasa untuk mendapatkan apa yang diinginkan, karena telah mulai mengerti hubungan sebab akibat, pengertian ini disebabkan pengalaman dan pembelajaran anak yang didapat dari kebiasaan yang ditunjukkan pada dirinya.

3. Tahapan Kognitif Operasional Konkrit.

Dimulai dari usia 7-11 tahun, pada tahapan ini anak mulai menggunakan bentuk operasi-operasi mental atas pengetahuan yang mereka miliki, yaitu pada tahapan sebelumnya telah terbentuk pengertian, melihat sudut pandang dari berbagai pandangan dan menghubungkannya dari satu dimensi ke dimensi lainnya. Dengan melihat multi dimensi anak sudah dapat menyampaikan sesuatu dengan mengurangi, menambah dan mengubah suatu informasi yang diterimanya. Jadi anak sudah mengerti apakah sesuatu itu baik atau buruk bagi dirinya. Dengan operasional konkrit anak belajar membentuk sistem logika, melakukan sesuatu tindakan dengan berfikir terlebih dahulu dan mulai menyadari adanya peraturan.

4. Tahapan Kognitif Operasional Formal

Dimulai usia 11 tahun sampai dengan dewasa, pada tahapan ini individu sudah memahami suatu sistem dan pola-pola yang lebih komplek dan abstrak. Tahapan ini anak mengoperasikan mental tingkat yang lebih tinggi, yaitu memecahkan masalah individunya menggunakan pengujian dan hipotesis sehingga sudah bisa mengenal dirinya sendiri.

2.9.2. Psiko- Afektif.

Afektif merupakan suatu perasaan yang dimiliki seseorang terhadap sesuatu. Perasaan adalah suasana yang menyenangkan, tidak menyenangkan, suka dan tidak suka,baik dann buruk. Setiap individu dalam menerima peristiwa dengan rasa senang dan puas maka ia akan memperkuat afektifnya, jika sebaliknya tidak mampun menerima situasi yang dialaminya , ia merasa kecewa maka afektifnya merasa lemah dan ditekan. Perasaan ini mempunyai sifat evaluatif, yaitu penilaian terhadap apa yang dilihat, didengar dan dirasakannya. Seperti jika anak merasa senang melihat sesuatu benda maka ia akan terus mengamatinya hingga ia mengerti dan merasa puas terhadap benda tersebut.

2.9.3. Psiko- Motorik.

Suatu bentuk perkembangan tubuh, jasmani individu yang diikuti dengan aktifitas dirinya terhadap suatu benda dan lingkungannya. Anggota badan tumbuh dengan kecepatan yang berbeda-beda, diantara anggota satu dengan anggota yang lain, pertumbuhan menunjukkan bahwa setiap individu mempunyai periode perkembangnya sendiri-sendiri. Walaupun didapati adanya norma-norma perkembangan yang sifatnya normal.

Oleh karena itu perkembangan motorik merupakan suatu proses aktivitas individu dengan pertumbuhan yang terkoordinasi diantara jasmani, fisiologi, dan psikologi.

Pertumbuhan jasmani terlihat pada usia 3 tahun, proposi badan dan jaringan urat daging terus berkembang hingga usia 5 tahun. Proposi badan yang seimbang antara ukuran kepala dan anggota badang. Dengan keseimbangan ini memungkinkan perkembangan motorik pada anak sehingga pada usia 3 tahun sudah bisa berjalan tanpa mengalami kesukaran meskipun pada tempat yang tidak rata. Pertumbuhan jasmani dan perkembangan motorik jasmani tidak terlepas dari kematangan perkembangan anak sendiri. Anak akan mengalami pertumbuhan dan perkembangan sesuai dengan usia kematangan secara fisiologis dan psikologisnya.

1. Pertumbuhan Fisiologis.

Perkembangan sistem saraf akan meningkatkan gerak reflek, reflek ini akan terkoordinasi secara baik bersamaan dengan bertambahnya usia individu anak dan mulai dapat mengendalikan reflek-reflek melalui otak. Perkembangan otak diimbangi dengan berkembangannya mekanisme otot. Jika otot belum matang maka tidak akan terjadi koordinasi antara mekanisme otot dan otak. Sehingga dapat dikatakan pertumbuhan antara jasmani dengan pertumbuhan fisiologi sangat penting, karena keduanya untuk memberikan perkembangan pada masing-masing individu.

2. Pertumbuhan Psikologis.

Dorongan yang muncul pada individu pada tahun-tahun awal adalah gerakan reflek naluriah yang dilakukan tanpa dipelajari lebih dahulu. Dengan bertambahnya usia anak, maka dorongan reflek akan berkembang dan merubah sifatnya dari reflek naluri menjadi reflek yang dipelajari. Adanya pengalaman atau sesuatu yang dipelajari maka individu akan melakukan aktivitasnya sesuai dengan yang telah dialami atau yang diterima dari lingkungan kepadanya. Aktivitas motorik antara individu satu dengan lainnya tidak sama, ini terjadi kerena perkembangan jasmani, fisiologi dan psikologi mengalami perbedaan yang diakibatkan lingkungan memberikan pengalaman, memperlakukan, dan memotivasi potensi dasar dari individu tersebut. Setiap periode perilaku motorik tertentu akan mengalami pertumbuhan sesuai dengan mana yang lebih dominan diantara perkembangannya. Salah satu ketrampilan terlihat lebih cepat berkembang, tetapi ketrampilan yang lainnya belum mampu dilakukannya.

Perkembangan ketrampilan dan perkembangan motorik dapat diprediksi sesuai dengan usia dan aktivitas sebelumnya.

2.10. Hubungan Umur Dengan Keselamatan

Seringkali kecelakaan terjadi karena orang tua tidak mewaspadai dilakukan oleh anak. Di Amerika Serikat penelitian menunjukan bahwa sebab dari kecelakaan yang menyebabkan kematian terhadap anak dengan usia dibawah 4 tahun, sebagian besar dari sebab tersebut dapat di cegah. Ancaman terbesar terhadap jiwa dan kesehatan anak-anak adalah cidera. Karena itu para orang tua sudah seharusnya memahami perilaku anak yang berhubungan keselamatan sesuai dengan tingkatan usia anak.

Berikut ini merupakan *Age-Related Safety Sheets, The Injury Prevention Program (TIPP)* dari *American Academy of Pediatrics.*

A. Usia 1 Hingga 2 tahun

Pada tahap usia ini anak akan mulai dapat berjalan, berlari, memanjat, melompat dan mengeksplorasi segala sesuatu, karena semua itu merupakan hal baru yang bisa dilakukan oleh anak, maka merupakan tahap yang paling berbahaya dari kegiatannya. Merupakan tanggung jawab dari orang tua untuk untuk melindungi anak mereka dari bahaya. Anak pada usia ini tidak mengerti tentang bahaya dan perduli dengan kata "tidak" selagi asik dengan kegiatan barunya. Bahaya terhadap racun anak-anak akan berusaha terus untuk memasukan apa saja kedalam mulutnya, walaupun dirasakan tidak enak. Mereka akan berusaha membuka lemari ataupun laci , membongkar dan membuka botol, dengan demikian bahan-bahan berbahaya dan beracun termasuk obat-obatan, harus disimpan dan dijauhkan dari jangkauan anak-anak. Harus diperhatikan bahwa bahan-bahan berbahaya tesebut berada dalam kemasan pelindungnya. Bahaya terjatuh awasi tangga menuju lantai atas, peletakan kursi, meja, jendela dan hal-hal lain yang dapat dijadikan tempat anak memanjat ke tempat yang berbahaya. Bahaya terbakar, dapur merupakan tempat berbahaya selagi orang tua menyiapkan makanan. Minyak dan cairan panas lainnya serta makanan panas yang teciprat kepada anak-anak dapat menyebabkan cidera serius. Tempatkan anak-anak ketempat yang lebih aman ketika orang tua melakukan aktifitas hingga tidak dapat memberikan perhatian penuh. Anak-anak yang sedang belajar berjalan akan memegang segala sesuatu sebagai pegangan mereka, termasuk pintu oven, pemanas ruangan dan lainnya, maka jangan tempatkan anak-anak pada area dimana ada objek panas yang dapat mereka jangkau. Jangan membawa anak bersamaan dengan sesuatu yang panas, seperti menggendong anak sambil membawa minuman panas. Bahaya tenggelam, anak-anak pada usia ini sangat menyukai bermain dengan air, jangan pernah meninggalkan anak sendirian di dalam ataupun di dekat dengan bathtub, air yang menggenag, kolam renang atau tempat air lainnya, walaupun hanya sebentar.

B. Usia 2-4 tahun

Hampir sama pada tahapan usia sebelumnya pada usia ini anak-anak masih akan bahaya dan akan mengacuhkan peringatan ketika mereka bermain dan mengeksplorasi sesuatu. Terlebih karena kemampuan mereka pada tahap usia ini sangat luar biasa maka mereka pun akan berhadapan dengan variasi bahaya yang tanpa batas ketika berada di dalam rumah maupun lingkungan sekitar. Seperti terjatuh keluar dari jendela, ke lantai bawah, dari sepeda dan dari apapun yang mereka bisa panjat. Anak pada usia ini akan mencoba untuk mengeksplorasi segala sesuatu termasuk peralatan yang dapat menghasilkan api, seperti kompor, korek api dan bahkan senjata api. Langkah pencegahan terbaik adalah jauhkan hal-hal tersebut dari jangkauan anak-anak.

C. Usia 5 tahun

Anak pada usia ini akan belajar melakukan segala hal yang dapat menyebabkan cidera serius seperti mengendarai sepeda atau menyebrang jalan. Walaupun mereka mempelajari sesuatu dengan cepat, namun mereka tetap belum dapat menilai apa itu aman. Orang tua harus tetap melindungi anak-anak. Ajarkan pada anak untuk tidak bermain-main dengan api dan peralatan penghasil api seperti korek api dan korek gas, jauhkan korek api dari jangkauan mereka, banyak kebakaran terjadi karena peletakan korek api yang tidak benar.

D. Usia 6 Hingga 7 Tahun

Pada tahap usia ini anak akan semakin mandiri. Mereka akan mulai dapat mengerjakan sesuatu yang berbahaya untuk membuktikan pada orang lain bahwa mereka telah tumbuh dewasa, walaupun sebenarnya belum bisa dengan benar menilai suara, jarak dan kecepatan dari kendaraan yang bergerak. Anak pada tahap usia ini dapat belajar beberapa hal sederhana yang dapat dilakukan untuk menjaga keselamatan, tetapi orang tua masih harus bertanggung jawab penuh terhadap keselamatan mereka.

E. Usia 7 Hingga 9 Tahun

Pada tahap usia ini anak akan mulai mengerjakan segala sesuatu oleh mereka sendiri. Mereka akan mulai meminta pendapat teman sebagai persetujuan. Mereka juga akan mencoba untuk menantang sesuatu dan mungkin mereka akan mengacuhkan peringatan atau aturan dari orang dewasa. Tetapi anak-anak akan belajar tentang keselamatan melalui bantuan dan peringatan dari orang tua. Anak pada usia ini akan sering keluar tanpa orang tua dan masih memiliki potensi pada kecelakaan.

F. Usia 9 Hingga 10 Tahun

Pada tahap usia ini anak akan semakin sering melakukan segala suatu di luar rumah dan jauh dari orang tua, mereka akan semakin lama menghabiskan wktu di atas sepeda atau kendaraan bermotor.

Anak pada usia ini sering kali merasa tidak perlu orang dewasa untuk mengawasi kegiatan mereka. Orang tua harus memperhatikan hal tersebut dan harus sering kali memperingatkan mereka kembali tentang keselamatan.

2.11. Resiko Korek Api Gas Terhadap Anak -Anak

Tidak seperti halnya pada orang dewasa anak-anak masih belum mengerti benar tentang suatu bahaya, mereka cenderung memainkan sesuatu yang menarik perhatian mereka tanpa mempertimbangkan resikonya, termasuk bermain sesuatu yang berhubungan dengan api seperti korek api gas. Bermain dengan korek api gas dapat menyebabkan bahaya seperti cidera atau kebakaran, resiko kebakaran dapat bertambah sangat tinggi ketika anak-anak bermain dengan korek api gas didekat dengan material yang mudah tebakar, seperti memainkannya diatas tempat tidur. Kelalaian dari orang tua dalam mengawasi anak-anak mereka sering sekali menjadi penyebab dari awal terjadinya suatu hal yang tidak diinginkan.

Korek api pada anak mempunyai resiko tersendiri, seperti kita tahu bahwa anak kecil termasuk balita lebih mudah menyalakan korek api gas daripada menyalakan korek api batang. Disayangkan bahwa penelitian yang berhubungan dengan hal tersebut sangat terbatas di Indonesia, peneliti sendiri belum berhasil menemukan literatur maupun studi yang berhubungan dengan resiko korek api gas terhadap anak kecil.

Namun diberbagai negara penelitian tentang hal tersebut sudah banyak dilakukan sejak bertahun-tahun lalu. Di berbagai negara khususnya di Amerika Serikat, negara-negara Eropa dan lainnya menyatakan begitu banyak kecelakaan yang berhubungan dengan aktifitas anak kecil bermain dengan korek api gas. Salah satunya seperti yang dilakukan oleh *AAMI Fire Screen Index* pada tahun 2004 di berbagai kota di Australia, yang menyebutkan bahwa 1 dari 20 orang Australia (5 %) mempunyai pengalaman kecelakaan yang berhubungan dengan api yang melibatkan anak-anak mereka, berikut merupakan variasinya :

- 24 % akibat dari anak-anak yang bermain korek api (gas dan lainnya)
- 18 % termasuk yang berhubungan dengan minyak atau kebakaran akibat memasak
- 10 % melibatkan keluarga akibat ancaman dari *bushfire*
- 7 % akibat dari anak-anak yang duduk terlalu dekat dengan api
- 5 % akibat kelalaian terhadap anak-anak
- 3 % akibat dari pemanas pakaian yang berasal dari heater atau radiator

Sedangkan pada penelitian yang sama menyatakan hasil bahwa 1 dari 8 orang tua (13 %) tidak memberitahu anak mereka (dibawah 15 th) tentang bahayanya api dan seperempat (25 %) dari warga Australia menyatakan bahwa anak-anak mereka tidak tahu apa yang harus dilakukan terhadap api. (*AAMI Fire Screen*, 2004).

U.S Safety Commision pada tahun 1991 mempublikasikan bahwa setiap tahunnya di Amerika Serikan sekitar 180 orang meninggal akibat kebakaran yang diawali oleh anak balita yang bermain korek api, sebagian besar melibatkan korek api gas habis buang (*disposable butane lighters*) bukan korek api batang (*matches*). Walaupun peringatan terhadap terhadap orang tua agar memperhatikan aktifitas anak-anak mereka, terutama terhadap korek api gas, namun studi yang dilakukan oleh New York Federal menunjukan bahwa 50 % dari anak kecil berumur dibawah 5 tahun cukup cerdas dan cukup kuat untuk menyalakan korek api gas, bahkan hanya dengan satu tangan.

2.12. Regulasi Keselamatan Korek Api

Di Indonesia Badan Standarisasi Nasional (BSN) mengeluarkan Standar Nasional Indonesia (SNI) Standar Keselamatan Korek Api Gas (SNI 19-7120-2005), tetapi ketentuan ini hanya diterapkan untuk korek api biasa, sedangkan di Amerika Serikat *U.S. Consumer Product Safety Comission* (U.S. CPSC) sejak 12 Juli 1994 menerbitkan *Safety Standard for Cigarette Lighter* (16 C.F.R. Part 1210) yang mewajibkan konsep "*Child Resistant*" bagi seluruh korek api yang akan digunakan di Amerika Serikat, baik yang diproduksi di dalam negeri maupun yang diimport dari luar

Amerika Serikat. Begitu juga dengan Uni Eropa dengan *European Standard* EN 13869, 2002.

2.13. Tingkat keselamatan.

Dalam mendesain dan pembuatan suatu komponen atau produk perlu mempertimbangkan suatu desain struktur kekuatan yang baik. Pertimbangan dalam suatu desain melihat jenis-jenis kondisi internal dan lingkungan yang akan bekerja pada komponen produk tersebut. Pembuatan komponen tidak terlepas dari pemilihan material yang baik, material tidak boleh rusak atau defleksi saat kondisi operasional digunakan. Para pendesain harus mengetahui sifat-sifat mekanik setiap komponen yang digunakan dalam produknya. Dalam mendesain harus bisa menentukan batasan-batasan beban yang bekerja ditiap komponen sehingga terjaga kualitas dan fungsi produknya.

Batasan-batasan beban dinamakan kekuatan standar dan nilainya sering ditentukan secara statistik atau pengalaman. Para pendesain komponen harus mempertimbangkan unsur ketidakpastian elemen-elemen penting seperti kondisi sebenarnya dan lingkungan penggunaannya. Saat desain sebenarnya, nilai ambang batas dari desain kekuatan dan perhitungan kekuatan dikatagorikan masuk dalam batasan kekuatan standar. Nilai ambang batas tersebut dinamakan beban yang diperbolehkan.

Beban yang dibolehkan merupakan beban kekuatan standar dibagi tingkat keselamatan (Safety Factor). Nilai tingkat keselamatan umumnya bernilai lebih dari satu dan ditentukan dari penggunaan komponen, kondisi penggunaan dan kondisi lingkungan sekitar. Jika nilai tingkat keselamatan lebih besar maka nilai beban yang diperbolehkan lebih kecil dibandingkan beban standarnya, sehingga pendesain harus merencanakan suatu cara perhitungan penambahan kekuatan komponen. Dalam pelaksanaannya penguatan komponen akan meningkatkan disisi berat dan biaya. Semakin tinggi tingkat keselamatan , nilai beban yang diperbolehkan untuk komponen semakin rendah dari nilai beban standarnya.

Jika tingkat keselamatan diterapkan seperti seharusnya, terjadinya kegagalan secara yakin dapat dikurangi dengan menjaga kemampuan sistem yang ada. Resiko terjadinya manusia yang cedera dan kerugian ekonomi lainnya dapat dicegah dan desain dapat ditentukan dengan efisien.

Ada beberapa poin-poin untuk mempertimbangkan ketika memilih suatu tingkat keselamatan.

- Tingkat keselamatan harus lebih besar dari 1.0 untuk mencegah kegagalan.
- Jika tingkat keselamatan adalah terlalu besar, sia-sia dan tidak efisien.
- Jika tingkat keselamatan adalah terlalu kecil, keselamatan menjadi suatu resiko.

2.14 Tingkat Resiko.

Produsen produk berkewajiban untuk memberitahukan kepada konsumen tingkat resiko yang kemungkinan terjadi atas berfungsinya maupun kegagalan yang terjadi dari produk yang dipakai oleh masyarakat. Kegagalan diakibatkan oleh kesalahan produksi, tidak berfungsinya system ataupun pengoperasian yang salah. Informasi yang perlu disampaikan kepada pengguna adalah tingkat resiko yang ditimbulkan baik dari kerusakan pada kesehatan maupun ancaman terhadap keselamatan. Produk yang mempunyai resiko yang rendah tidak harus tidak mempunyai resiko, akan tetapi tetap mempunyai resiko yang rendah dan masih sepadan dengan manfaat yang dihasilkan dari produk tersebut.

Tingkat resiko dapat dilihat dari penilaian jenis kerusakan yang ditimbulkan seperti tabel di bawah.

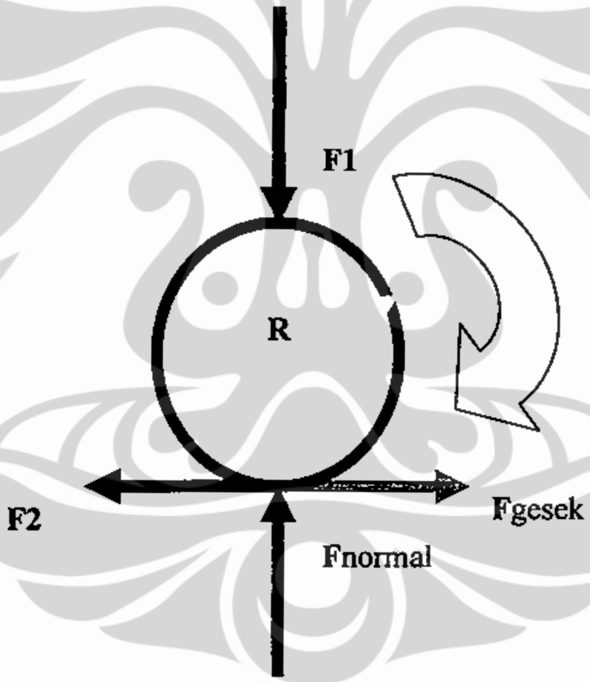
Tabel 2.2 Tingkat resiko

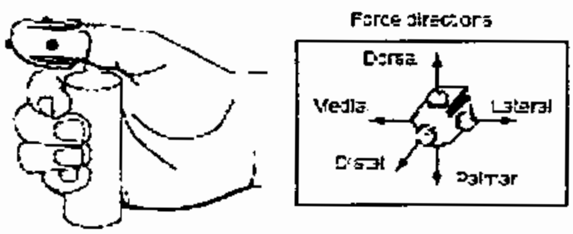
Overall Probability of Health/Safety Damage		Kemungkinan terjadinya hazard		
		1%	10%	100% (All)
Kemungkinan Rusaknya kesehatan/keselamatan yang diakibatkan Oleh produk Yang berpotensi bahaya	Hazard akan selalu timbul Dan akibat yang ditimbulkan dapat diprediksi sebelumnya	Menengah	Tinggi	Sangat tinggi
	Hazard mungkin terjadi akibat satu atau dua kondisi	Rendah	Medium	Tinggi
	Hazard hanya akan terjadi bila beberapa kondisi yang saling bertemu	Sangat rendah	Rendah	Menengah

2.15 Distribusi Gaya.

Untuk menyalakan api, korek api digenggam dan ibu jari berapa diatas roda penggerak. Roda penggerak ditekan terlebih dahulu agar roda penggerak sisi luar menekan penghubung plastic dan menempel pada roda pemantik, kekuatan gaya tekan kebawah diperlukan membebaskan pengaman dan menggerakkan roda pemantik dalam biomechanic disebut dengan arah gerakan ibu jari kebawah "palmar" dalam distribusi ini diberikan notasi F1.

Setelah ditekan, arah ibu jari digerakkan untuk memutar roda penggerak, dalam biomechanic disebut dengan arah gerakan ibu jari "Distal", dalam distribusi ini disebut dengan gaya tangensial dan diberikan notasi F2.





Gambar 2.24. Distribusi Gaya.

F1 = arah gaya "palmar" merupakan gaya arah ke bawah

Fnormal = gaya perlawanan dari F1 untuk terjadinya gesekan pada batu api.

F2 = arah gaya "distal" merupakan gaya tangensial untuk memutar roda.

Fgesek = Fgesek akan timbul karena adanya gaya F1 yang telah bisa memutar roda penggerak dan gaya F2 yang menyentuh permukaan batu api.

Arah gaya Fgesek adalah berlawanan dengan gaya F2.

Momen puntir dengan notasi T = adalah jarak jari2 (R) dari titik pusat putaran dikalikan gaya tangensial yang terjadi F2.

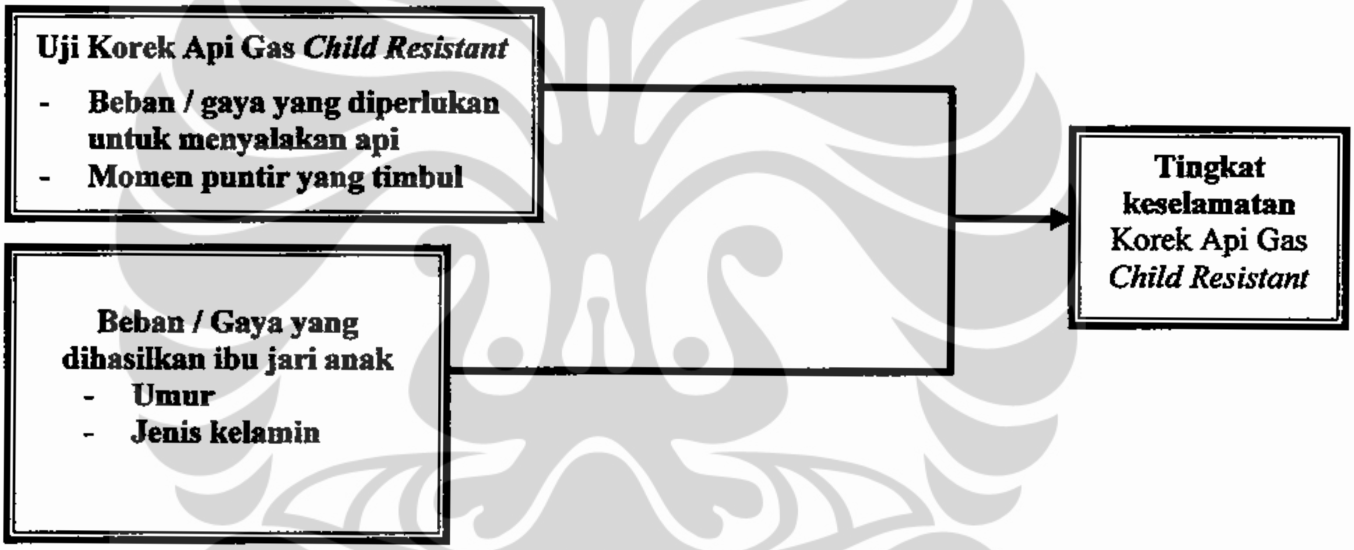
Sehingga Momen Puntir T = R x F2.

Setelah dilakukan analisis data kekuatan gaya arah "palmar" F1 dari anak-anak responden dan digunakan untuk mendapatkan berapa tingkat keselamatannya jika dibandingkan dengan data analisis dari beban yang diterima oleh korek pada load test.

BAB 3

KERANGKA KONSEP

3.1. Model Kerangka Konsep



Gambar 3.1.Model Kerangka Konsep

3.2. Definisi Operasional

Berikut ini merupakan tabel dari variabel – variabel yang digunakan dalam penelitian ini berikut definisi operasional (dalam kaitannya dengan penelitian ini), instrumen penelitian yang digunakan, hasil ukur dan katagori skala dari hasil ukur :

Tabel 3.1. Tabel Definisi Operasional

No	Variabel	Definisi Operasional	Instrumen	Hasil Ukur	Skala
1	Beban / gaya yang diperlukan untuk memantik api	Merupakan energi yang diperlukan untuk dapat memutar roda pemantik api, sehingga dapat menimbulkan percikan api dalam suatu satuan gaya	*Load Test*	Satuan Newton	Ratio
2	Beban / Gaya yang dihasilkan	Merupakan energi yang sanggup dihasilkan ibu jari oleh responden untuk menekan suatu beban	*Push Gauge*	Satuan Newton	Ratio
3	Umur	Usia responden terhitung dari saat lahir sampai saat dilakukan uji	Formulir isian	▪ 0-60 bulan ▪ >60-84 bulan ▪ >84-108 bulan	Interval

No	Variabel	Definisi Operasional	Instrumen	Hasil Ukur	Skala
4	Momen puntir	Merupakan hasil perkalian antara jari-jari roda pemutar dengan gaya tangensial	Parameter hasil uji	Satuan Newton Meter	Ratio.
5	Tingkat keselamatan	Merupakan kondisi keamanan model korek api gas, dimana beban yang diperlukan untuk memutar roda pemantik agar dapat menghasilkan percikan api tidak dapat dicapai oleh anak berusia di bawah 60 bulan (5 tahun).	Hasil uji lab & uji eksperimen	▪ **Aman** ▪ **Tidak Aman**	Ordinal
Keterangan		**Hasil ukur tingkat keselamatan/ angka keamanan didapat berdasarkan perbandingan antara kekuatan gaya arah "palmar" F1 dari anak-anak responden dengan data analisis dari beban yang diterima oleh korek pada load test.**		– **Aman** Apabila hasil eksperimen menghasilkan bahwa seluruh responden (anak <60 bln [5 th]) menghasilkan gaya lebih rendah dari beban pada roda pemantik korek api *child resistant*	

		– **Tidak Aman** Apabila hasil eksperimen menghasilkan bahwa dari seluruh responden (anak <60 bln[5 th]) menghasilkan gaya lebih tinggi dari beban pada roda pemantik korek api *child resistant*

BAB 4

METODOLOGI PENELITIAN

4.1. Disain Penelitian

Penelitian ini merupakan penelitian observasi dan eksperimental karena :

a. Melakukan uji laboratorium terhadap korek api *child resistant* produksi PT. TDI untuk mengukur beban yang diperlukan untuk dapat menghasilkan nyala api dengan mesin *load test.*

b. Melakukan eksperimen secara langsung terhadap kekuatan beban ibu jari anak berusia di bawah 108 bulan (9 tahun).

c. Membandingkan hasil beban untuk menyalakan api dengan load test dengan hasil eksperimen kekuatan beban terhadap anak berusia hingga 60 bulan (5 tahun.)

d. Melakukan penghitungan statistik untuk melihat hubungan antara umur dan beban kekuatan ibu jari anak yang diteliti

4.2. Lokasi dan Waktu Penelitian

Penelitian ini dilakukan di beberapa tempat, yaitu pada bulan Mei 2008 di laboratorium milik PT. Tokai Dharma Indonesia di Jalan Raya Jakarta - Bogor, KM. 36. Sukmajaya, Depok 16412 – Jawa Barat, Uji eksperimental terhadap anak dilakukan di *PlayGroup* Tadika Puri, Jl. Halmahera, Depok Utara dan SD Yaspen Tugu Ibu, Jl. Sentosa Raya, Depok II Tengah. Penelitian dilakukan pada tanggal 15 Desember sampai 22 Desember 2007.

4.3. Populasi dan Sampel Penelitian

4.3.1. Populasi Penelitian

Populasi dalam penelitian ini adalah seluruh korek api *child resistant* produksi PT. TDI dan seluruh anak pada usia di bawah 108 bulan (9 tahun). Masing-masing jumlahnya tidak diketahui secara pasti namun penulis memastikan masing-masing jumlahnya di atas 100.000.

4.3.2. Penentuan Jumlah Sampel

Sampel adalah sebagian atau wakil populasi , dilakukan terhadap 30 anak berusia dibawah 5 tahun dan 60 anak berusia 5 – < 9 tahun, perhitungan jumlah sampel didasarkan pada rumus (Prof. DR. Sugiyono, 2006). Metode penentuan jumlah sampel, dimana populasinya diatas 100.000 dan tidak diketahui simpangan bakunya maka digunakan rumus sebagai berikut :

$$n \geq \frac{pq}{(\sigma_p)^2}$$

$$\sigma_p^2 = \left(\frac{Ho - Ha}{z}\right)^2$$

Dimana :

n = Ukuran sampel yang diperlukan

p = Prosentase hipotesis (Ho) dinyatakan dalam peluang yang besarnya = 0,50

q = 1- 0,50 = 0,50

σ_p^2 = perbedaan antara yang ditaksir pada hipotesis kerja (Ha) dengan hipotesis nol (Ho), dibagi dengan z pada tingkat kepercayaan tertentu.

Karena peneliti berhipotesis bahwa paling sedikit hasil penelitian adalah 70% dari standar yang ditetapkan dengan tingkat kepercayaan yang akan dipakai adalah 95% maka :

Ho = 0,70 ; Ha = 0.50

z = 1,96

hasil perhitungannya adalah :

$$\sigma_p^2 = \left(\frac{70\,\% - 50\,\%}{1{,}96}\right)^2 = \left(\frac{0{,}20}{1{,}96}\right)^2 = 0{,}0104$$

Maka besarnya ukuran sampel yang diperlukan sebagai sumber data pada tingkat kepercayaan 95 % adalah :

$$n \geq \left(\frac{0{,}50 \,.\, 0{,}50}{0{,}0104}\right) = \left(\frac{0{,}25}{0{,}0104}\right) = 24{,}0292$$

Berarti jumlah sampel yang diperlukan adalah sebanyak 25 orang, **pada penelitian ini akan diambil masing-masing 30 orang.**

Sedangkan sampel untuk korek api *child resistant* yang akan diuji baik untuk uji laboratorium maupun uji eksperimen berjumlah **50 buah korek api model M13LCS** (*Child Resistant – Cigarette Lighter*), dengan perhitungan rumus sampel yang sama, namun peneliti berhipotesa bahwa paling tidak kondisi korek api adalah 90% sesuai standar dan spesifikasi yang ditetapkan. Hasil dari perhitungan rumus penentuan jumlah sampelnya adalah paling tidak (minimal) sampel yang diperlukan adalah 7 buah korek api *child resistant*.

Berikut merupakan perhitungannya :

Karena peneliti berhipotesis bahwa paling sedikit hasil penelitian adalah 90% dari standar yang ditetapkan dengan tingkat kepercayaan yang akan dipakai adalah 95% maka :

Ho= 0,90 ; Ha = 0,50

z = 1,96

hasil perhitungannya adalah :

$$\sigma_p^{\ 2} = \left(\frac{90\ \% - 50\ \%}{1,96} \right)^2 = \left(\frac{0,40}{1,96} \right)^2 = 0,04165$$

Maka besarnya ukuran sampel yang diperlukan sebagai sumber data pada tingkat kepercayaan 95 % adalah :

$$n \geq \left(\frac{0,50\ .0,50}{0.04165} \right) = \left(\frac{0,25}{0,04165} \right) = 6,002400$$

Berarti jumlah sampel yang diperlukan adalah sebanyak 7 buah korek api *child resistant*. **Pada penelitian ini digunakan sampel sebanyak 50 korek api.**

4.3.3. Teknik Pengambilan Sampel

Pengambilan sampel untuk anak akan menggunakan teknik **sampel berstrata atau stratified sample**, karena peneliti berpendapat bahwa populasi terbagi atas tingkatan-tingkatan dan terdapat perbedaan ciri atau karakteristik pada setiap tingkatan tersebut, maka perbedaan ini tidak boleh diabaikan dan setiap perbedaan harus terwakilkan dalam sampel (Prof. Dr. Suharsini Arikunto, 2006)

Sedangkan untuk sampel korek api *child resistant* akan digunakan teknik pengambilan sampel **secara acak atau random sample**, karena peneliti berpendapat bahwa pada pada keseluruhan korek api *child resistant* bersifat homogen yang artinya tidak terdapat perbedaan tingkatan/strata atau karakteristik lainnya pada korek api *child resistant*, perbedaan hanya terdapat pada warna, dimana pembedaan karakteristik warna bukan merupakan objek dari penelitian ini.

4.4. Uji Validitas dan Reliabilitas Alat Uji

Untuk menguji validitas dari alat *load test* dan *push gauge* telah dilakukan proses kalibrasi alat.

a. *Load test*, dilakukan kalibrasi dengan anak timbangan 2000 gram, dikalibrasi oleh PT. Caltesys Indonesia No. C009329 pada tanggal 18 April 2007.

b. *Push- pull gauge*, dilakukan kalibrasi oleh PT. Caltesys Indonesia No. C010976 pada tanggal 27 Juli 2007.

4.5. Teknik Pengumpulan Data

a. Data yang diambil merupakan data primer hasil dari survey dengan media bantu berupa ***push gauge*** terhadap responden dan hasil uji beban korek api child resistant dengan alat bantu ***load test***.

b. Sebelum dilakukan uji terhadap korek api akan diambil secara random 50 buah korek api *child resistant* yang akan dijadikan sampel. Seluruh sampel merupakan korek api yang sama dan akan diberikan tanda atau kode untuk keperluan inventori data.

c. Uji eksperimen akan dilakukan 3 tahap untuk setiap katagori usia

Masing-masing :

30 responden untuk usia : 0 - 60 bulan

30 responden untuk usia : > 60 – 84 bulan

30 responden untuk usia : > 84 - 108 bulan

Dilakukan seperti diatas agar setiap tingkatan umur yang merupakan fokus pada penelitian ini terwakili

d. Dalam setiap tahap akan dilakukan terhadap responden dengan katagori usia dan jenis kelamin secara proporsional.

e. Setelah itu dilakukan proses data *collecting* untuk mengumpulkan data yang sudah ada

f. Selanjutnya dilakukan proses *data entry* dengan memasukan pada program *SPSS* di komputer.

g. Setelah semua data dimasukkan lalu dilakukan proses *cleaning* untuk mensortir dan membersihkan data dari *error sample.*

4.6. Pengolahan dan Analisa Data

Data uji keselamatan yang didapat akan diolah dan dianalisis dengan program SPSS , sedangkan untuk hasil eksperimen terhadap anak akan diolah dan di analisis secara statistik untuk mendapatkan hubungan antara umur dan gaya yang sanggup dihasilkan. Karena hasil data yang akan dianalisa merupakan hubungan antara data yang bersifat katagorik umur dan diuji dengan data yang bersifat numerik (beban / gaya), maka instrumen statistik yang akan digunakan Analisa data menggunakan instumen statistik berupa metode *Chi-Square Test of Dependence*.

Rumus Chi-Square : $$X^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

$$E = \frac{Tk}{Tb} Tb$$

Dimana :

X^2 = *Chi-Square*

O_i = Frekuensi dari data ke – *i* yang diobservasi (*observed*)

E_i = Frekuensi dari data ke – i yang diharapkan *(expecteded)*

Tk = Total kolom

Tb = *Total baris*

Chi-Square Test of Dependence digunakan untuk menganalisa frekuensi dari dua variabel dengan banyak katagori untuk menentukan apakah kedua variabel tersebut berhubungan satu sama lain atau sebaliknya tidak berhubungan (Roni Kountur, 2006). Pada penelitian ini karena tingkat keyakinan yang diharapkan sebesar 95% maka alpha (α) yang digunakan dalam tabel *Chi-Square* : 0,05.

Hasilnya nanti akan melihat apakah ada hubungan yang signifikan (dengan tingkat kepercayaan 95%) atau tidak antara karakteristik umur anak dengan beban yang dihasilkan oleh ibu jari. Akan dilihat apabila pada alpha (α) 0,05 nilai *chi-square* hitung dengan degree of freedom (DF) lebih tinggi dari nilai *chi-square* pada tabel lebih besar maka dapat dinyatakan pada tingkat kepercayaan 95% terdapat hubungan yang signifikan antara beban dengan salah satu karakteristik anak kecil. Sebaliknya apabila nilai chi-square hitung lebih rendah dari nilai chi-square tabel maka pada tingkat kepercayaan 95% dinyatakan tidak terdapat hubungan yang signifikan.

Sedangkan untuk mengetahui seberapa besar korelasi diantara variabel-variabel yang saling berhubungan akan menggunakan uji korelasi (*the power of testing*) pearson dan uji koefisien korelasi spearman, dengan rumus :

Rumus uji korelasi :

$$\bar{x} = \mu + z\left(\frac{s}{\sqrt{n}} \right)$$

$$z = \frac{\bar{X} - \mu}{s/\sqrt{n}}$$

Dimana :

Z = *z-score*

$\bar{x}$ = rata-rata kritis

μ = probabilitas

s = sampel

n = populasi

Dengan uji ini akan terlihat nilai *r* (1-β) yang merupakan tingkat keeratan hubungan (korelasi) tertentu antara beban yang dihasilkan dengan karakteristik anak kecil. Dengan katagori korelasi sebagai berikut :

hasilnya akan menghasilkan daerah 1-β dengan katagori :

0-0,2 / 0 - -2 = korelasi sangat rendah (hampir tidak ada hubungan)

>0,2–0,4 / <-2 - -0,4 = korelasi rendah

>0,4-0,6 / <-0,4 - -0,6 = korelasi sedang

>0,6-0,8 / > -0,6 - -0,8 = korelasi tinggi

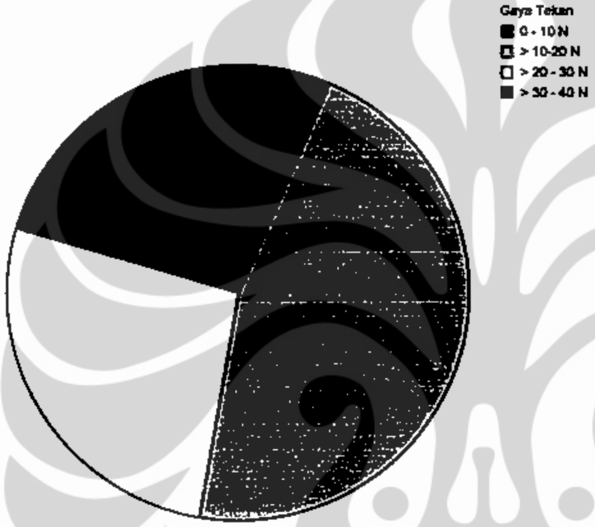
>0,8-1 / < -0,8 - -1 = korelasi sangat tinggi

Uji korelasi ini akan menentukan apakah hubungan antara varibel yang diteliti bersifat linear atau tidak linear, apabila hasilnya linear maka akan ditentukan hubungannya liner positif atau negatif berikut katagori tingkat korelasinya (*level of correlation*)

BAB 5

HASIL PENELITIAN

5.1 Hasil Gaya Tekan Responden



Gambar 5.1 Grafik distribusi gaya tekan

Tabel. 5.1 Frequency gaya tekan

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0 - 10 N	6	6.5	6.5	6.5
	> 10-20 N	44	47.3	47.3	53.8
	> 20 - 30 N	30	32.3	32.3	86.0
	> 30 - 40 N	13	14.0	14.0	100.0
	Total	93	100.0	100.0	

Tabel 5.2 Tabel umur dan gaya tekan

Umur Responden * Gaya Tekan Crosstabulation

Count

		Gaya Tekan				Total
		0 - 10 N	> 10-20 N	> 20 - 30 N	> 30 - 40 N	
Umur Responden	0 - 60 bulan	3	29	0	0	32
	> 60 - 84 bulan	3	12	16	0	31
	> 84 - 108 bulan	0	3	14	13	30
Total		6	44	30	13	93

Tabel 5.3 Tabel hasil Chi-square

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	68.014(a)	6	.000
Likelihood Ratio	83.028	6	.000
Linear-by-Linear Association	47.197	1	.000
N of Valid Cases	93		

a 6 cells (50.0%) have expected count less than 5. The minimum expected count is 1.94.

Tabel 5.4 Tabel korelasi Pearson umur dan gaya tekan

Correlations

		Umur Responden	Gaya Tekan
Umur Responden	Pearson Correlation	1	.716(**)
	Sig. (2-tailed)	.	.000
	N	93	93
Gaya Tekan	Pearson Correlation	.716(**)	1
	Sig. (2-tailed)	.000	.
	N	93	93

** Correlation is significant at the 0.01 level (2-tailed).

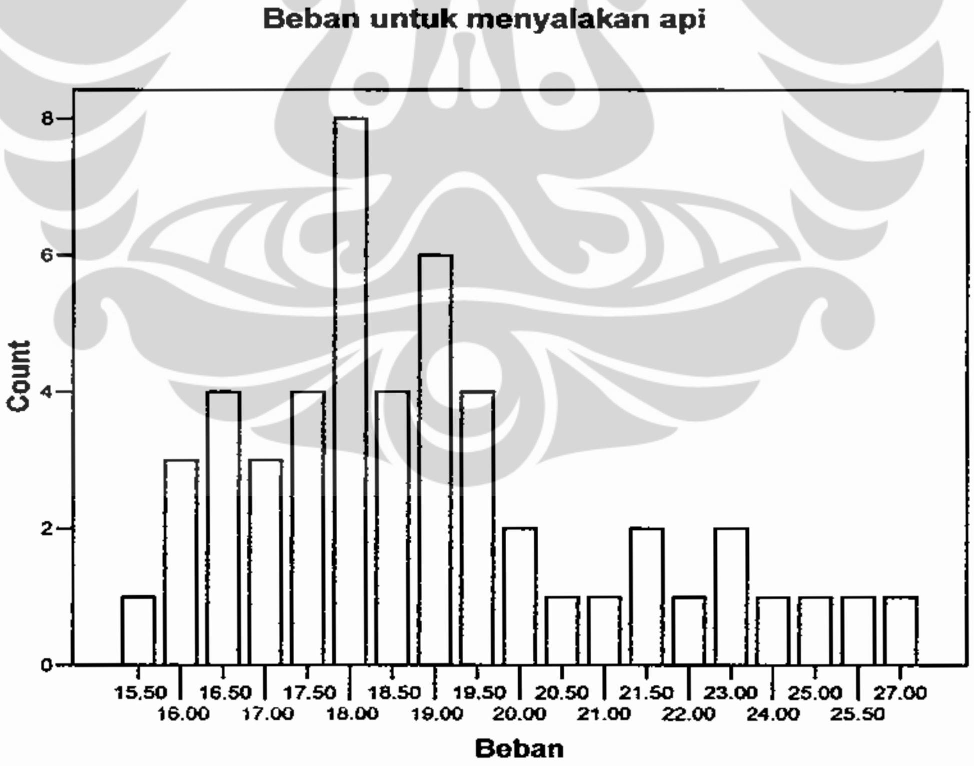
Tabel 5.5 Tabel korelasi Spearman umur dan gaya tekan

Correlations

			Umur Responden	Gaya Tekan
Spearman's rho	Umur Responden	Correlation Coefficient	1.000	.736(**)
		Sig. (2-tailed)	.	.000
		N	93	93
	Gaya Tekan	Correlation Coefficient	.736(**)	1.000
		Sig. (2-tailed)	.000	.
		N	93	93

** Correlation is significant at the 0.01 level (2-tailed).

5.2. Hasil Gaya Mesin Load Test



Gambar 5.2 Grafik Beban gaya hasil uji mesin load test

Tabel 5.6 Tabel beban dan frequency hasil uji mesin load test

Beban

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15.50	1	2.0	2.0	2.0
	16.00	3	6.0	6.0	8.0
	16.50	4	8.0	8.0	16.0
	17.00	3	6.0	6.0	22.0
	17.50	4	8.0	8.0	30.0
	18.00	8	16.0	16.0	46.0
	18.50	4	8.0	8.0	54.0
	19.00	6	12.0	12.0	66.0
	19.50	4	8.0	8.0	74.0
	20.00	2	4.0	4.0	78.0
	20.50	1	2.0	2.0	80.0
	21.00	1	2.0	2.0	82.0
	21.50	2	4.0	4.0	86.0
	22.00	1	2.0	2.0	88.0
	23.00	2	4.0	4.0	92.0
	24.00	1	2.0	2.0	94.0
	25.00	1	2.0	2.0	96.0
	25.50	1	2.0	2.0	98.0
	27.00	1	2.0	2.0	100.0
	Total	50	100.0	100.0	

Tabel 5.7 Tabel Statistik hasil uji beban mesin load test

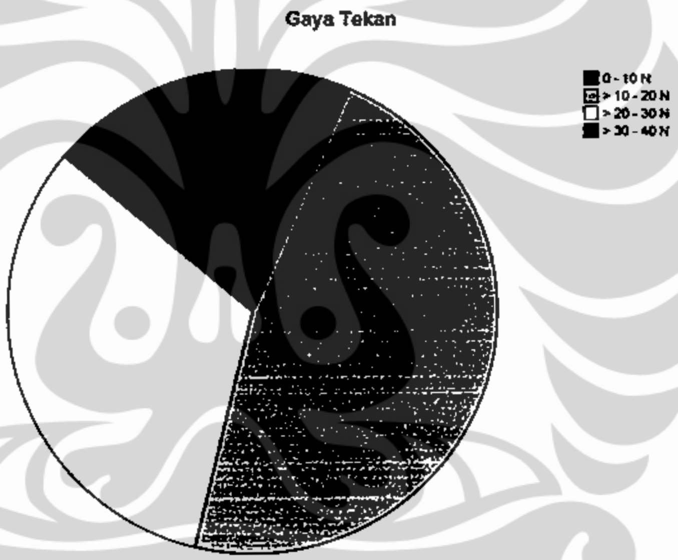
Statistics

		Beban	Torque
N	Valid	50	50
	Missing	0	0
Mean		19.0900	.10038
Median		18.5000	.09800
Mode		18.00	.095
Variance		6.609	.000
Minimum		15.50	.080
Maximum		27.00	.138
Sum		954.50	5.019

BAB 6

PEMBAHASAN

6.1. Hasil Penelitian Gaya Yang Dihasilkan Oleh Responden



Gambar 6.1 Grafik Distribusi gaya tekan

Tabel 6.1 Tabel Frequency gaya tekan

Gaya Tekan

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0 - 10 N	6	6.5	6.5	6.5
	> 10-20 N	44	47.3	47.3	53.8
	> 20 - 30 N	30	32.3	32.3	86.0
	> 30 - 40 N	13	14.0	14.0	100.0
	Total	93	100.0	100.0	

Berdasarkan hasil penelitian didapatkan hasil bahwa gaya tekan yang dihasilkan oleh seluruh responden terbanyak terdapat antara gaya diatas 10 – 20 Newton, yaitu sebanyak 44 orang atau sebesar 47,3 %, tidak ada seorang responden yang menghasilkan gaya diatas 40 Newton. Untuk gaya antara diatas 20-30 N terdapat 30 responden atau 32,3 % dari keseluruhan rsponden yang berjumlah 93 orang, lalu katagori antara gaya diatas 30 – 40 N berjumlah 13 orang atau 14 % dan yang terkecil terdapat pada katagori gaya antara 0 - 10 N, yang berjumlah 6 orang atau 6,5 % dari keseluruhan responden yang berjumlah 93 orang.

6.2. Hubungan Antara Umur Dengan Gaya Tekan Yang Dihasilkan

Tabel 6.2 Tabel umur dan gaya tekan.

Umur Responden * Gaya Tekan Crosstabulation

Count

		Gaya Tekan				Total
		0 - 10 N	> 10-20 N	> 20 - 30 N	> 30 - 40 N	
Umur Responden	0 - 60 bulan	3	29	0	0	32
	> 60 - 84 bulan	3	12	16	0	31
	> 84 - 108 bulan	0	3	14	13	30
Total		6	44	30	13	93

Berdasarkan tabulasi silang hasil penelitian diatas didapatkan hasil bahwa untuk katagori usia 0 – 60 bulan, hanya terdapat pada dua katagori gaya, yaitu diatas 10 – 20 N, sebanyak 29 orang atau 90,6 % dan katagori gaya antara 0 – 10 N, sebanyak 3 orang atau 9,4 % dari keseluruhan responden dengan katagori usia 0 – 60 bulan yang berjumlah 32 orang.

Pada katagori usia diatas 60 – 84 bulan frekuensi tertinggi terdapat pada katagori gaya diatas 20 – 30 N, yaitu sebanyak 16 orang atau sebesar 51,6 % dari keseluruhan responden yang berusia diatas 60 – 84 bulan yang berjumlah 31 orang. lalu katagori gaya diatas 10 – 20 N, sebanyak 12 orang atau 38,7 % dan yang terendah pada katagori gaya antara 0 – 10 N, sebanyak 3 orang atau 9,7 % dan tidak ada responden dengan katagori gaya diatas 30 N dari keseluruhan responden dengan usia 60 – 84 bulan.

Pada katagori usia diatas 84 – 108 bulan frekuensi tertinggi terdapat pada katagori gaya diatas 20 – 30 N, yaitu sebanyak 14 orang atau sebesar 46,7 % dari keseluruhan responden yang berusia diatas 84 - 108 bulan yang berjumlah 30 orang. Selanjutnya katagori gaya diatas 30 - 40 N, sebanyak 13 orang atau 43,3 %, lalu katagori gaya diatas 10 – 20 N, sebanyak 3 orang atau 10 % dan tidak ada responden dengan katagori gaya antara 0 – 10 N dari keseluruhan responden dengan usia 84 – 108 bulan.

1. Uji Statistik

Chi-Square Test of Dependence digunakan untuk menganalisa frekuensi dari dua variabel dengan banyak katagori untuk menentukan apakah kedua variabel tersebut berhubungan satu sama lain atau sebaliknya tidak berhubungan

Tabel 6.3 Tabel Hasil Chi-Square.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	68.014(a)	6	.000
Likelihood Ratio	83.028	6	.000
Linear-by-Linear Association	47.197	1	.000
N of Valid Cases	93		

a 6 cells (50.0%) have expected count less than 5. The minimum expected count is 1.94.

2. Uji Signifikansi

Didapatkan hasil dengan menggunakan metode Chi-square dengan tingkat kepercayaan 95 % / (α) = 0,05 didapatkan hasil nilai chi-square hitung sebesar **68.014** dengan degree of freedom (df) 6.

Berdasarkan tabel chi-square untuk df = 6 dan α = 0,05 terdapat nilai chi-square sebesar 12,592.

Karena nilai chi-square hitung lebih tinggi dibanding dengan nilai chi-square tabel, Maka secara statistik dinyatakan bahwa **terdapat hubungan yang signifikan antara umur dengan gaya tekan** yang dihasilkan.

3. Uji Korelasi

Tabel 6.4 Tabel Korelasi Pearson umur dan gaya tekan

Correlations

		Umur Responden	Gaya Tekan
Umur Responden	Pearson Correlation	1	.716(**)
	Sig. (2-tailed)	.	.000
	N	93	93
Gaya Tekan	Pearson Correlation	.716(**)	1
	Sig. (2-tailed)	.000	.
	N	93	93

** Correlation is significant at the 0.01 level (2-tailed).

Tabel 6.5 Korelasi Spearman Umur dan gaya tekan.

Correlations

			Umur Responden	Gaya Tekan
Spearman's rho	Umur Responden	Correlation Coefficient	1.000	.736(**)
		Sig. (2-tailed)	.	.000
		N	93	93
	Gaya Tekan	Correlation Coefficient	.736(**)	1.000
		Sig. (2-tailed)	.000	.
		N	93	93

** Correlation is significant at the 0.01 level (2-tailed).

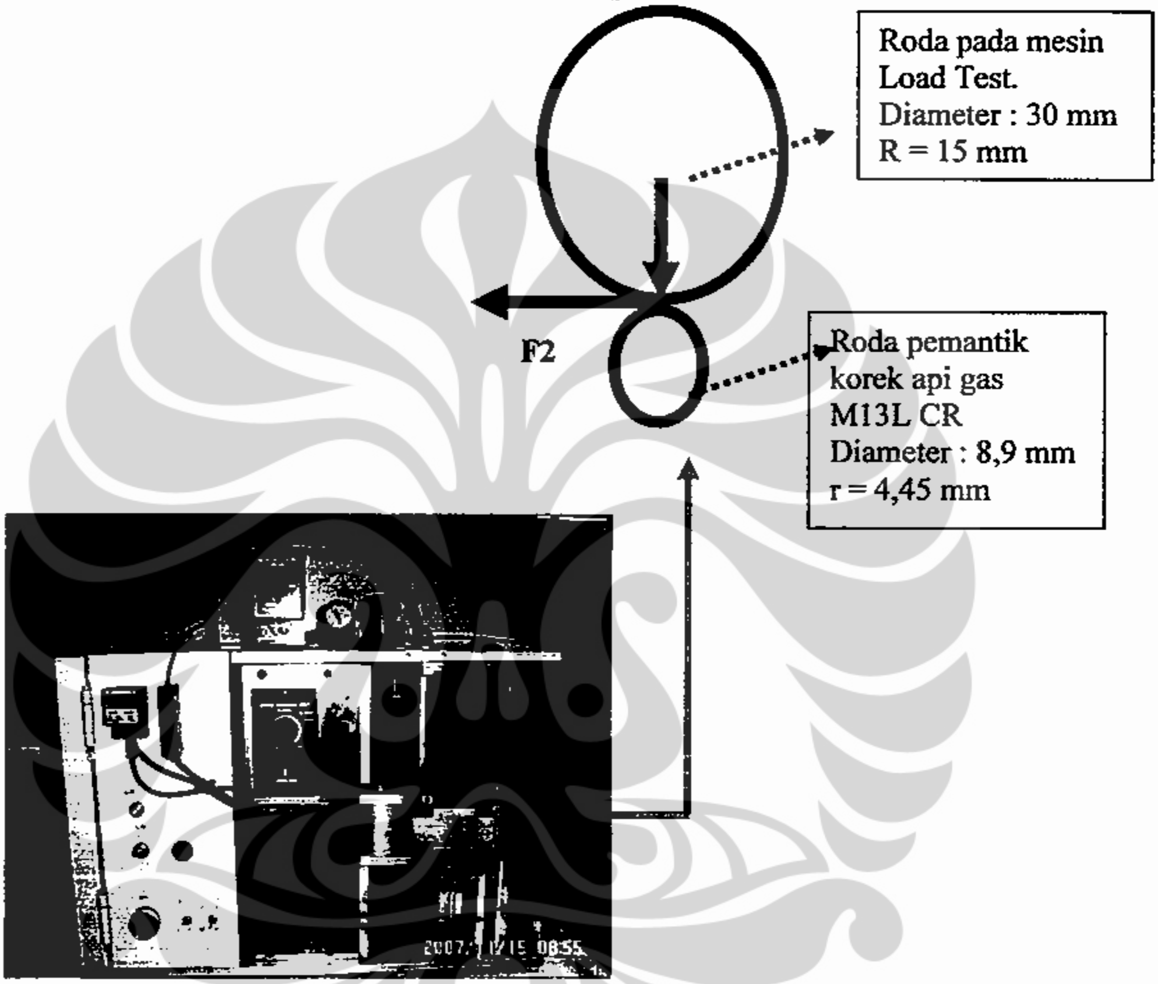
Uji korelasi berdasarkan hasil penelitian :

Pearson R : **0,716**

Spearman Correlation : **0,736**

Maka secara statistik dinyatakan bahwa antara umur dengan gaya tekan terdapat **korelasi dalam tingkat yang tinggi dengan sifat linear(+) / positif**. Yang berarti semakin tinggi usia maka akan semakin tinggi gaya yang sanggup dihasilkan, begitu juga sebaliknya, semakin rendah usia maka akan semakin rendah gaya yang sanggup dihasilkan.

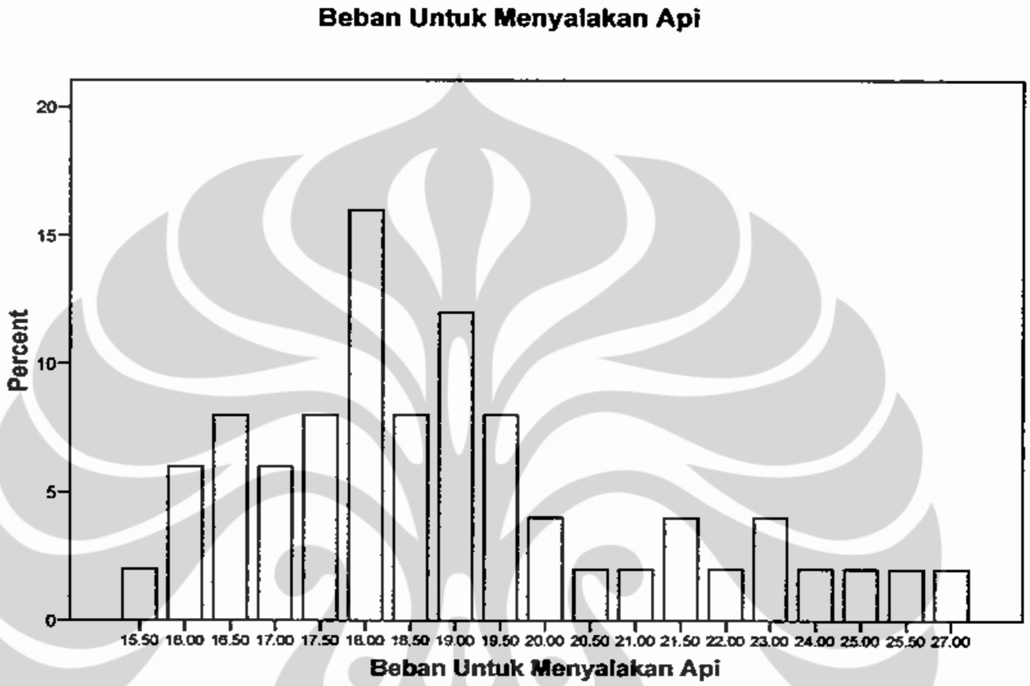
6.3. Hasil Penelitian beban yang dilakukan pada mesin *Load Test*



Pada mesin load test untuk melakukan test berapa gaya tekan F1 yang terukur dalam mesin load test untuk setiap benda uji. Parameter yang dapat dicatat adalah Gaya tekan F1 dan momen puntir T.

Distribusi frekuensi dan beban yang terukur untuk menyalakan api adalah sebagai berikut.

i. Distribusi Frekuensi



Gambar .6.2 Grafik beban gaya hasil uji mesin load test

Berdasarkan grafik diatas frekuensi terbesar terdapat pada beban 18 N, yaitu sebanyak 8 kali atau 16 % dari keseluruhan uji beban sebanyak 50 kali, selanjutnya beban 19 N, sebanyak 6 kali atau 12 %, lalu beban 16.5 N, 17.5 N, 18.5 N dan 19.5N, masing sebanyak 4 kali atau 8%, lalu beban 16 N dan 17 N, masing-masing 3 kali atau 6 %, lalu dan frekuensi beban yang terendah adalah 15.5 N, 20.5 N, 21 N, 22 N, 24 N, 25 N, 25.5 N dan 27 N, masing-masing 1 kali atau 2 % dari keseluruhan uji sebanyak 50 kali. Lebih jelasnya dapat terlihat pada tabel berikuti ini berikut torsi (torque) yang tercatat pada masin load test.

Tabel 6.6 Tabel beban dan frequency hasil uji mesin load test

Beban Untuk Menyalakan Api

Beban	Torque	Frequency	Percent
15.50	0,080	1	2.0
16.00	0,085	3	6.0
16.50	0,090	4	8.0
17.00	0,092	3	6.0
17.50	0,093	4	8.0
18.00	0,095	8	16.0
18.50	0,098	4	8.0
19.00	0,099	6	12.0
19.50	0,103	4	8.0
20.00	0,104	2	4.0
20.50	0,106	1	2.0
21.00	0,108	1	2.0
21.50	0,111	2	4.0
22.00	0,114	1	2.0
23.00	0,118	2	4.0
24.00	0,124	1	2.0
25.00	0,128	1	2.0
25.50	0,130	1	2.0
27.00	0,138	1	2.0
Total	———	50	100.0

ii. Nilai Mean, Median, Modus, Minimum dan Maksimum

Tabel.6.7 Tabel beban mean, median, min,max load

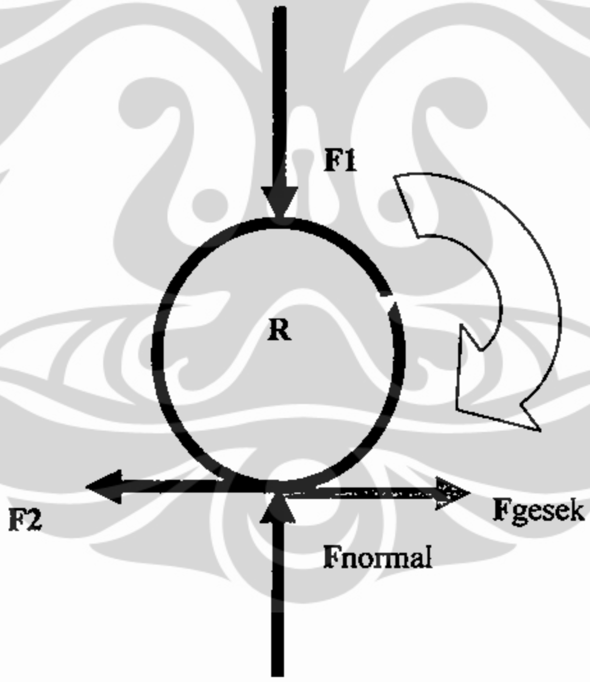
Statistics

Beban Untuk Menyalakan Api

N	Valid	50
	Missing	0
Mean		19.0900
Median		18.5000
Mode		18.00
Variance		6.609
Skewness		1.261
Std. Error of Skewness		.337
Minimum		15.50
Maximum		27.00
Sum		954.50

Dari tabel diatas dapat terlihat bahwa dari hasil uji coba terhadap korek api gas *child resistant* bahwa rata-rata beban yang diperlukan untuk memantik api sebesar 19,09 Newton. Untuk nilai tengah (median) dari 50 kali percobaan adalah : 18,5 Newton sedangkan beban yang paling sering dibutuhkan sebesar 18 Newton, yaitu sebanyak 8 kali dari 50 kali uji coba.

Sedangkan beban tertinggi sebesar 27 Newton dan beban terendah sebesar 15,5 Newton. Beban terendah yang tercatat di mesin penguji (load Test Machine), adalah sebesar 15,5 N, sesungguhnya gaya aktual yang diperlukan untuk menekan dan memutar roda pemantik adalah sebesar :



Gambar 6.3. Distribusi gaya.

F1 = arah gaya "palmar" merupakan gaya arah ke bawah

Fnormal = gaya perlawanan dari F1 untuk terjadinya gesekan pada batu api.

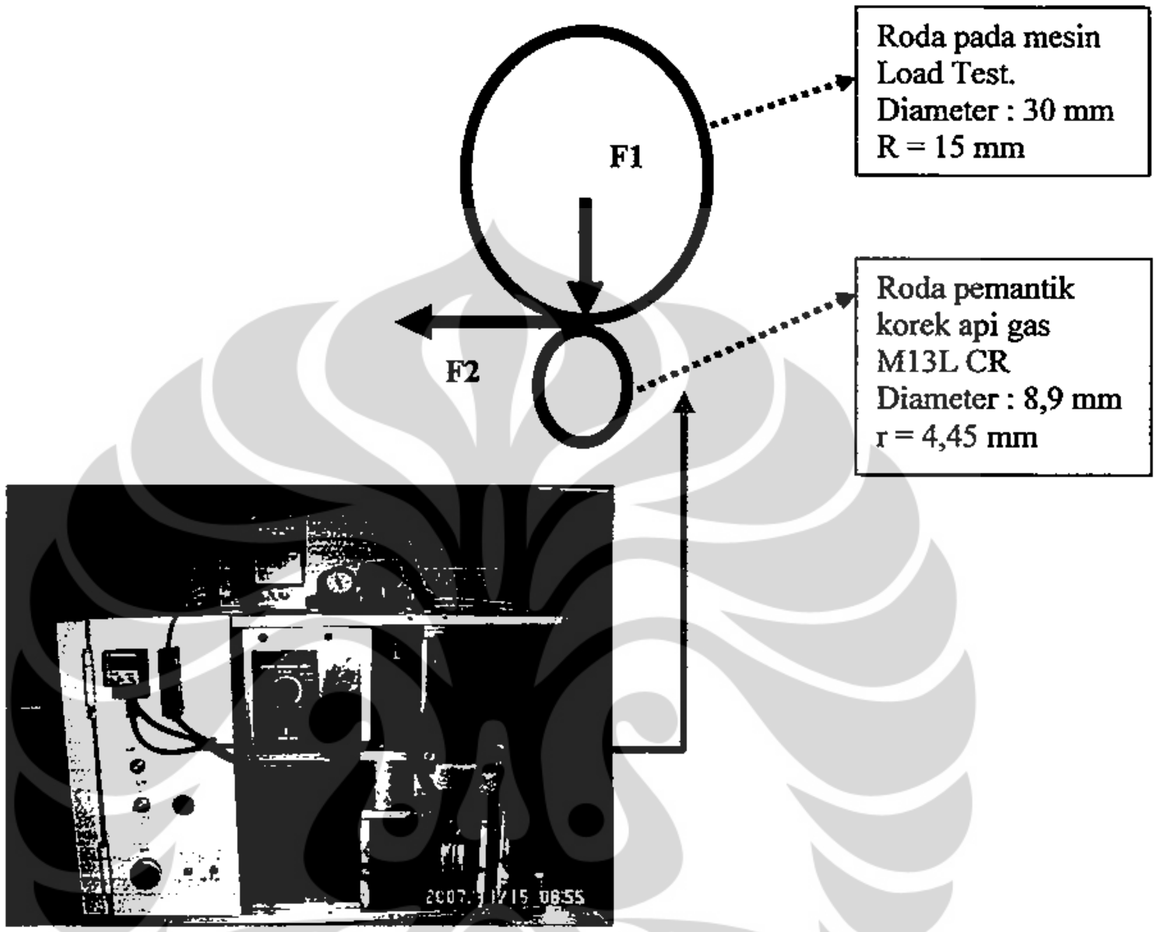
F2 = arah gaya "distal" merupakan gaya tangensial untuk memutar roda.

Fgesek = Fgesek akan timbul karena adanya gaya F1 yang telah bisa menghubungkan dengan poros dan memutar roda penggerak dan gaya F2 yang menyentuh permukaan batu api.

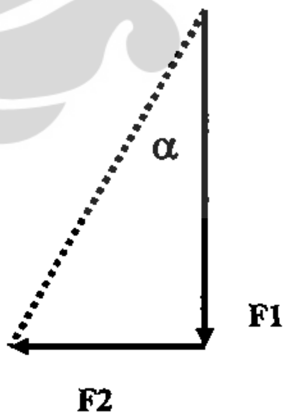
Arah gaya Fgesek adalah berlawanan dengan gaya F2.

Momen puntir dengan notasi T = adalah jarak jari2 (R) dari titik pusat putaran dikalikan gaya tangensial yang terjadi F2.

Sehingga Momen Puntir T = R x F2.



Perhitungan pada mesin load test



Torque $= F2_{load} \times R_{load}$

0,08 (Nm) = F2 (Newton) x 0,015 (meter)

$F2_{load}$ = 0,08 / 0,015

= 5,333 Newton

$F1_{load}$ = 15,5 Newton (Beban terendah)

$F1_{load}$ = 15,5 Newton adalah beban terendah yang terukur yang dapat menyalakan api, Beban ini dipakai sebagai acuan kekuatan terendah yang akan digunakan sebagai perhitungan untuk beban yang terjadi pada korek api test.

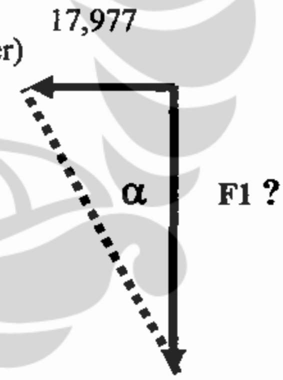
Sudut α

$$\text{Tg } \alpha = F2 / F1$$
$$= 5{,}333 / 15{,}5$$
$$= 0{,}344086$$

Perhitungan pada roda pemantik.

Momen puntir yang memutarkan roda pemutar pada mesin, diteruskan untuk memutarkan roda penggerak pada korek uji, dengan demikian momen puntir pada roda mesin sama dengan momen puntir pada roda pemutar, sehingga perhitungannya menjadi:

Dengan momen puntir (Torque) yang sama :



$$0{,}08 \text{ (Nm)} = F2_{korek} \text{ (Newton)} \times R_{korek} \text{ (meter)}$$
$$= F2_{korek} \times 0{,}00445$$
$$F2_{korek} = 0{,}08 / 0{,}00445$$
$$= 17{,}977 \text{ (Newton)}$$
$$\text{Tg } \alpha = F2_{korek} / F1_{korek}$$
$$0{,}344086 = 17{,}977 / F1_{korek}$$
$$F1_{korek} = 17{,}977 / 0{,}344086$$
$$= \mathbf{52{,}245 \text{ Newton.}}$$

Maka beban gaya $F1_{korek}$ aktual untuk menekan roda penggerak yang terendah yang diterima oleh korek api gas adalah : 52,245 Newton

Bahwa hasil dari penelitian menunjukkan bahwa seluruh responden (anak < 60 bulan) menghasilkan gaya tekan ibu jari yang lebih rendah dari beban pada roda pemantik pada korek api *child resistant* hasil dari uji korek api pada load test mesin.

Dan produk hasil penelitian ini dinyatakan **aman** bagi anak hingga usia <60 bulan atau kurang 5 tahun (konsep *child resistant*).

Dapat disimpulkan tingkat resiko yang dicapai adalah sangat rendah, mekanisme pengaman child resistant berfungsi dengan baik.

BAB 7

KESIMPULAN DAN SARAN

7.1. Kesimpulan.

Dari hasil penelitian ini dapat disimpulkan sebagai berikut :

a. Dari 93 responden uji beban ibu jari untuk beban terendah 0- 10 Newton dapat dicapai katagori usia hingga 84 bulan.

b. Sedangkan beban tertinggi hingga 40 Newton dicapai katagori usia hingga 108 bulan.

c. Terdapat hubungan yang signifikan antara umur dengan gaya tekan yang dihasilkan, semakin tinggi usia maka akan semakin tinggi gaya yang sanggup dihasilkan, semakin rendah usia semakin rendah gaya yang dihasilkan.

d. Dari 50 sample pengujian di load test beban terendah 15,5 Newton dan beban tertinggi adalah 27 Newton, beban rata-rata 19,09 Newton.

e. Untuk beban load test terendah 15,5 Newton, sesungguhnya gaya yang mampu diperlukan untuk menyalakan korek api adalah 52,245 Newton.

f. Kemampuan beban ibu jari anak hingga usia <60 bulan (5 tahun) adalah 20 Newton.

g. Bahwa hasil eksperimen menghasilkan bahwa seluruh responden (anak < 60 bulan) menghasilkan gaya tekan ibu jari lebih rendah dari beban pada roda pemantik korek api *child resistant* hasil dari uji korek api pada load test mesin.

h. Korek api *child resistat* mempunyai tingkat keselamatan hingga 2,61 kali dari kemampuan beban kekuatan ibu jari anak hingga usia batasan 5 tahun. Dan produk hasil penelitian ini dinyatakan **aman.**

i. Tingkat resiko yang dicapai adalah sangat rendah, mekanisme pengaman child resistant berfungsi dengan baik, hazard hanya akan timbul bila beberapa kondisi yang saling bertemu.

7.2. Saran.

a. Penggunaan korek api gas dengan sistem *child resistant* sudah seharusnya diterapkan di Indonesia.

b. Regulasi yang dikeluarkan Badan Standardisasi Nasional, SNI Keselamatan Korek Api Gas wajib diterapkan untuk melindungi konsumen atas produk sejenis yang diproduksi diluar standard.

c. Memberikan sosialisasi, penyebaran brosur tentang pemilihan korek api gas yang aman dipakai dan diproduksi sesuai SNI serta aman bagi anak.

d. Memberikan sosialisasi agar para pemakai korek api gas, tidak meletakkan korek api dalam jangkauan anak-anak dan membaca dengan seksama pesan keselamatan yang ada.

e. Memberikan bimbingan dan menyediakan mainan kepada anak sesuai yang sesuai dengan tingkatan usianya.

f. Masyarakat agar lebih memperhatikan kegiatan anak-anak yang berpotensi menimbulkan bahaya terhadap keselamatan.

g. Kepada pembaca dan atau pemerhati keselamatan untuk melakukan penelitian lebih lanjut dari korek api child resistant dari aspek yang lain.

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Jenis kel	umur	BB	TB	IMT	IMT	gaya t	umur	gol gaya	Umur	IMT	jenis kel
w	54	13.5	0.99	13.7741	kurus	1.8	balita	2	1	1	1
w	56	22	1.19	15.53563	kurus	1.88	balita	2	1	1	1
p	53	26	1.2	18.05556	kurus	1.86	balita	2	1	1	2
w	57	23	1.115	18.50027	kurus	1.64	balita	2	1	1	1
p	51	18.5	1.06	16.46493	kurus	1.4	balita	2	1	1	2
w	51	19.5	1.15	14.7448	kurus	1.6	balita	2	1	1	1
p	59	36	1.2	25	gemuk	1.88	balita	2	1	3	2
p	50	17	1.1	14.04959	kurus	0.92	balita	1	1	1	2
p	57	17	1.09	14.30856	kurus	1.68	balita	2	1	1	2
p	50	17.5	1.08	15.00343	kurus	1.62	balita	2	1	1	2
p	52	19	1.16	14.1201	kurus	1.26	balita	2	1	1	2
w	51	19	1.07	16.59534	kurus	1.3	balita	2	1	1	1
p	50	23.5	1.07	20.52581	normal	1.72	balita	2	1	2	2
p	52	16	1.1	13.22314	kurus	1.32	balita	2	1	1	2
p	52	19.5	1.16	14.49168	kurus	1.4	balita	2	1	1	2
w	53	18	1.14	13.85042	kurus	1.38	balita	2	1	1	1
p	54	24	1.15	18.14745	kurus	1.7	balita	2	1	1	2
p	52	18	1.14	13.85042	kurus	1.44	balita	2	1	1	2
w	50	15	1.04	13.86834	kurus	1.32	balita	2	1	1	1
w	52	17	1.08	14.57476	kurus	0.54	balita	1	1	1	1
w	38	14	1	14	kurus	1.14	balita	2	1	1	1
w	40	15	1.03	14.13894	kurus	1.54	balita	2	1	1	1
w	41	16	1	16	kurus	1.38	balita	2	1	1	1
w	42	16.5	1.06	14.68494	kurus	1.2	balita	2	1	1	1
p	39	12.5	0.97	13.28515	kurus	1.06	balita	2	1	1	2
w	40	14.5	0.95	16.06648	kurus	1.22	balita	2	1	1	1
p	42	14	0.95	15.51247	kurus	1.24	balita	2	1	1	2
w	39	12	0.93	13.87444	kurus	1.08	balita	2	1	1	1
w	38	15.5	0.95	17.17452	kurus	1.18	balita	2	1	1	1
w	38	12	0.9	14.81481	kurus	1.88	balita	2	1	1	1
p	59	16.5	1.07	14.41174	kurus	1.22	balita	2	1	1	2
w	58	32	1.08	27.43484	gemuk	0.72	balita	1	1	3	1
w	61	28	1.09	23.56704	normal	1.4	TK	2	2	2	1

Jenis kel	umur	BB	TB	IMT	IMT	gaya t	umur	gol gaya	Umur	IMT	jenis kel
p	77	18	1.16	13.37693	kurus	3	TK	4	2	1	2
p	75	33	1.35	18.107	kurus	2.46	TK	3	2	1	2
p	85	32	1.28	19.53125	kurus	2.22	TK	3	2	1	2
w	81	18	1.21	12.29424	kurus	2.08	TK	3	2	1	1
w	85	16	1.13	12.53035	kurus	2.42	TK	3	2	1	1
w	76	17	1.11	13.79758	kurus	2.44	TK	3	2	1	1
w	82	20	1.2	13.88889	kurus	2.38	TK	3	2	1	1
w	74	24	1.24	15.60874	kurus	1.8	TK	2	2	1	1
p	72	20	1.2	13.88889	kurus	3	TK	4	2	1	2
p	75	22	1.23	14.54161	kurus	2.66	TK	3	2	1	2
p	80	19	1.19	13.41713	kurus	2.24	TK	3	2	1	2
p	83	26	1.22	17.46842	kurus	2.22	TK	3	2	1	2
w	82	22	1.21	15.0263	kurus	1.92	TK	2	2	1	1
p	77	22	1.24	14.30801	kurus	2.7	TK	3	2	1	2
w	77	21	1.21	14.34328	kurus	2.38	TK	3	2	1	1
p	75	21	1.16	15.60642	kurus	2.42	TK	3	2	1	2
w	78	29	1.24	18.86056	kurus	2.72	TK	3	2	1	1
p	83	19	1.19	13.41713	kurus	1.76	TK	2	2	1	2
p	80	18	1.16	13.37693	kurus	2.3	TK	3	2	1	2
p	62	28	1.09	23.56704	normal	1.22	TK	2	2	2	2
w	62	14	0.98	14.57726	kurus	0.82	TK	1	2	1	1
p	65	21	1.07	18.34221	kurus	1.5	TK	2	2	1	2
p	67	17	1.06	15.12994	kurus	1.34	TK	2	2	1	2
w	62	22.5	1.14	17.31302	kurus	1.36	TK	2	2	1	1
p	61	18	1.04	16.64201	kurus	1.04	TK	2	2	1	2
p	61	16	1	16	kurus	1.26	TK	2	2	1	2
w	64	22.5	1.05	20.40816	normal	1.46	TK	2	2	2	1
w	61	17	1.07	14.84846	kurus	0.64	TK	1	2	1	1
w	63	27	1.14	20.77562	normal	1.5	TK	2	2	2	1
w	65	19	1.13	14.87979	kurus	0.92	TK	1	2	1	1

	nomor	jk	usia	bb	tb	imt	gaya
1	1	1	2	17.00	1.07	1.00	1.00
2	2	1	2	27.00	1.14	2.00	2.00
3	3	1	2	19.00	1.13	1.00	1.00
4	4	1	1	17.00	1.08	1.00	1.00
5	5	1	2	28.00	1.09	2.00	2.00
6	6	2	1	16.50	1.07	1.00	2.00
7	7	2	2	16.00	1.00	1.00	2.00
8	8	1	2	22.50	1.05	2.00	2.00
9	9	1	1	32.00	1.08	3.00	1.00
10	10	2	2	28.00	1.09	2.00	2.00
11	11	1	2	14.00	.98	1.00	1.00
12	12	2	2	21.00	1.07	1.00	2.00
13	13	2	2	17.00	1.06	1.00	2.00
14	14	1	2	22.50	1.14	1.00	2.00
15	15	2	2	18.00	1.04	1.00	2.00
16	16	1	1	13.50	.99	1.00	2.00
17	17	1	1	22.00	1.19	1.00	2.00
18	18	2	1	26.00	1.20	1.00	2.00
19	19	1	1	23.00	1.12	1.00	2.00
20	20	2	1	18.50	1.06	1.00	2.00
21	21	1	1	19.50	1.15	1.00	2.00
22	22	2	1	36.00	1.20	3.00	2.00
23	23	2	1	17.00	1.10	1.00	1.00
24	24	2	1	17.00	1.09	1.00	2.00
25	25	2	1	17.50	1.08	1.00	2.00
26	26	2	1	19.00	1.16	1.00	2.00
27	27	1	1	19.00	1.07	1.00	2.00
28	28	2	1	23.50	1.07	2.00	2.00
29	29	2	1	16.00	1.10	1.00	2.00
30	30	2	1	19.50	1.16	1.00	2.00
31	31	1	1	18.00	1.14	1.00	2.00
32	32	2	1	24.00	1.15	1.00	2.00
33	33	2	1	18.00	1.14	1.00	2.00
34	34	1	1	15.00	1.04	1.00	2.00
35	35	1	1	14.00	1.00	1.00	2.00
36	36	1	1	15.00	1.03	1.00	2.00
37	37	1	1	16.00	1.00	1.00	2.00
38	38	1	1	16.50	1.06	1.00	2.00
39	39	2	1	12.50	.97	1.00	2.00
40	40	1	1	14.50	.95	1.00	2.00

	nomor	jk	usia	bb	tb	imt	gaya
41	41	2	1	14.00	.95	1.00	2.00
42	42	1	1	12.00	.93	1.00	2.00
43	43	1	1	15.50	.95	1.00	2.00
44	44	1	1	12.00	.90	1.00	2.00
45	45	2	2	18.00	1.16	1.00	4.00
46	46	2	2	33.00	1.35	1.00	3.00
47	47	2	2	32.00	1.28	1.00	3.00
48	48	1	2	18.00	1.21	1.00	3.00
49	49	1	2	16.00	1.13	1.00	3.00
50	50	1	2	17.00	1.11	1.00	3.00
51	51	1	2	20.00	1.20	1.00	3.00
52	52	1	2	24.00	1.24	1.00	2.00
53	53	2	2	20.00	1.20	1.00	4.00
54	54	2	2	22.00	1.23	1.00	3.00
55	55	2	2	19.00	1.19	1.00	3.00
56	56	2	2	26.00	1.22	1.00	3.00
57	57	1	2	22.00	1.21	1.00	2.00
58	58	2	2	22.00	1.24	1.00	3.00
59	59	1	2	21.00	1.21	1.00	3.00
60	60	2	2	21.00	1.16	1.00	3.00
61	61	1	2	29.00	1.24	1.00	3.00
62	62	2	2	19.00	1.19	1.00	2.00
63	63	2	2	18.00	1.16	1.00	3.00
64	64	2	3	26.00	1.18	1.00	4.00
65	65	2	3	30.00	1.12	2.00	4.00
66	66	2	3	28.00	1.20	1.00	4.00
67	67	1	3	29.00	1.20	2.00	3.00
68	68	1	3	31.00	1.11	3.00	3.00
69	69	1	3	32.00	1.17	2.00	3.00
70	70	1	3	34.00	1.16	3.00	4.00
71	71	1	3	30.00	1.21	2.00	3.00
72	72	2	3	28.00	1.19	1.00	4.00
73	73	2	3	37.00	1.24	2.00	4.00
74	74	1	3	36.00	1.20	3.00	4.00
75	75	1	3	25.00	1.28	1.00	3.00
76	76	2	3	32.00	1.26	2.00	4.00
77	77	2	3	30.00	1.30	1.00	4.00
78	78	2	3	36.00	1.34	2.00	4.00
79	79	2	3	32.00	1.23	2.00	4.00
80	80	2	3	28.00	1.22	1.00	4.00

	nomor	jk	usia	bb	tb	imt	gaya
81	81	2	3	32.00	1.24	2.00	4.00
82	82	2	3	25.00	1.21	1.00	4.00
83	83	1	3	25.00	1.18	1.00	3.00
84	84	1	3	30.00	1.19	2.00	3.00
85	85	1	3	31.00	1.22	2.00	3.00
86	86	1	3	27.00	1.24	1.00	3.00
87	87	2	3	25.00	1.27	1.00	4.00
88	88	2	3	29.00	1.25	1.00	4.00
89	89	1	3	34.00	1.30	2.00	3.00
90	90	1	3	35.00	1.18	3.00	3.00
91	91	1	3	23.00	1.19	1.00	2.00
92	92	2	3	36.00	1.20	3.00	4.00
93	93	1	3	27.00	1.22	1.00	2.00

data responden3 -

	Name	Type	Width	Decimals	Label	Values
1	nomor	String	8	0	responden	None
2	jk	Numeric	8	0	Jenis Kelamin	{1, wanita}...
3	usia	Numeric	8	0	Umur Respond	{1, 0 - 60 bula
4	bb	Numeric	8	2	Berat Badan	None
5	tb	Numeric	8	2	Tinggi Badan	None
6	imt	Numeric	8	2	Indeks Massa	{1.00, Kurus}...
7	gaya	Numeric	8	2	Gaya Tekan	{1.00, 0 - 10 N

	Missing	Columns	Align	Measure
1	None	8	Left	Nominal
2	None	8	Right	Scale
3	None	8	Right	Scale
4	None	8	Right	Scale
5	None	8	Right	Scale
6	None	8	Right	Scale
7	None	8	Right	Scale

TOKAI DHARMA INDONESIA

3L CR IGNITION LOAD TEST DATA

APITULATION OF DAILY REPORT

Document no.	F.8240-QAP.53-A00
Effective	12-01-2002
Revised	-

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e	No.	14,0	14,5	15,0	15,5	16,0	16,5	17,0	17,5	18,0	18,5	19,0	19,5	20,0	20,5	21,0	21,5	22,0	23		Result
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗										18.5
	2	✓	✓	✓	✓	✓	✓	✓	✓	⊗											18
	3	✓	✓	✓	✓	✓	✓	✓	⊗												17.5
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	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗		23
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	5	✓	✓	✓	✓	✓	✓	✓	✓	⊗											18
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	3	✓	✓	✓	✓	✓	✓	✓	⊗												17.5
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗	24
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	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗					21
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗		23
	5	✓	✓	✓	✓	✓	✓	✓	✓	⊗											18
	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗									19
	2	✓	✓	✓	✓	✓	✓	⊗													17
	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗			22
	4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗								19.5
	5	✓	✓	✓	✓	✓	⊗														16.5
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	3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	⊗									19
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	Total																				

arks :

QA Manager	Inspector

CALTESYS
CALIBRATION & TESTING SYSTEM

PT Caltesys Indonesia adalah laboratorium kalibrasi yang berakreditasi ISO/IEC 17025
Seluruh peralatan kalibrasi yang digunakan tertelusur pada Standar Nasional dan Internasional

PT Caltesys Indonesia is an ISO/IEC 17025 accredited calibration laboratory. All calibration instruments used are traceable to the National and International Standards

sertifikat kalibrasi | calibration certificate

Nomor (Number) : C010976

Identitas Alat *(Instrument Identity)*	
Nomor Identifikasi *Identification Number*	: -
Nama *Name*	: Push Pull
Merek Pabrik *Manufacturer*	: Aikoh
Tipe / Nomor Seri *Type / Serial Number*	: AN-30 / 102596
Rentang Ukur / Resolusi *Range / Resolution*	: 3 Kg / 0.02 Kg
Identitas Pemilik *(Owner Identity)*	
Nama Perusahaan *Name / Company*	: PT. TOKAI DHARMA INDONESIA
Alamat *Address*	: Jl. Raya Jakarta Bogor Km. 36 Sukmajaya, Depok 16412
Identitas Standar *(Standard Identity)*	
Nama *Name*	: Weight SM065, SM066, SM012, SM013
Ketelusuran *Traceability*	: Hasil kalibrasi yang dilaporkan tertelusur ke-satuan pengukuran SI melalui LK-053-IDN
Tanggal Diterima *Date of Acceptance*	: 26 Juli 2007
Tanggal Kalibrasi *Date of Calibration*	: 27 Juli 2007
Tempat Kalibrasi *Place of Calibration*	: PT. Caltesys Indonesia
Kondisi Lingkungan *Environment Condition*	: Temperatur : 25 °C Kelembaban : 35% Rh
Metoda Kalibrasi *Calibration Method*	: MKSP PP-01
Ketidakpastian Kalibrasi *Calibration Uncertainty*	: Ketidakpastian Kalibrasi dengan faktor cakupan (k) = 2 dan pada tingkat kepercayaan (CL) = 95%
Hasil Kalibrasi *Calibration Result*	: Terlampir dalam Sertifikat Kalibrasi ini
Diterbitkan Tanggal *Issue Date*	: 30 Juli 2007

Disetujui oleh,
Approved By

CALTESYS TESTING SYSTEM

Samsudin
Manajemen Teknis

KAN

CALTESYS
CALIBRATION & TESTING SYSTEM

Ruang Lingkup Kalibrasi / *Scope of Calibration*

Dimensi / *Dimension* — Massa / *Mass* — Tekanan / *Pressure* — Gaya / *Force* — Torsi / *Torque* — Suhu / *Temperature* — Listrik / *Electricity* — Volumetri / *Volumetric* — Hydrometer / *Hydrometer* — Waktu & Frekuensi / *Time & Frequency* — Spektro-Fotometri / *Spectro-Photometric* — Alat Uji Kimia / *Chemical Analytical Equipment*

hasil kalibrasi | calibration result

Nomor (Number) : C010976

Penujukan Alat kg	Penunjukan Std kg
0.0	0.00
0.3	0.30
0.6	0.60
0.9	0.90
1.2	1.20
1.5	1.50
1.8	1.80
2.1	2.10
2.4	2.40
2.7	2.70
3.0	3.00
Ketidakpastian kalibrasi (±)	0.01

[redacted]

CALTESYS
CALIBRATION & TESTING SYSTEM

Sertifikat Kalibrasi
Calibration Certificate

Nomor (Number) : C009329

Identitas Alat *(Instrument Identity)*

Nomor Identifikasi *Identification Number*	:	-
Nama *Name*	:	Anak Timbangan
Merek Pabrik *Manufacturer*	:	Troemner
Tipe / Nomor Seri *Type / Serial Number*	:	AD 1602-2 KF1 / 21386
Rentang Ukur *Range*	:	2000 g

Identitas Pemilik *(Owner Identity)*

Nama Perusahaan *Name / Company*	:	PT. TOKAI DHARMA INDONESIA
Alamat *Address*	:	Jl. Raya Jakarta Bogor Km. 36 Sukmajaya, Depok 16412

Identitas Standar *(Standard Identity)*

Nama *Name*	:	Anak Timbangan SM082
Ketelusuran *Traceability*	:	Hasil kalibrasi yang dilaporkan tertelusur ke-satuan pengukuran SI melalui PTB

Tanggal Diterima *Date of Acceptance*	:	17 April 2007
Tanggal Kalibrasi *Date of Calibration*	:	18 April 2007
Tempat Kalibrasi *Place of Calibration*	:	PT. Caltesys Indonesia
Kondisi Lingkungan *Environment Condition*	:	Temperatur : 20.3°C Kelembaban : 48% Rh
Metoda Kalibrasi *Calibration Method*	:	MKSP MW-01
Ketidakpastian Kalibrasi *Calibration Uncertainty*	:	Terlampir dalam Sertifikat Kalibrasi ini
Hasil Kalibrasi *Calibration Result*	:	Terlampir dalam Sertifikat Kalibrasi ini
Diterbitkan Tanggal *Issue Date*	:	19 April 2007

Disetujui oleh,
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CALTESYS
CALIBRATION & TESTING SYSTEM

Samsudin
Manajemen Teknis

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KAN
Komite Akreditasi Nasional

[redacted]

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HASIL KALIBRASI

RESULT OF CALIBRATION

Nomor (Number) : C009329

Massa Nominal gram	Massa Konvensional gram	Ketidakpastian (±) gram
2000	2000.01	0.01

PT Caltesys Indonesia • Puri Niaga II • Jl. Puri Kencana Blok J1-2V • Jakarta 11610
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NEWS from CPSC

U.S. Consumer Product Safety Commission

Office of Information and Public Affairs Washington, DC 20207

FOR IMMEDIATE RELEASE
November 2, 2000
Release # 01-026

CPSC Consumer Hotline: (800) 638-2772
CPSC Media Contact: Ken Giles, (301) 504-7052

Child-Resistant Lighters Bring Down Fire Deaths CPSC report shows 43% decline in deaths from lighter fires

WASHINGTON, D.C. - A federal safety standard requiring cigarette lighters to be child-resistant has led to dramatic decreases in fires, deaths and injuries, according to a report issued today by the U.S. Consumer Product Safety Commission (CPSC).

The new report shows that fire deaths associated with children playing with lighters dropped 43 percent since the CPSC required cigarette lighters to be child-resistant starting in 1994. Deaths related to children playing with lighters fell from 230 in 1994 to 130 in 1998. Children under age 5 accounted for 170 of the deaths in 1994 and 40 of the deaths in 1998.

Overall, fires related to lighters dropped by 45 percent between 1994 and 1998. In 1994, there were 11,100 residential fires associated with children playing with lighters. By 1998, that number declined to 6,100 fires. By comparison, residential structure fires due to other causes decreased by 15 percent in that period.

Injuries related to lighter fires also declined. Injuries dropped 49 percent, from 1,600 in 1994 to 810 in 1998.

The study estimates that 4,800 fires, 130 deaths, 950 injuries and $76.4 million in property damage were prevented because of the cigarette lighter safety standard in 1998 alone.

The cigarette lighter safety standard requires disposable and novelty lighters to have a child-resistant mechanism that makes lighters difficult for children younger than age 5 to operate. At the time the standard was developed, it was estimated that children younger than age 5 ignited 73 percent of all residential structure fires started by children playing with cigarette lighters.

"Children try to copy their parents, so a cigarette lighter becomes a tempting plaything," said CPSC Chairman Ann Brown. "Cigarette lighters today are safer because they are less likely to cause a fire if they fall into the wrong hands."

Despite the good news, fires caused by children playing with lighters remain a concern. It is expected that the new CPSC standard requiring child-resistant mechanisms on household multi-purpose lighters, which will become effective in December 2000, will help reduce fires and fire deaths even further.

Send the link for this page to a friend! The U.S. Consumer Product Safety Commission is charged with protecting the public from unreasonable risks of serious injury or death from more than 15,000 types of consumer products under the agency's jurisdiction. Deaths, injuries and property damage from consumer product incidents cost the nation more than $700 billion annually. The CPSC is committed to protecting consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard or can injure children. The CPSC's work to ensure the safety of consumer products - such as toys, cribs, power tools, cigarette lighters, and household chemicals - contributed significantly to the 30 percent decline in the rate of deaths and injuries associated with consumer products over the past 30 years.

To report a dangerous product or a product-related injury, call CPSC's hotline at (800) 638-2772 or CPSC's teletypewriter at (800) 638-8270, or visit CPSC's web site at www.cpsc.gov/talk.html. To join a CPSC email subscription list, please go to www.cpsc.gov/cpsclist.asp. Consumers can obtain this release and recall information at CPSC's Web site at www.cpsc.gov.

NEWS from CPSC

U.S. Consumer Product Safety Commission

Office of Information and Public Affairs Washington, DC 20207

FOR IMMEDIATE RELEASE
April 6, 2005
Release #05-149

CPSC Consumer Hotline: (800) 638-2772
CPSC Media Contacts: Leonardo Alcivar or Scott Wolfson
(301) 504-7908 or (301) 504-7051

CPSC Approves First Step Toward Mandatory Standard for Cigarette Lighters

WASHINGTON, D.C.–The U.S. Consumer Product Safety Commission (CPSC) voted unanimously (2-0) on April 1, 2005, to move forward with the first of three steps in developing a new mandatory safety standard for cigarette lighters. The vote to approve an Advanced Notice of Proposed Rulemaking, which is open for public comment, sets the Commission on a path to consider a way to prevent most mechanical malfunctions of lighters and reduce the fire hazard associated with some lighters.

CPSC already has a mandatory standard for child-resistant cigarette lighters that addresses the hazard of children under 5 years of age starting fires with lighters. That standard for child-resistance applies to imported as well as domestically-manufactured disposable and novelty lighters.

"Fires are a leading cause of consumer product related deaths, and reducing residential fire deaths is one of our top priorities," said CPSC Chairman Stratton. "By developing fire safety standards for mattresses, upholstered furniture, and cigarette lighters, CPSC can help save many lives while maintaining reasonable cost to consumers and manufacturers."

The Commission could pursue one of three options during the rulemaking process: 1) a mandatory standard based either on the current voluntary "Standard Consumer Safety Specification for Lighters" (ASTM F-400) or on other performance requirements; 2) a mandatory labeling rule; or 3) a decision to defer to the voluntary standard.

There are nearly one billion cigarette lighters sold in the U.S. annually. Over 700 million lighters are imported each year, with about 400 million coming from China. From 1997 through 2002, CPSC estimated that more than 3,000 people went to hospital emergency rooms for injuries resulting from malfunctioning lighters. Most of these injuries involved thermal burns to the face, hands, and fingers. For the same time period, CPSC received 256 incident reports related to cigarette lighter malfunctions and failures; 65 percent of these cigarette lighter failures resulted in fires, leading to 3 deaths and 6 serious injuries.

The voluntary standard for lighters addresses the risk of fire, death, and injury associated with mechanical malfunctions of lighters. However, it is unclear how many lighters sold in the U.S. actually comply with the voluntary standard.

Fire deaths associated with children playing with lighters dropped dramatically since the mandatory standard for child-resistance became effective in July 1994 – from 230 in 1994 to 130 in 1998. Children under age 5 accounted for 170 of the deaths in 1994 and 40 of the deaths in 1998. In 1994, there were 11,100 residential fires associated with children playing with lighters. By 1998, that number declined to 6,100 fires.

Even lighters with child-resistant mechanisms are not child-proof, so all lighters should always be kept out of the reach of children.

—

Send the link for this page to a friend! The U.S. Consumer Product Safety Commission is charged with protecting the public from unreasonable risks of serious injury or death from more than 15,000 types of consumer products under the agency's jurisdiction. Deaths, injuries and property damage from consumer product incidents cost the nation more than $700 billion annually. The CPSC is committed to protecting consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard or can injure children. The CPSC's work to ensure the safety of consumer products - such as toys, cribs, power tools, cigarette lighters, and household chemicals - contributed significantly to the 30 percent decline in the rate of deaths and injuries associated with consumer products over the past 30 years.

To report a dangerous product or a product-related injury, call CPSC's hotline at (800) 638-2772 or CPSC's teletypewriter at (800) 638-8270, or visit CPSC's web site at www.cpsc.gov/talk.html. To join a CPSC email subscription list, please go to www.cpsc.gov/cpsclist.asp. Consumers can obtain this release and recall information at CPSC's Web site at www.cpsc.gov.

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Inj Prev 2002;8:192-196

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ORIGINAL ARTICLE

Study of the effectiveness of the US safety standard for child resistant cigarette lighters

L E Smith, M A Greene and H A Singh

Hazard Analysis Division, Directorate for Epidemiology, US Consumer Product Safety Commission, Bethesda, Maryland

Correspondence to:
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lsmith@cpsc.gov

ABSTRACT

Objective: The purpose of this research is to evaluate the effectiveness of the US Consumer Product Safety Commission's (CPSC) Safety Standard for Cigarette Lighters, which requires that disposable cigarette lighters be resistant to operation by children younger than age 5.

Methods: Fire data on children playing with lighters were solicited from selected US fire departments for incidents occurring from 1997–99, to identify the proportion of such fires caused by children younger than age 5 playing with cigarette lighters. These data were compared with similar data from 1985–87. An odds ratio was used to determine if there was a significant decrease in cigarette lighter fires caused by children younger than age 5 compared to children ages 5 and older. To estimate fires that would have occurred without the standard, the odds ratio, adjusted for population, was applied to 1998 national estimates of fires occurring. National estimates of 1998 fire losses were based on data from the National Fire Incident Reporting System and the National Fire Protection Association to which the 1997–99 age and lighter type distributions were applied. The difference between the fire losses that would have occurred and those that did occur represented fire losses prevented.

Results: In the post-standard study, 48% of the cigarette lighter fires were started by children younger than age 5, compared with 71% in the pre-standard study. The odds ratio of 0.42 was statistically significant ($p<0.01$). This represented a 58% reduction in fires caused by the younger age group compared to the older age group. When applied to national fire loss data, an estimated 3300 fires, 100 deaths, 660 injuries, and $52.5 million in property loss were prevented by the standard in 1998, totaling $566.8 million in 1998 societal savings.

Conclusions: The CPSC standard requiring child resistant cigarette lighters has reduced fire deaths, injuries, and property loss caused by children playing with cigarette lighters and can be expected to prevent additional fire losses in subsequent years.

Keywords: cigarette lighter; lighter; fire; child play; child resistant

Abbreviations: CPSC, Consumer Product Safety Commission; NFPA, National Fire Protection Association; NFIRS, National Fire Incident Reporting System

In 1985, the US Consumer Product Safety Commission (CPSC) was petitioned to begin rulemaking to require disposable cigarette lighters to be resistant to operation by children. Subsequently, the US CPSC estimated that children younger than age 5 playing with cigarette lighters ignited 5900 residential fires that resulted in 170 deaths and 1150 injuries annually for the period 1986–88.[1] Disposable lighters were involved in 97% of those fires and accounted for about 95% of the estimated 488 million disposable lighters sold annually during that period.[2]

In response to those findings, CPSC developed the Safety Standard for Cigarette Lighters (16 CFR Part 1210), which applies to products manufactured or imported after 12 July 1994. The standard requires disposable and novelty cigarette lighters to have a child resistant mechanism that makes the lighters difficult for children younger than age 5 to operate. A lighter with one type of child resistant ignition mechanism is shown in fig 1⌐. The definition of disposable lighters includes non-refillable lighters and inexpensive refillable lighters. Novelty lighters are defined as those that resemble or depict articles appealing to children younger than age 5, or that have entertaining audio or visual effects. Novelty lighters may be either disposable or refillable. The standard excludes "multipurpose" lighters such as those used to light barbecue grills and fireplaces, which were not evident as a child play hazard when work on the standard occurred. These lighters now are covered by a separate standard (16 CFR Part 1212) which took effect for products manufactured or imported after 22 December 2000.

Figure 1 Cigarette lighter with a child resistant ignition mechanism. Note: This is one of many types of child resistant mechanisms. The metal shield must be depressed before the sparkwheel can be turned to produce a spark. The force required to depress the shield is difficult for young children to achieve.

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The child resistance of a cigarette lighter is determined by tests conducted by lighter manufacturers using panels of children between the ages of 42 and 51 months. Lighters used for the tests have no fuel. When activated, they produce an audible or visual signal. Child resistant lighters must be designed so that at least 85% of children included in the test panel are not able to operate the lighters under timed test conditions.

The purpose of this paper is to evaluate the effect of the Safety Standard for Cigarette Lighters. Based on information indicating that disposable cigarette lighters have an average product life of two to three months, CPSC concluded that virtually all disposable cigarette lighters in US households would be child resistant by late 1997 and initiated a study to evaluate the effectiveness of the standard.[3]

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In brief, the evaluation of standard effectiveness involved three phases. The first phase involved a comparison of the age distributions of children playing with cigarette lighters before and after the standard, based on two CPSC studies. The result was an odds ratio comparing the reduction in fires among the younger age group (affected by the standard) to the reduction among the older age group (not affected by the standard). The second phase involved application of the post-standard CPSC study age and lighter type distributions to national estimates of fire losses derived from National Fire Protection Association (NFPA) and National Fire Incident Reporting System (NFIRS) data, to estimate fire losses that were still occurring after the standard. The third and final phase involved application of the odds ratio to the post-standard estimates to estimate hypothetical losses that would have occurred without the standard. The difference represented fire losses prevented. Datasets used in this paper are listed in table 1 and described below.

View this table: **Table 1** Data sources
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Phase 1: comparison of the age distributions

The before and after standard age distributions were identified in two CPSC data collection studies. The pre-standard data collection occurred from 1985–87.[4] CPSC field staff across the country contacted fire jurisdictions in their local areas requesting notification of all fires started by children playing with cigarette lighters as they occurred during the ongoing data collection period. A total of 113 fires involving children playing with lighters were reported to CPSC by the fire service. CPSC field staff then completed a follow up investigation identifying the age of the child who started the fire, the characteristics of the lighter involved, fire casualties, property loss, and a description of the incident scenario.

After implementation of the standard, CPSC conducted a second data collection during the period October 1997 to February 1999. As in the first study, CPSC's field offices requested notification from nearby fire jurisdictions on all fires started by children playing with lighters as they occurred. Participating fire departments submitted their fire incident and investigation reports documenting fire cause for all fires that involved a child playing with any type of lighter. When a child younger than age 5 started the fire, the fire department also completed a CPSC questionnaire providing additional detail on the age of the child and the lighter characteristics. Lighters used in fires started by children younger than age 5 were collected whenever possible. The study included reports from 108 local fire jurisdictions in 31 states and consisted of 375 fires that resulted in 23 deaths and 95 injuries. Lighter type was identified in all but seven of the 375 fires.

In both studies, fires attended by the fire service that were caused by children playing with lighters were identified via a set of standardized incident codes contained in the NFIRS. Fire departments were requested to report to CPSC every incident that met these specific criteria and submit their standard fire cause documents, a fire incident report and an investigation report, to CPSC. Although the fire service has no universally accepted definition of when a fire should be considered child play rather than arson, the decision is usually based on the perceived ability of the child to understand the consequences of his actions.

Since lighter fires may have decreased for reasons other than the standard, the analysis focused on the change in the proportion of cigarette lighter fires caused by children younger than age 5 (affected by the standard) compared to children age 5 and older (not affected by the standard). The procedure had the effect of controlling for a variety of other factors that were likely to have contributed to a reduction of fire losses over the years.

Odds ratio methods were used for the comparison. Children younger than age 5 were considered the treatment group *t*. Children ages 5 and older were considered the comparison group *c*. Time periods before and after the standard were designated *b* and *a* respectively, with *n* representing the number of incidents. The odds that an event occurred before the standard for the treatment group was:

with the analogous expression for the control group. The incident odds ratio, was then defined as ODDS comparison/ODDS treatment. An additional adjustment was made for changes in the US population at risk in the two time periods because a decrease in the relative proportion of children younger than age 5 in the population could be confounded with the effect of the standard. To adjust for the change in population, we calculated the population odds ratio for children younger than age 5 and ages 5–9 in the general population in both time periods and applied it to the crude odds ratio from the two studies. Confidence intervals and hypothesis tests used the standard error for the odds ratio found in Fleiss (1981, equation 5.19, page 63).[5]

Phase 2: national estimates

To translate the odds ratio into prevented fire losses, we first estimated post-standard fire losses. This was done by applying the fire starter age and lighter type distributions from the post-standard CPSC data collection to 1998 national estimates of residential fires caused by children playing with lighters, based on NFPA and NFIRS data.

The NFPA survey is based on a stratified random sample of fire departments in the US and provides annual estimates of all residential structure fires, deaths, injuries, and estimated property loss. It does not identify fire cause.[6]

Fires caused by children playing with lighters were identified in the NFIRS. NFIRS is a compilation of fire incident reports completed by US fire departments on fires they attend. Reports are submitted voluntarily to the US Fire Administration, which assembles the reports to construct the NFIRS database. In 1998, NFIRS contained 156 600 residential structure fires, about 40% of the residential structure fires estimated by NFPA. The NFIRS reporting code that identifies lighters includes both cigarette and multipurpose lighters. Age of the fire starter is not included. While NFIRS is not a probability sample, the US Fire Administration has stated that to the best they can determine, the distribution of participating fire departments is reasonably representative of the entire nation.[7]

To develop 1998 fire loss estimates for all ages of children playing with all types of lighters, the percentage of all NFIRS residential structure fires that involved children playing with lighters was calculated. Unknown values of the variables used in the analysis were allocated proportionally among the known values.[8,9] The process was repeated for deaths, injuries, and property loss. Then, the percentages were applied to NFPA estimates of US residential structure fires and fire losses (deaths, injuries, and property loss) to provide national estimates of US residential structure fires and losses that involved all ages of children playing with all types of lighters.[10]

Estimates of 1998 fire losses by age group and lighter type were developed by applying the 1997–99 study age and lighter type distributions to the 1998 national estimates of all lighter child play fires and fire losses.

Phase 3: fire losses prevented

Finally, fire losses prevented by the standard were computed. If the standard had no effect, then one could expect that the rate of change in fires involving the treatment group (children younger than age 5) from 1985–87 and 1997–99 would have been the same as the comparison group. This would put the hypothetical sample estimate for fires caused by children younger than age 5 as $n^*_{ta} = n_{ta}/OR$ where OR is the age adjusted odds ratio. Incidents saved would then $n^*_{ta} - n_{ta}$ or $n_{ta}(1-1/OR)$. To obtain national estimates, the national estimate of fires caused by children younger than age 5 was inserted in the formulas above.

Hypothetical deaths, injuries, and property loss were derived by first calculating the 1998 per fire rates of estimated death, injury, and property loss caused by children younger than age 5 playing with cigarette lighters. Then, the rates were multiplied by the estimate of hypothetical fires, to obtain estimates of the hypothetical number of fire deaths and injuries, and amount of property loss that would have occurred in those fires. The difference between the hypothetical fire losses and the 1998 fire losses that occurred represented the losses prevented by the standard.

The overall societal cost associated with the fire losses was calculated by summing the estimated monetary value of the deaths, injuries, and estimated property loss involved. CPSC's Directorate for Economic Analysis valued each death at $5 million and each injury at $50 000.[11,12]

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Estimate of standard effectiveness

Table 2 presents the age distribution of the children who started cigarette lighter child play fires in the two CPSC studies, one pre-standard and one post-standard. The table shows that 71% of the fires were started by children younger than age 5 in the 1985–87 study, while 48% of the incidents were started by children younger than age 5 in the 1997–99 study. The age adjusted odds ratio of 0.42 was statistically significant ($p<0.01$), with a 95% confidence interval of 0.23 to 0.62. This suggests that the standard was associated with a 58% reduction in cigarette lighter fires caused by children younger than age 5.

View this table: [in this window] **Table 2** Age distributions of the fire starters playing with cigarette lighters in two CPSC studies

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National estimates of post-standard fire losses

Application of post-standard age and lighter type distributions to 1998 national estimates of all fires caused by children playing with lighters indicated that children younger than age 5 caused an estimated 2400 cigarette lighter fires that resulted in 70 deaths, 480 injuries, and $38.2 million in property loss in 1998 (table 3). Among only cigarette lighter fires, children younger than age 5 ignited an estimated 48% of the fires that resulted in 80% of the deaths, 71% of the injuries, and 48% of the property loss. Less than 1% of the cigarette lighter fires caused by children younger than age 5 involved novelty lighters, the same proportion as in the pre-standard data.

View this table: [in this window] [in a new window] **Table 3** Estimated 1998 residential structure lighter child play fire losses attended by the fire service

National estimates of fire losses prevented

Table 4 presents 1998 estimated cigarette lighter fires and fire losses caused by children younger than age 5 that would have occurred if the standard had no effect. This estimate of 5700 cigarette lighter fires is 3300 more fires than the 1998 estimate of fires that occurred. The actual fire estimate of 2400 represents a 58% reduction from the "no effect" estimate. Maintaining the 1998 estimated per fire loss rates for cigarette lighter fires caused by children younger than age 5 shown in table 3, the 1998 fire losses prevented were estimated at 100 deaths, 660 injuries, and $52.5 million in property loss. Total societal cost prevented was estimated at $566.8 million for 1998.

View this table: [in this window] [in a new window] **Table 4** Estimated 1998 cigarette lighter child play fire losses prevented by the CPSC standard

Types of cigarette lighters involved in post-standard fires

Among 191 lighter fires ignited by children younger than age 5 in the post-standard data collection, 144 involved cigarette lighters, 46 involved multipurpose lighters, and one could not be identified (table 5). Among the 92 cigarette lighters that could be identified as either disposable or refillable, two (2%) were refillable, the same proportion as in the pre-standard data. Cigarette lighters are often destroyed in fires to the extent that the type cannot be identified.

View this table: [in this window] [in a new window] **Table 5** Lighters involved in fires ignited by children younger than age 5, 1997–99

Disposable cigarette lighters operated by children younger than age 5, when collected, were evaluated to determine if the child resistant feature had been defeated. Of the 69 disposable lighters collected, 59 were manufactured with a child resistant mechanism and 10 were not. The child resistant features had been defeated on 13 of the 59 lighters (22%) It was not possible to determine whether the 10 lighters manufactured without child resistant features were illegally manufactured or imported after the standard took effect or whether they were older, pre-standard, models.

Multipurpose lighters

The estimates of lighter fires shown in table 3 additionally identified the recent involvement of multipurpose lighters as a contributor to lighter child play fires and fire losses. Children younger than age 5 playing with multipurpose lighters caused an estimated 800 fires, 20 deaths, 50 injuries, and $15.6 million in residential property loss in 1998. There was no product safety standard addressing those incidents at the time.

DISCUSSION

It is estimated that the CPSC Safety Standard for Cigarette Lighters reduced cigarette lighter child play fires caused by children younger than age 5 by 58%. This conclusion is based on the assumption that, after adjusting for changes in the population, the standard is the only known factor that affects child play fires involving the younger age group but not the older age group. Many factors are believed to contribute to the general reduction of residential fires over the years but they are unlikely to affect younger children more than older children. These factors include public education, improvements in building construction, reductions in the size of the smoking population, and the increased presence of smoke alarms. It may be expected that the increased presence of smoke alarms would increase the proportion of fires that did not require the presence of the fire service. However, once a fire reaches the threshold level that results in fire service attendance, those captured for this analysis, it is not clear that the greater presence of smoke alarms changes the risk equation for the two age groups.

Taking into account the estimated fire losses that would have occurred if the standard had no effect, it is estimated that the CPSC safety standard was responsible for reductions of 3300 fires, 100 deaths, 660 injuries, and $52.5 million in property loss in 1998. These reductions represent total 1998 societal savings of $566.8 million. It is noted that these savings apply only to 1998 and that additional savings are expected in subsequent years.

To some extent these estimates may be conservative. First, children of ages 52–59 months were included in the group considered to be affected by the standard—that is, children younger than age 5. However, because they were not included in the tests used to qualify lighters it cannot be concluded that the standard should be expected to protect them to the same extent. Second, the estimates included here refer only to fires attended by the fire service. To the extent that additional losses, mostly injuries and property damage, occurred in unreported fires, estimates of losses prevented are underestimated. Third, despite the expectation that homes would be fully saturated with child resistant lighters by 1998, review of the lighters involved indicated that some lighters were not child resistant. If all the lighters in homes had been child resistant, the effectiveness of the standard would have been greater than estimated. It is reasonable to expect that the number of pre-standard, non-child resistant lighters will continue to decline over time.

The 1997–99 study also documented that multipurpose lighters were a cause of child play fires, a hazard that was not evident when the cigarette lighter standard was developed. To address this hazard, CPSC developed the "Safety Standard for Multi-Purpose Lighters" (16 CFR Part 1212) which became effective on 22 December 2000, and includes the same child resistant performance requirements as the cigarette lighter standard. Since the performance requirements are the same as for cigarette lighters, proportionally similar savings may be expected in the future.

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These results document the value of the US standard in reducing fire deaths caused by children playing with cigarette lighters. To our knowledge, only Canada has a similar standard in effect, although discussions are underway in several other countries and in the European Union. Based on the US experience, adoption of a child resistant lighter standard by other countries could be expected to reduce fire deaths to children in those countries.

Key points

- Fires, deaths, and injuries caused by young children playing with cigarette lighters have been reduced as a result of the standard requiring child resistant lighters.
- Casualties could be prevented in other countries by adoption of a child resistant lighter standard with similar requirements.
- The standard is not a substitute for parental supervision.
- Continuing media campaigns are needed to inform caregivers that some young children, and most older children, can still operate cigarette lighters.
- Lighter safety campaigns should specify both cigarette lighters and multipurpose lighters.

Many fire deaths involving lighters remain. Increased efforts to educate parents could help further reduce cigarette lighter deaths and injuries caused by child play. Messages should focus on two issues—first, the effectiveness of the standard, to encourage parents not to remove the child resistant feature, and second, the limitations of the standard. Parents may not be aware that some children as young as age 2 have been known to operate lighters, or that the child resistant features may not be equally effective for older children. Also, the CPSC standard is intended to make cigarette lighters child resistant, but not child proof. While the standard can increase the time needed for a child to operate the lighter, it may not prevent some children from operating the lighters with enough practice. Given the similarity of the hazard and performance requirements, educational materials addressing child play fires should specifically include multipurpose lighters since it may not be evident to parents that multipurpose lighters pose the same hazard.

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The opinions expressed by the authors do not necessarily represent the views of the US CPSC. Since this material was written in the authors' official capacities it is in the public domain and, in accordance with 17 USC 1005, may be freely copied or reprinted. The authors acknowledge the contribution of the reviewers who provided comments to improve the earlier draft.

This material as well as additional material on the subject are contained in the *report Fires Caused by Children Playing with Lighters: An Evaluation of the the CPSC Safety Standard for Cigarette Lighters*, September 2000. The report is available at www.cpsc.gov/library.

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(WO/2005/008133) CHILD RESISTANT ACTUATION MECHANISM FOR GAS LIGHTERS AND OTHER DEVICES

Note: OCR Text

Child resistant actuation mechanism for gas lighters and other devices This invention relates to child resistant actuation mechanisms for gas lighters and other devices.

It is often desirable to make it difficult for small children to actuate devices, by which is meant any article which includes at least one working component which is operable by a user. Examples include staplers and other small household objects, latches and the like, such as for child safety gates or cupboard doors, buckles for pushchairs, and numerous other mechanical devices.

Electromechanical devices include DIY tools such as drills, remote control switch units, such as for stairlifts or garage doors, and any other object having a mechanically operated switch with which a child may come into contact.

Gas lighters are a particularly good example and will be used to illustrate the present invention, although it is by no means limited thereto. These well known devices consist essentially of a small pressurized fuel gas container or reservoir, a valve which is operable (conveniently by means of a lever) to allow fuel to escape, and means, such as a piezoelectric device or a sparkwheel cooperating with a flint, for generating a spark to ignite the gas. Common types of gas lighters include small cigarette lighters for carrying in the pocket, and larger utility lighters which are equipped with an elongate nozzle and are typically used for igniting burners on gas cookers, lighting barbecues and camp fires and the like.

It is well known that children are liable to play with objects such as lighters, and serious accidents can occur as a result. Lighters must therefore be designed to minimize the chance of a child being able to light them. In other words, they should be child-resistant, though perfect child-proofing is of course impossible.

Ideally, an adult should be able to use the lighter easily and a child should find it impossibly difficult to use. But in practice this obviously cannot be achieved, and a lighter is regarded as child-resistant if it provides a balance between these two conflicting requirements which is as good as is reasonably feasible and which fulfils minimum child resistance criteria.

A minimum standard for child resistance in lighters has been specified in the USA by means of a functional test by the Consumer Product Safety Commission : 16 CFR Parts 1145 and 1210, Risks of Injury Associated with Lighters That Can Be Operated by Children ; Safety Standard for Cigarette Lighters ; Rules: Federal Register, Monday July 12 1993. The degree to which a lighter is child resistant may be objectively determined by applying the test described in these Rules and Regulations.

Piezoelectric gas lighters, which is to say, gas lighters which are equipped with piezoelectric spark generators, typically include an operating button in the form of a pushbutton or trigger which is depressed by the user to generate a spark and/or to open the valve. A cooperating safety button may be provided, so that both the operating button and the safety button must be operated together or in sequence in order to produce a flame. Gas lighters with flint ignition may similarly be provided with an operating button or a sliding cap which must be depressed or pivoted in order to draw a serrated friction element across the flint and so produce a sheaf of sparks. Alternatively, so called"roll-and-press"lighters are provided with a wheel assembly which the user's thumb rotates to produce sparks before falling onto a pushbutton forming part of the valve lever, so releasing fuel which is ignited by the sparks.

In early child resistant lighters, a catch mechanism was arranged to block the movement of the operating button or the valve lever unless the user first moved the catch to the enabled position. In later variants, such as US 6,102, 689 to Man for a roll-and-press lighter, the catch was arranged to return automatically to the disabled position after operation of the lighter.

However, where a safety catch can be left in the unblocking condition by an adult user, a child could subsequently operate the lighter. It is preferred therefore to provide a safety catch or safety button which remains in the blocking condition at all times unless operated by the user, so that the safety catch or safety button must be operated substantially at the same time as the operating button.

By providing an operating button and a safety button, two or more consecutive movements may be required substantially simultaneously to operate the lighter.

For example, our earlier published PCT patent application, WO 01/51855 discloses a utility lighter wherein the safety button is located away from the trigger on the top of the lighter body so as to be inoperable by a child using one hand. The safety button must be depressed forwardly and downwardly in order to unblock the trigger, and returns automatically to the blocking position when released, adding a further level of difficulty for children.

Although devices operating generally on this"blocking"principle may be effective in preventing children from operating a lighter, the application of excessive force to the child resistant blocking mechanism could damage it and leave the lighter vulnerable to unintended use. In order to overcome this problem, an alternative"enabling"approach has recently emerged, in which an operable mechanism of the lighter is arranged to be selectively disabled from operating the lighter without its movement being blocked. The adult user must then enable the mechanism in addition to operating it in order to operate the lighter.

US 6, 287, 109 to Hirota & Co. Ltd. discloses a piezoelectric cigarette lighter which exemplifies the latter"enablement"approach. In the disabled condition, a slider piece mounted in a button on the top of the lighter may be depressed by the user without either producing a spark or releasing fuel. In order to ignite the lighter, the user must first slide the slider piece forwards towards the burner. This aligns a downwardly extending abutment on the slider piece with a corresponding abutment on a latch element which in turn operates the spark generator and the fuel release lever. The slider piece and button may then be depressed to operate the fuel lever and the spark generator and so produce a flame.

US 6,336, 807 to Hsu discloses a utility lighter having a pair of sprung rods slidably mounted in a pivotable frame. The frame is pivoted by means of a separate safety lever on the side of the lighter casing to move the rods into alignment respectively with the fuel lever and the spark generator, so that when the trigger is depressed it presses against both of the rods to actuate the fuel lever and the spark generator and so produce a flame. In the disabled condition, the rods are misaligned so that the trigger may be depressed without producing a spark.

While both the"blocking"and"enablement"approaches may prevent ignition by children, it remains possible especially with simpler lighters of this type that children may eventually achieve ignition by playing with the operating and safety buttons for an extended period. Some lighters therefore adopt an alternative approach by adjusting the amount of force required to operate the lighter so as to be readily achievable by adults but not by children.

 <P>An example of this approach is JP 2002048341 A to Tokai Corp. , in which a roll- and-press lighter is provided with a strong spring underneath the lever. The user must press down hard enough to depress the lever against the enhanced spring force.

In a similar approach, the child may be distinguished from the adult user by the amount of pulp on the ball of the user's thumb. For example, US 6,095, 796 to Sung discloses a piezoelectric lighter wherein an operating button is inset into a safety button. The operating button must be depressed below the top of the safety button in order to ignite the lighter, which is achievable by an adult but not by a child due to the greater amount of pulp on the adult's digit.

While the latter two lighters will distinguish between the child and the adult user, the possibility remains that a child may be able to ignite them by unforeseen means. For example, the child may attempt to ignite the Tokai lighter by rolling it against furniture or along the floor. Similarly, the child may attempt to insert the tip of its finger or even a small object into the aperture in the safety button of the Sung lighter, so as to depress the operating button.

The need therefore remains for a reliable mechanism for preventing the operation by children of lighters as well as other devices such as electric tools, remote controls, locks, and numerous other mechanical and electromechanical devices which could cause damage or injury to the child or others if inadvertently actuated.

It is the object of the present invention to provide an actuation means for lighters and other devices which is readily operable by an adult user yet reliably prevents operation by children under five years of age.

According to the present invention there is provided a child resistant actuation means for a device, the device having at least one operable component ; characterised in that the actuation means comprises a volumetrically displaceable material together with an actuation surface accessible by a user of the device, wherein the operable component is operatively coupled to the actuation surface by the material such that the operable component is operable by the application by the user of an actuating force to the actuation surface.

Preferably the displaceable material is a gel and the actuation surface comprises a flexible membrane forming part of the outer surface of the device which is gripped by the user during operation. The component may be operable by the application of a predetermined minimum actuating force and/or by the displacement of a predetermined minimum volume of the gel. Preferably the user must apply the actuating force over at least a minimum surface area of the membrane, which conveniently is arranged to correspond to the surface area which may be engaged in normal use of the device by one hand of an adult user.

When a small child applies a force to a surface, the characteristics of its interaction with the surface may be distinguished from those of an adult in several key respects. The overall size of its hand and the length of its fingers, and hence the surface area that it can cover, will typically be much smaller than those of an average adult. The amount of pulp on its digits and palm will be less than that of an adult, as will the strength of its grip and the force that it can apply with its fingers. Many other specific characteristics are similarly distinctive.

There is of course considerable variation within both the adult and the child population; for example, many adults suffer from arthritis and other conditions which may reduce the amount of force that they are able to apply with their hands.

By operatively coupling the actuation surface to the component by means of a gel or similar material, the invention makes it possible to select the operating characteristics of the device so as to distinguish more reliably between the child and the adult user by means of all of these distinguishing characteristics, separately or in combination, while still ensuring that the device is readily operable by adults.

The operable component may be operatively coupled to the actuation surface indirectly, for example via an intermediate mechanism or enabling device interposed between the gel and the operable component. The user may then be required to operate a separate safety button or a trigger to enable the intermediate mechanism so that the actuation force is transmitted from the actuation surface to the operable component. Similarly, a disabling or blocking device may be interposed for disabling the operation of the operable component unless the disabling device is first placed in an enabling condition by operation of a separate safety button.

Alternatively, the operable component may itself comprise an enabling or disabling device for respectively decoupling or disabling the action of a separate trigger or safety button which in turn is operable by the user to actuate an operable mechanism of the device.

Means may also be employed to determine the parameters within which the user may interact with the actuation surface. For example, a lighter may include one or more operating buttons or safety buttons located away from the actuation surface, so that a child cannot grip the surface with both hands and at the same time operate the buttons. The actuation surface may be arranged within a protective frame, so that it cannot be operated by pressing against a hard surface, but only by pressure by a deformable surface such as the pulp of the user's palm and digits.

The actuation surface may also be arranged to conform to a three dimensional profile, so that it cannot be actuated by pressure against a flat object or even an internal corner of an object, but only by gripping the device substantially all the way around its body.

In this specification : "Operable mechanism"means any component or components of the device which can be operated, directly or indirectly, by the user. In gas lighters, operable mechanisms include fuel release valves, parts thereof and associated components, ignition means, parts thereof and associated components, blocking devices, enabling devices, disabling devices and operating elements.

"Operable component"means an operable mechanism which can be operated by the application by the user of an actuating force to the actuation surface.

"Disabling device"or"disabling mechanism"means an operable mechanism which is effective, directly or indirectly to prevent the operation of another operable mechanism.

"Blocking device"or"blocking mechanism"means a disabling device which is effective to mechanically impede the operation of another operable mechanism.

"Enabling device"or"enabling mechanism"means an operable mechanism which is effective, directly or indirectly to operatively couple or decouple one operable mechanism to or from another operable mechanism. The operable mechanisms may include in particular operating elements or operable components.

"Operating element"means an operable mechanism which is accessible for direct actuation by the user. In this specification the terms"trigger"and"button"are synonymous with"operating element".

Further advantages and features of the invention will become apparent from the following description and the accompanying drawings, in which various embodiments are described solely by way of illustration and without any limitation to the scope of the invention. Referring to the drawings: Fig. 1A is a side view of a first lighter with a gel capsule in a protective frame forming an actuation surface; Fig. 1B shows the first lighter in use; Fig. 1C shows the first lighter with the protective frame and gel capsule removed; , Fig. 1D is a plan view of the first lighter corresponding to Fig. 1C ; Fig. 2 shows the protective frame of the first lighter; Fig. 3A is a side view of the gel capsule of the first lighter; Fig. 3B is a cross section through line X-X of Fig. 3A; Fig. 3C is an end view of the gel capsule of Fig. 3A; Fig. 4A shows a first alternative operable component of the first lighter in the rest position; Fig. 4B shows the operable component of Fig. 4A in the operated position; Figs. 5A and 5B show a second alternative operable component in respectively the rest and operated positions; Figs. 6 and 7 show respectively third and fourth alternative operable components in the rest position; Fig. 8A is a side view of a second lighter with a flexible handgrip forming an actuation surface; Fig. 8B shows the second lighter with the flexible handgrip removed; Fig. 8C is an end view of the inner handle of the second lighter with the handgrip removed; Fig. 8D is a longitudinal section through the inner handle of the second lighter showing a first alternative embodiment; Fig. 8E is a view corresponding to Fig. 8D in a second alternative embodiment ; Fig. 9 is a longitudinal section through the flexible handgrip of the second lighter; Fig. 10 shows a partial internal view of a third lighter, with the trigger shown in longitudinal section; Fig. 11 shows a similar view of a fourth lighter; Fig. 12 shows a development of the third lighter ; Fig. 13 is a side view of the first lighter, partially cut away to show a development of the operable component of Figs. 4A and 4B ; Fig. 14 shows a disabling mechanism cooperating with the actuation means; Fig. 15 shows a fifth lighter with a gel capsule retained in a protective frame to form an actuation surface; Fig. 16 shows the fifth lighter with the lighter casing and gel capsule cut away to show a first alternative operable component; Fig. 17 shows the gel capsule of the fifth lighter ; Fig. 18 shows the fifth lighter with the lighter casing and gel capsule cut away to show a second alternative operable component; and

Fig. 19 shows the fifth lighter with the lighter casing cut away to show a third alternative operable component.

Corresponding reference numerals are used for corresponding parts throughout.

Referring to Figs. 1A-1D, a first utility lighter comprises a lighter body 1 supporting a nozzle 2 at one end and a handle section 3 at the other. A fuel reservoir is arranged within the body together with various operable mechanisms, including a piezoelectric ignition unit and a fuel release valve operated by a lever.

A trigger 7 is arranged on the lower surface of the lighter body and a safety button 8 on the upper surface. The handle comprises a generally cylindrical inner handle 4 with a collar 5 at one end and a series of small locating holes 6 at the other. An upper section of the inner handle is cut away to accommodate a lever 10.

Referring also to Figs. 2 and 3A-3C, the handle section is provided with an actuation surface formed by a gel capsule 30 and a protective frame 20. The capsule comprises a double walled tube of deformable elastomeric material with three textured grip pads 31 moulded on the outer surface of its outer wall 32, which thus forms a flexible membrane. The outer wall 32 and inner wall 33 are joined at both ends 34 to define a through bore 35 and an annular space between the two walls which is filled with a gel 36. Alternatively any other suitable volumetrically displaceable fluid might be used.

The protective frame 20 is formed from plastics material and comprises a generally tubular structure with an end wall 21, an opposite open end 22 and three cutouts 23. Internal ribs 24 are formed adjacent the end wall and have locking projections 25 on their inner faces. A circular wall 26 is formed around the inner surface of the frame. Preferably the side wall 27 of the frame is resiliently depressible.

The capsule is filled with gel before it is sealed and then slid over the inner handle 4 so that the inner handle passes through the bore 35 and is gripped snugly by the inner wall 33. The capsule is positioned so that the three grip pads 31 lie respectively on the bottom and sides of the handle as shown in Fig. 1A, and the protective frame is then slid over the capsule and inner handle until the grip pads are aligned with the cutouts. The open end 22 of the frame is secured to the collar 5 and the locking projections 25 engage in the locating holes 6 in the inner handle, locking the frame securely in place on the handle. In this position the frame is spaced apart from the handle and supported at its rear end by the internal ribs 24, and the capsule 30 is trapped axially between the lighter body next to the collar 5 at one end and the wall 26 at the other, so that it is held securely in position with the grip pads protruding slighly through the cutouts as shown.

When the user grasps the lighter, his thumb falls naturally onto the safety button 8 with his index finger on the trigger 7, and the palm and the remaining three fingers embrace the actuation surface which comprises the grip pads 31 together with the depressible side wall of the frame 20. It will be seen from Fig. 1B that in this position all or most of the surface area of the bottom and right side grip pads 31 is covered by the user's hand while about 60 percent of the surface area of the left side grip pad, which is visible in the drawing, is covered. When the user applies an actuating force by squeezing the handle, the grip pads 31 as well as the resilient frame are compressed. Since the gel is confined between the inner handle and the surrounding frame, it is displaced by the pressure and tends to bulge out in the areas of the pads which are not covered by the user's hand. It also presses inwardly against the inner wall 33 of the capsule so as to operatively couple the actuation surface to the lever 10 by transmitting the actuating force to depress the lever into the inner handle. The lever in turn may be arranged to transmit the actuating force to another operable component of the lighter as further explained below.

The degree of depression of the lever which results from the user gripping the handle can be carefully controlled by adjusting various parameters, including inter alia the stiffness of the frame, the size and shape of the cutouts, the quantity and viscosity of the gel, the overall shape and surface area of the actuation surface, the thickness and flexibility of the capsule walls, the shape and surface area of the lever 10 and the magnitude of any restoring force acting on the operable component. Separate biasing means may also be provided for biasing the lever or other operable component to the rest position so as to resist the actuating force, and these too will be adjustable to control the degree of depression of the lever.

By accurately controlling the degree of depression of the lever which results respectively from an adult or a child grasping and squeezing the lighter handle, the operating characteristics of the lighter can be selected so as to ensure that operation of the lighter is easily achievable by adults while being as difficult as possible for children.

For example, the lighter may be configured so that it is operable only when the user applies an actuating force to at least a minimum surface area of the membrane. A child's characteristically smaller hands will be unable to cover as much of the surface area of the grip pads and the resilient frame as those of an adult, so that when it squeezes the handle the gel will bulge out in the uncovered areas, relieving the pressure and avoiding depression of the lever.

The lever or other operable component may also be arranged so that in order to operate it the user must apply at least a minimum actuating force to the actuation surface. Where separate biasing means are provided for restoring the operable component to the rest position, the minimum actuating force may also be adjusted by adjusting the biasing means.

The lighter may also be arranged so that in order to operate the operable component the user must apply an actuating force to the actuation surface so as to displace at least a minimum volume of gel. Thus for instance when a child compresses the handle, its hand will apply insufficient force to displace the minimum volume necessary to depress the lever through the required distance, and the smaller size of its hand will be insufficient to confine the gel, allowing the applied actuating force to be dissipated by displacement of the gel by bulging of the free area of the membrane outwardly through the cutouts and between and around the child's fingers.

In practice all of these parameters may be controlled and adjusted together by means of empirical tests to produce an optimum combination of child resistancy and ease of use. The requirement for the simultaneous application of at least a minimum actuating force and at least a minimum volumetric displacement is particularly difficult for a small child to understand, so that even by observing the repeated operation of the lighter by an adult, a small child will find it difficult or impossible to understand the key requirements for successful operation. The lighter thus provides a significant intellectual barrier to operation by children as well as a physical impediment.

Desirably, the actuating surface is arranged as shown so that it covers the curved surface of the lighter handle around most or all of its circumference. This makes it virtually impossible for a child to apply an actuating force by pressing the handle against a floor or furniture.

The lighter illustrated includes a trigger 7 and a safety button 8. Neither of these components is essential, and in its simplest form the lighter may be operated merely by compression of the actuation surface, which is arranged to directly operate the fuel release lever and ignition mechanism. Desirably however, by constraining the user to operate one or both of these operating elements at the same time as compressing the handle, it is made much more difficult for a child to apply the required actuating force by for example squeezing the handle with both hands. More than two operating elements may be provided.

The buttons may be arranged so that they are operable by different fingers of the same adult hand, but too far apart for a child to operate with one hand. They may also be arranged so that more than one movement is required-for example, the safety button 8 may be arranged so that it has to be slid forwards towards the nozzle and then depressed in order to release or enable the trigger or the gel actuation means. This makes it even more difficult for a child to operate one or both of the buttons by unconventional means while applying an adequate actuating force to the actuation surface.

It will be understood from the foregoing that the actuation means may be arranged so as to directly operate either or both of the ignition means and the fuel release valve, or alternatively to operate any other operable mechanism of the lighter.

This might be for example a disabling or blocking mechanism for preventing the operation by the trigger or safety button of another operable mechanism.

Alternatively it could be an enabling mechanism for selectively operatively coupling and decoupling the trigger or safety button from another operable mechanism, so that the actuating force must be applied as the trigger or safety button is depressed in order to operate the operable mechanism.

The trigger and safety button can similarly be arranged to block or enable another operating element or to operate any other operable mechanism of the lighter.

Furthermore, the operation of the actuation means may similarly be prevented by a disabling or blocking mechanism which is operable by the trigger or the safety button. The actuation force may also be selectively transmitted to the operable component by enabling means operable by the trigger or safety button, so that the user must depress the trigger or safety button at the same time as applying the actuating force to the handle in order for the actuating force to operate the operable component.

It will be understood that numerous variations on these and other interactions are possible within the scope of the appended claims. Some examples of the possible interactions between the actuation surface and the various operable mechanisms of gas lighters will however now be described by way of further illustration.

Referring to Figs. 4A and 4B, the lever 10 of the first lighter is arranged above the fuel reservoir 41 and pivoted about an axle 40 on the lighter body. A fuel release valve 42 is arranged to selectively release fuel from the reservoir via a flexible pipe 43 which passes it along the nozzle 2 to a burner where it is ignited to form a flame.

The valve is opened by means of one end 44 of a lever 45 which is arranged to one side of the reservoir and is pivoted about an axle 46 on the lighter body. The valve locates in a slot in the lever end 44. The distal end of the lever 10 is arranged to press downwardly against the other end 47 of the lever 45 so that the lever 45 is pivoted to open the valve and release fuel as the lever 10 is pressed downwardly from the rest position (Fig. 4A) to the operated position (Fig. 4B) by the actuation force A. In this embodiment the fuel release valve 42 and associated mechanism 10,45 thus forms the operable component, and the lever 10 is biased to the rest position by an internal spring in the fuel valve.

Referring to Figs. 5A and 5B, in an alternative embodiment the lever 10 is arranged to move a blocking component 50 against the restoring force of a coil spring (not shown) from a blocking position (Fig. SA) in which it engages an abutment surface 51 of an operating element or other operable mechanism 52 of the lighter, to an unblocking position (Fig. 5B) in which it is disengaged from the abutment surface 51 and free to move in a slot 53. The operating element or operable mechanism 52 may then be moved slidingly in guides 54 in the lighter body in its operating direction B.

The element 52 may form part of the lighter trigger 7, in which case an extension 55 on its rear end may operate the piezoelectric ignition unit or the valve lever.

Alternatively it may form part of the piezoelectric ignition unit or valve lever assembly, in which case it may be displaceable in the operating direction B by depression of the trigger or safety button. Alternatively it could form an extension of the safety button, which in turn blocks operation of the trigger, so that an actuating force must be applied to the actuation surface in order to unblock the safety button, which may then be depressed by the user in the operating direction B to unblock the trigger, which in turn may then be depressed to actuate the valve lever and the ignition means.

Referring to Fig. 6, in a further alternative embodiment the fuel pipe 43 is arranged to run through corresponding holes in three plates 60,61, 62, plates 60 and 62 forming part of the lighter body. The plate 61 is arranged to depend from the distal end of the lever 10 so that the three plates together form a clamp which in the rest position shown forms a disabling device which prevents fuel from passing along the pipe. The lever 10 is biased to the rest position by a leaf spring 63 so that an actuating force must be applied to the actuation surface to release the clamp and allow fuel to pass from the valve to the burner.

Referring to Fig. 7, in a still further embodiment the first lighter is equipped with electronic ignition means instead of piezoelectric ignition means, operated by a battery by means of a switch controlled by the safety button 8. Fuel is released by depression of the trigger 7.

A circuit breaker 70 is arranged so that it normally open circuits the supply from the battery to the switch, and is operable by depression of the lever 10 to close the circuit and enable the switch to work. Thus depression of the trigger 7 will release fuel for combustion, but it will not be ignited unless the safety button 8 is depressed at the same time as the user applies an actuating force to the actuation surface sufficient to depress the lever 10 to close the contacts of the circuit breaker 70. In this embodiment the operable component is thus the circuit breaker 70 which forms a disabling mechanism which normally prevents operation of the ignition means.

Referring to Figs. 8A-8C, a second utility lighter similar to the first comprises a lighter body 1, a nozzle 2 and a cylindrical inner handle 4 with a collar 5 at one end. A trigger 7 and safety button 8 may similarly be provided for operating various operable mechanisms within the lighter. Unlike the first lighter however, the inner handle has a bore 80 which opens out at the rear end 81 of the inner handle.

Referring also to Fig. 9, a flexible elastomeric handgrip 90 is fixed over the inner handle 4 and sealed by welding or adhesive to the collar 5. The handgrip has a flexible tubular side wall 91 and an end wall 92, which is furnished on its inner face with small projections 93. Axial ribs 94 are provided on the inner surface of the handgrip adjacent its rear end wall 92. The ribs 94 and collar 5 hold the handgrip in spaced relationship from the inner handle, while the flexible side wall 91 forms an actuation surface which is depressed inwardly when the user grips it.

The space between the inner handle 4 and the handgrip 90 is filled with gel. When the user applies an actuating force to the handgrip, the gel is squeezed out of the handgrip and through the space between the rear end 81 of the handle and the rear end wall 92 of the handgrip, which are spaced apart by the projections 93, and into the bore 80.

Referring to Fig. 8D, the actuation surface may be operatively coupled to the piezoelectric spark generator 82 by arranging for its plexor to be depressible by a piston 83 slidingly arranged in the bore 80. Separate sealing means (not shown) may be provided for ensuring a pressure-tight seal between the piston 83 and the wall of the bore 80. When the user applies an actuating force to the actuation surface 91, the piston is forced along the bore and the piezoelectric device 82 is actuated.

Referring to Fig. 8E, in alternative embodiments the actuation surface may be operatively coupled instead to other operable mechanisms of the lighter, by arranging a pipe 84 to communicate with the bore 80 so as to transfer the actuating force via the gel within the pipe to the operable component elsewhere within the lighter body.

Referring to Fig. 10, a third lighter includes a lighter body 1 which supports an actuation surface similar to that of the second lighter, and a trigger 7. No safety button is provided. A pipe 84 containing gel is arranged to transmit the actuating force from the actuation surface to an expansible bellows 100. The bellows is arranged between an abutment 101 on the lighter body and a lever 102, which in turn is pivoted about an axle 103 mounted on the lighter body.

The trigger 7 is arranged to operate a piezoelectric spark generating device 104 by means of a flexible extension 105 which is mounted on the trigger at one end and has an abutment surface 106 at the other. In the operative position, the abutment surface 106 engages a corresponding abutment surface 107 on the plexor of the piezoelectric device, so that as the trigger is depressed in the operating direction C the piezoelectric device is compressed to produce a spark at the burner. The valve lever 108 is operated by an extension on the trigger, which cannot be seen in this view.

The distal end of the flexible extension 105 is moveable in a direction transverse to the operating direction C of the trigger, and is inherently resilient so that it is normally biased to the rest position as shown. In this position the abutment surfaces

106,107 are misaligned so that depression of the trigger in the direction C will cause the extension 105 to ride up the sloping top surface 109 of the piezoelectric plexor without compressing it, and hence will not produce a spark.

In order to enable operation of the trigger to ignite the released fuel, the user must apply an actuating force to the actuation surface sufficient to displace a minimum volume of gel, which is carried by the pipe 84 to the bellows 100, causing the bellows to expand. This in turn depresses the lever 102 in the downward direction D, which in turn presses with a sliding abutment surface 110 against the flexible extension 105, causing the abutment surfaces 106,107 to move into alignment.

The trigger may then be depressed in the direction C to transfer the trigger pressure to the piezoelectric device and so produce a spark. The operable component thus comprises an enabling device which enables actuation of the trigger.

Referring to Fig. 11, a fourth lighter similarly comprises an actuation surface, a trigger 7, a piezoelectric device 104, and a valve lever 108, together with a flexible extension 105 mounted on the trigger, and these parts work in the same way as in the third lighter. The trigger is enabled by depressing the extension 105 by means of a lever 111 similar to that of the third lighter, which pivots about an axle 112 in the lighter body 1. In this embodiment however the lever is actuated by depression of an integral safety button 8 which protrudes from the top of the lighter casing 1.

A blocking device is provided for preventing the depression of the safety button, and comprises a slider 113 which is slidingly received within the lever 111 and moves together with it in the downward or enabling direction D when the safety button 8 is depressed. The slider is biased to the rest position as shown by a coil spring 114, and in this position an abutment surface 115 on the bottom of the slider abuts against a corresponding abutment surface formed by the upper surface of a projection 116 from the lighter body.

In order to unblock the safety button so that it can be depressed to enable the trigger, the slider must be displaced in the unblocking direction E so that the surfaces 115, 116 are no longer in abutment. This is achieved by applying an actuating force to the actuation surface, which displaces a sufficient quantity of gel via the pipe 84 into an expansible bellows 117. The bellows expands against an abutment 118 to force a plunger 119 and pushrod 120 in the unblocking direction E against the restoring force of a coil spring 121. The pushrod bears slidingly on the end face 122 of the slider 113 so as to urge it to the unblocking position.

In this embodiment the actuation means is thus arranged to operate a blocking mechanism which in turn releases the safety button for depression, which in turn enables actuation of the ignition means by depression of the trigger. In the disabled or rest condition, the trigger may be depressed freely without producing a spark.

Referring to Fig. 12, in a development, the third lighter is formed as shown in Fig.

10 but with an additional blocking device which normally prevents depression of the lever 102 in the enabling direction D by the actuating force. The blocking device comprises a projection 130 formed integrally with the lever 102 and having an abutment surface 133. A sliding safety button 8 is provided on the top of the lighter casing 1, and has an integral downward projection 132 with a corresponding abutment surface 131 which in the rest position as shown engages the abutment surface 133 to obstruct depression of the lever 102.

When the user applies an actuating force to the actuation surface, the lever 102 will not move downwards and the trigger will not be enabled unless the user also slides the safety button forwards in the unblocking direction F against the restoring force of a spring (not shown). The safety button thus forms a blocking device which selectively operatively decouples the actuation surface from the operable component, which in this embodiment is the enabling means 100,102, 105 and associated components. The piezoelectric device and fuel lever may then be operated by depressing the trigger to ignite the lighter.

Referring to Fig. 13, the first lighter is shown with the protective frame and gel capsule removed and the casing partially cut away to show a development of the fuel release mechanism of Figs. 4A and 4B. In this embodiment the axle 46 of the fuel release lever 45 is mounted at the distal end 140 of an enabling lever 141 rather than on the lighter body. The enabling lever 141 is mounted in turn on an axle 142 on the lighter body so that its proximal end 143 is depressible by depression of the safety button 8 in the enabling direction G. The safety button 8 and the proximal end 143 of the enabling lever are biased upwardly to the rest position by spring means, which cannot be seen in this view.

In the rest position, the axle 46 of the fuel lever is moved downwards by the enabling lever so that when the user applies an actuating force A to the actuation surface so as to depress the lever 10, the end 47 of the fuel lever is not depressed by the distal end of the lever 10 and fuel is not released. In order to operate the lighter, the user must first depress the safety button 8 to the enabled position as shown, so that the axle 46 is raised to its operating position. In this position the actuating force may be applied to depress the lever 10, which will bear against the raised end 47 of the fuel release lever so as to open the valve. In this embodiment the safety button thus forms an enabling device which selectively couples and decouples the actuating force from the operable component, which in the example illustrated is the fuel release mechanism.

Referring to Fig. 14, a disabling device is illustrated whereby the actuation means may be selectively disabled from operating the operable component. The gel is communicated to the operable component via a pipe 84 which is arranged to pass through a clamp similar to that shown in Fig. 6. In this embodiment the central plate 150 of the clamp is moveable from the disabling position shown, in which the pipe 84 is sealed, to the enabling position, in which gel is allowed to pass along the pipe, by a safety button 8 which protrudes from the lighter body 1 and is depressible by the user against the restoring force of a leaf spring 151. When the user applies an actuating force to the actuation surface, the gel is prevented from coupling the actuating force via the pipe to the operable component unless the user first releases the clamp by depressing the safety button in the direction H. A one way valve is provided in parallel with the clamp for permitting gel to flow from the operable component towards the actuation surface. In this embodiment the safety button 8 thus forms a disabling means for operatively decoupling the actuation surface from the operable component until the safety button is depressed.

In an alternative embodiment, an enabling device may comprise a valve or clamp which is arranged to selectively connect the body of displaceable material with an internal reservoir or with another body of displaceable material. Operation of the valve will then selectively dissipate the actuating force applied by the user by displacement of the material into the other reservoir or body of material so that the operable component is not operated. Two bodies of material with separate actuation surfaces may for example be arranged to communicate in this way via a valve controlled by a safety button. A pressure relief valve may also be provided.

The lighter may thus be arranged to ensure that excessive pressure applied to the actuating surface is safely dissipated by displacement of the material.

Referring to Fig. 15,16 and 17, a fifth lighter comprises a lighter body 200 containing a fuel reservoir and supporting a valve operable to release fuel from the reservoir to a burner 201, and a metal shield 202 surrounding the burner. The lighter illustrated is of the roll-and-press type and includes an ignition system comprising a flint which is pressed resiliently against a serrated sparkwheel. The sparkwheel is mounted between two thumbwheels 203 to form a wheel assembly which is rotatable by the user to produce a sheaf of sparks. The sparkwheel cannot be seen in this view since it is covered by a protective strip 204. The valve is operable by a fuel release lever 190 whose proximal end 205 forms a pad which in use is pressed downwards in the direction I by the user so as to lift the distal end of the lever 190, which in turn lifts the valve assembly to release fuel to the burner.

The lower part of the lighter body comprises a rigid inner body 206 with smooth and generally continuous sides and base, which is covered by a protective frame 207. The protective frame is formed similarly to that shown in Fig. 2 with a generally tubular wall 208, which in this case has a cross sectional shape which is roughly rectangular but with rounded sides, a closed bottom end 209 and an open top end 210. A recess or collar, which cannot be seen in these views, is formed at the upper end of the inner body to receive the upper end 210 of the frame so that the remainder of the frame, including the closed bottom end 209, is spaced apart from the inner body. At each corner 211 of the frame a pair of internal ribs extend inwardly from the frame to support the frame rigidly against the inner body. Four cutouts 212 are formed, one respectively in each of the two narrow sides 213 and two broad sides 214 of the frame. Of course, only one cutout might alternatively be provided.

A gel capsule 215, shown in Fig. 17 disassembled from the lighter body, is formed generally as a cross with four arms 216 corresponding to the four sides of the body and joined by a central portion 217. The capsule comprises a double walled flexible membrane, having an inner wall which is to the back in the view shown in Fig. 17 and an outer wall 218. The inner and outer walls are joined by edge walls 219 to form an envelope defining a continuous space between the outer and inner walls so that each of the four arms 216 communicates with the other arms via the central portion 217. The capsule is filled with a gel.

During assembly, the capsule is arranged around the inner body 206 so that the inner wall of each arm 216 lies against one side of the inner body and the inner wall of the central portion 217 lies against the base of the inner body. The protective frame is then slid upwards over the assembled inner body and capsule with the inner ribs in between the arms until its open top end 210 snaps into a retaining groove in the collar. The capsule 215 is then retained snugly in position between the base, sides and collar of the inner body and the base and sides of the protective frame.

Four textured grip pads 220 are formed on the outer wall 218 of the capsule, one on each of the arms 216, so that in the assembled position they are accessible respectively through the cutouts 212. The grip pads form part of the flexible membrane and thus form together an actuation surface, which extends substantially all the way around the lighter body and which in use may be gripped by the user to apply an actuating force via the gel and the inner wall of the membrane to an operable component of the lighter.

Since the protective frame 207 is substantially rigid and is rigidly spaced apart from the inner body 206 by its internal ribs, the user must depress the actuation surface 220 by pressing the pulp of his fingers and palm into the cutouts 112. In alternative embodiments, the cutouts may be formed as relatively narrow apertures or slots which are too small to allow a child to insert its finger through the frame; this makes it still more difficult for a child to operate the lighter.

Although the cigarette lighter illustrated is a flint ignition lighter of the roll-and- press type, it will be appreciated that the arrangement of the fifth lighter will be equally applicable to piezoelectric and other types of cigarette lighter. The actuation surface may be operatively coupled to many different operable mechanisms of the lighter, whether the lighter is of the flint ignition, piezoelectric or other types, and many of the embodiments already described with reference to the first, second, third and fourth lighters may equally be applied, mutatis mutandis, to cigarette lighters as well as to utility lighters. Nevertheless, some examples of ways in which the actuating force may be operatively coupled to an operable component of a cigarette lighter are discussed below by way of further illustration.

Referring particularly to Fig. 16, the operable component may comprise a lever 230 which is hinged at its lower end 231 in the inner body 206 so that its upper end 232 is depressible inwardly into the inner body in the actuating direction J. In the example shown, an abutment surface 233 is formed on the upper end of the lever 230 so that in the rest position shown it abuts against a downwardly projecting wall 234 which is formed on the thumb pad 205. The lever is biased to the rest position by a leaf spring, which cannot be seen in this view, and thus forms a blocking mechanism which prevents fuel release by preventing depression of the fuel release lever. To operate the lighter, the user must apply a sufficient actuating force over a sufficiently large area of the actuation surface 220 so as to displace the gel enough to pivot the lever 230 inwardly in the direction J until its abutment surface 233 is clear of the wall 234. The thumb pad 205 may then be depressed in the downward direction I to operate the valve.

In alternative configurations, the lever 230 may be arranged to directly operate a valve lever or piezoelectric ignition mechanism, or another operable mechanism of the lighter.

Referring to Fig. 18, in an alternative embodiment the fifth lighter is provided with a pushrod 240 in place of the usual flint biasing spring. The pushrod is guided in a bore which runs axially through the centre of the lighter body from its upper end, which bears against the flint 244, to its lower end which terminates in a flat plate 241. The plate is biased downwardly by a coil spring 242 which abuts against the base 243 of the inner body 206. In use, the user applies an actuating force to the actuation surface 220 so that gel is displaced into the central portion 217 of the capsule. The plate 241 is then pressed upwardly by the inner wall of the central portion 217 of the gel capsule, which is trapped between the plate 241 and the inner surface of the closed bottom end 209 of the protective frame. This urges the pushrod 240 upwards against the flint 244, which in turn is pressed upwards against the sparkwheel so as to produce a sheaf of sparks when the user rotates the wheel assembly. In the rest position, the coil spring 242 relieves the pressure against the flint, which does not then produce sparks when the wheel assembly is rotated. In this embodiment, the operable component thus comprises an enabling device for enabling the normal operation of the ignition means.

Referring to Fig. 19, in a final alternative embodiment the lighter includes a flat plate 250 which slides up and down in guides formed in the upper end of the inner body 206. One edge wall 219 of the gel capsule 215 bears upwardly against a lower edge of the plate 250 so that when the user applies an actuating force to the actuation surface 220 the plate is urged upwardly in the actuating direction K.

The fuel release lever 190 is pivoted on an axle 191 which in normal lighters would be housed in the lighter body. In this embodiment however the lever axle 191 is housed in a hole 251 in the plate 250, so that the axle 191 moves up and down with the plate 250. In the downward position of the plate and axle, the fuel release lever is inoperable to open the valve.

In order to operate the lighter, the user must squeeze the actuation surface 220 so as to apply an actuating force to the plate 250, which then moves upwards in the direction K together with the lever axle 191. This places the lever axle 191 in the operable position, so that when the user presses down on the thumb pad 205 which forms the proximal end of the fuel release lever 190, the lever pivots about its axle 191 to raise its distal end and hence open the valve. A second plate corresponding to the plate 250 may be provided on the other side of the lighter for similarly housing the other end of the fuel lever axle.

In this embodiment the operable component thus comprises disabling means for preventing the normal operation of the fuel release mechanism. In alternative configurations, rather than housing the fuel release lever axle, the plate 250 could be arranged for example to release a braking device arranged to normally impede the rotation of the wheel assembly, or to raise a protective plate arranged between the sparkwheel and the burner for normally preventing the passage of sparks, or to directly actuate the valve.

In all of the above embodiments the volumetrically displaceable material is preferably a noncompressible fluid such as a gel or a liquid. Alternatively however it may be a gas, and the minimum volumetric displacement and actuation force which the user is required to apply to the actuation surface may then be determined in part by the resulting compression of the gas.

In alternative embodiments, the volumetrically displaceable material may be a plastically deformable material, such as a modified elastomer, perhaps moulded around the lighter body so as to form the handle so that the surface of the volumetrically displaceable material itself forms an actuation surface and no separate membrane or containing bladder is required. The actuation surface may itself comprise a resilient membrane which tends to return the operable component to the rest position by negative pressure of the displaceable material following release of the actuation surface by the user.

The minimum actuation force which the user is required to apply may also be dependent on the ratio of the area over which the actuation force is applied by the user to the volumetrically displaceable material, to the area over which the volumetrically displaceable material couples the actuation force to the operable component, forming a type of hydraulic system which divides or multiplies the effort of the user, and the biasing forces involved are selected accordingly.

In alternative embodiments the actuation surface need not necessarily comprise a flexible membrane. Thus for example the gel or fluid might be contained within a vessel provided with a plunger or piston which is displaced by the user by means of pressure against a flap or handle, or even by pulling on a tension element such as a lever, ring or the like.

In still further alternative embodiments, two or more distinct actuation surfaces may be provided, which may each communicate with the same body of volumetrically displaceable material, or alternatively with separate bodies of volumetrically displaceable material. Both surfaces must then be gripped by the user so as to apply the required actuation force to each body of material, either sequentially or simultaneously, in order to achieve ignition. The actuation surfaces may be spaced apart on the outer casing of the lighter so as to make it difficult for a child's small hand to reach both surfaces together.

For instance, one actuation surface may be arranged to actuate the lever and the other, the ignition mechanism of a gas lighter, so that both must be gripped simultaneously with sufficient force and over a sufficient surface area in order to achieve ignition.

Alternatively one actuation surface may be arranged to operate an operable component which enables or disables the operation of the other actuation surface, which in turn operates another operable mechanism of the lighter.

In summary, embodiments provide a child resistant actuation mechanism comprising a flexible actuation surface which is depressible by the user to couple an actuating force via a body of volumetrically displaceable material, such as a gel, to an operable internal component. The operable component may be an ignition or fuel release mechanism in a gas lighter, or an enabling or disabling device which interacts with another operable mechanism. The operation of the actuation means may also be enabled or disabled by another operable mechanism or by an operating element. The user may be required to apply a minimum force over a minimum surface area so as to achieve a minimum volumetric displacement of the gel in order to operate the operable component.

The invention may be applied to any user operable device as well as to gas lighters. For example, retractable craft knives and the like comprise a sharp blade which is retracted into a handle for safety and can be extended by means of a button or the like. It is therefore desirable to prevent small children from deploying the blade and injuring themselves. Thus a craft knife with a retractable blade may be provided with a safety interlock which prevents deployment of the blade until the interlock is actuated; a volumetrically displaceable material is arranged to form part of the outer casing of the knife, so that sufficient compression of the material actuates the interlock and releases the blade or the button which extends the blade.

Electrical remote control units, such as for example wireless controls for stairlifts and bathlifts, and power tools such as drills and the like may similarly cause accidents or injury if operated by small children. These and other devices may similarly be provided with a volumetrically displaceable material arranged to form part of the outer surface of the device which when displaced bears pressingly on a moving internal operable component, such as a spring biased electrical contact, which actuates or enables actuation of the device. Child safety gates and safety buckles may similarly be operated by arranging an external actuation surface with a body of gel which is operatively coupled to an internal latch mechanism. It is to be understood therefore that the embodiments illustrated are not exhaustive, and numerous adaptations and developments may be made thereto without departing from the scope of the claims.

Fire Safety

[Table of Contents]

Fire safety habits go with you everywhere. At home you would never leave matches or a lighter within the reach of children, but that's just where they may be at the home of a smoker or in a motel room. Look for and remove fire hazards when you enter a room. You can do grandparents a favor when you visit by making sure their smoke detectors are in working order. If your family is spending the night away from home, keep children under 5 near you so that in case of a fire, you can take them to safety. With older children, go over fire escape plans from sleeping rooms and agree on a place outside to meet. Never allow your child to sleep in a room without two exits. Never get too busy visiting with friends or relatives to check on children at least once every 30 minutes. Fire safety habits go with you everywhere. No exceptions! No excuses! No regrets!

Useful Info: Fire Safety and Your Child with Special Needs

If you have a child with special needs, talk to your doctor, therapist and/or local fire department about your home fire escape plan and how to get your child to safety quickly. To learn about products that can assist you in fire safety planning for your child with special needs, contact Riley Hospital's Community Education Department at 317-274-2964.

The Size of the Problem Nationwide

- U.S. fire departments respond to one home fire every 70 seconds.
- Each year, almost 50,000 children ages 14 and younger are injured in home fires. More than half of these children are 4 years or younger.
- Home fires caused by children are the leading cause of fire-related death and injury among children ages 9 and under.
- Home fires started by children are most likely to start in the bedroom or living room and areas where children are left alone to play.
- Nearly 80 percent of the home fires started by children are caused by children using matches or lighters to "play with fire."
- A working smoke alarm doubles the chance of surviving a fire.
- Fire-related deaths are three times more likely from smoke inhalation or toxic gases than from heat injury.
- In a typical home fire, you have only two minutes to escape from the house. The need for speed makes an escape plan necessary.

Source: National SAFE KIDS Campaign

Safety Habits: Protect Your Child from Home Fires
Install smoke alarms outside all sleeping areas and on all levels of your home.

Prevent home fires caused by children by removing fire hazards and setting house rules for fire safety.

Younger Children:

- Remove hazards: Store matches, lighters and flammable liquids out of reach, preferably in a locked area.
- Fire safety rule: If you find a lighter or match, do not touch. Tell an adult immediately.
- Fire safety rule: Never play with fire.

Older Children:

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Safety Standard for Cigarette Lighters

The Provisions and Requirements of the Safety Standard for Cigarette Lighters, Title 16, Code of Federal Regulations, Part 1210 (16 CFR 1210)

Scope of the Standard

Lighters subject to the standard include:

- Disposable Lighters and
- Novelty Lighters Manufacturered or imported into the United States of America after July 12, 1994

Definitions of Lighters

Disposable Lighrer [16C.F.R. s 1210.2(b)] means a ligher that is either is:

- (1) not refillable with fuel or
- (2) uses a gaseous fuel (butane, propane, etc,) under pressure, AND has a Customs Valuation or ex-factory price under $2.00 USD

Definitions, continued

Novelty Lighter [16C.F.R. s 1210.2(d)] means a lighter that

- Has entertaining audio or visual effects, or
- Depicts or resembles in physical form or functin articles commonly recognized as appealing to or intended for used by children under 5 years of age.

Novelty Lighter Examples

- Depict or resemble cartoon charachters like Popeye, Mickey Mouse, Joe Camel, Sesame Street characters, Bugs Bunny, Road Runner, Tom & Jerry, Caricatures of people or animals
- Toys (like mini home appliances, furniture, balls, yo-yo's)
- Guns (including pistols, rifles, cannons, machine guns, etc.)
- Clocks or watches
- Musical instruments (horns, violins, guitars, pianos, organs, drums, etc.)
- Vehicles (cars, boats, trains, planes, motorcycles, bicycles, space ships, sailing ships, etc.)
- Toy animals (horse, dogs, cats, dinosaurs, dragons, cows, pigs, etc.)
- Food or beverages (apples, organges, bananas, tomatoes, meat, ice cream cones, soda or bear cans, beer, wine or soda bottles, milk cartons)
- Articles of clothing, like shoes; parts of the body, like the hand or foot; skulls and skeletons
- Lighters shaped like cigarettes or cigars
- Lighters with lights or flashing lights

Novelty Lighters, continued

- A novelty lighter may operate on any fuel, including gas [butane, progane, etc.] or liquid fuel.

- Cost is not a factor in determining whether a lighter falls within the difinition of novelty lighter. Novelty lighters may be any price or Customs value.

Requirements for Cigarette Lighters -16 C.F.R. s 1210.3

- [a] Lighters subject to the standard shall be resistant to successful operation by at least 85% of the chiod-test panel when tested in the manner prescribed by s 1210.4
- [b] The mechanism of system of a lighter that makes the product child resistant must:
- [1] reset it self automatically after each operation of the ignition mechanism
- [2] not impair safe operation of the lighter when used in a mornal & convenient manner
- [3] be effective for the life of the lighter
- [4] not be easily overridden or deactivated.

Qualifications Testing

- Test portocol is at 16 C.R.R. s 1210.4
- Testing must be done with children residing in the United States of America.
- Each test must use at least one but on more than two 100 child test panels.
- The children in each test panel must reange in age from 42 to 51 months in age, and consist of 63-69 boys and 31-37 girls.
- Two children at a time are tested.
- No child may participate in more than one test panel or test more than one surrogate lighter.
- Five or more test sites are to be used, or children are to be drawn from a wariety of locations within a geographic area if one site is used.
- Place where children are tested must be familiar to the children or they must be given time to become accustomed to the site before the testing begins.
- Each tester must be at least 18 years old. Five or six adult testers are to be used for each 100 child panel and each should test approximately the same number of children.
- Sic (6) surrogate lighters are to be used with each panel of children.
- Each surrogate lighter should be tested with approximately the same number of children.
- Each surrogate lighter is to be tested, by an adult, before and after each child test to make sure it is working properly.
- Before testing, each surrogate lighter must be examined to verify that it approximates the production lighters in appearance, size, shape, and weight.
- Force measurements must be taken of each surrogate lighter before and after each 100 child panel to verify that they are within easonable operationg tolerances for a production lighter.
- Each child in the pair to be tested is first given a lighter and asked to produce the signal without being shown how to do it. The children are allowed 5 minutes to try to produce the signal.
- If one or both children successfully operate(s) the lighter in the first 5 minutes, the lighter is taken from teh child and not given back to that chilld.
- If neither child (or only one of the children) successfully operates the surrogate lighter in 5 minutes, the tester demonstrates how to opeate each lighter one time in view of both children.
- The lighter or lighters are then given back to the unsuccessful child (or children) and another 5 minutes is allowed to try to operate the lighter(s).
- After the test is over, both children are warned about the dangers of fire from real lighters and are made to promise that they will not play with lighters.
- Letter of the success or failure of their child to activate the surrogate lighter, and to thank them for allowing their cvhild to be tested nofifies the parents of each child.

Certification Requirement

- Each manufacturer or importer of disposable or novelty cigarette lighters must issue a Certificate of Compliance to accompany each shipping unit of lighters, or must otherwise furnish the Certificate to any distributor or retailer to whom the lighters are sold or delivered by the manufacturer or importers.
- The Certificate of Compliance shall state that the lighter "complies with the Consumer Product Safety Standard for Cigarette lighters (16CFR 1210)".
- The certificate shall also contain the name and address of the manufacturer or importer issuing the certificate, and
- The date or dates of manufacture of all the lighters covered by the certificate.
- Also, if the address of hte manufacturer or importer is different than the place of manufacture, the address of the manufacturing facility must also be on the certificate of compliance.
- The certificate must be based on either a reasonable testing program of each production lot of lighters, or on a test of each individual lighter unit.

Labeling Requirement

- The standard requires that each unit of disposable or novelty lighterj must be labeled with (1) an identification of the time period, not to exceed 31 days, during which the lighter was made, and (2) an identification of the manufacturer of the lighter.
- Either, or both, of the above may be placed on the lighter in code.

Reporting Requirement

- At least 30 days before any disposable or novelty lighter is first imported into the United States, every manufacturer and importer must provide a written report to the Office of Compliance in Bethesda, Maryland showing that the product to be imported complies with the safety standard. [16 C.F.R. s 1210.17(b)]
- The report shall include: (1) The name, address, and principal place of business of the manufacturer or importer.
- (2) A detailed description of hte lighter model and the child-resistant feature(s) used in that model.
- (3) A description of the qualification testing, including a description of hte surrogate lighters tested, the specifications of the surrogate lighters, and identify of the testing organization.
- (4) An identification of the place or places where the lighters are made (i.e., the actual street address of the manufacturing plant.)
- (5) The location(s) where the qualifications test records, the production rcords, and the quality control test records are kept.
- (6) A prototype or production unti of the lighter model. 3 lighter units should be sent in with the report.

For More Information

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Code of Federal Regulations
Title 16 Commercial Practices

PART 1210—SAFETY STANDARD FOR CIGARETTE LIGHTERS

58 FR 37584, July 12, 1993, unless otherwise noted.

Source:

Subpart A—Requirements for Child Resistance

Authority:

15 U.S.C. 2056, 2058, 2079(d).

§1210.1 Scope, application, and effective date.

This part 1210, a consumer product safety standard, prescribes requirements for disposable and novelty lighters. These requirements are intended to make the lighters subject to the standard's provisions resistant to successful operation by children younger than 5 years of age. This standard applies to all disposable and novelty lighters, as defined in §1210.2, that are manufactured or imported after July 12, 1994.

§1210.2 Definitions.

As used in this part 1210:

(a) *Cigarette lighter*. See *lighter*.

(b) *Disposable lighter*—means a lighter that either is:

(1) Not refillable with fuel or

(2)(i) Its fuel is butane, isobutane, propane, or other liquified hydrocarbon, or a mixture containing any of these, whose vapor pressure at 75 °F (24 °C) exceeds a gage pressure of 15 psi (103 kPa), and

(ii) It has a Customs Valuation or ex-factory price under $2.00, as adjusted every 5 years, to the nearest $0.25, in accordance with the percentage changes in the monthly Wholesale Price Index from June 1993.

(c) *Lighter*, also referred to as *cigarette lighter*, means a flame-producing product commonly used by consumers to ignite cigarettes, cigars, and pipes, although they may be used to ignite other materials. This term does not include matches or any other lighting device intended primarily for igniting materials other than smoking materials, such as fuel for fireplaces or for charcoal or gas-fired grills. When used in this part 1210, the term *lighter* includes only the disposable and novelty lighters to which this regulation applies.

(d) *Novelty lighter* means a lighter that has entertaining audio or visual effects, or that depicts (logos, decals, art work, etc.) or resembles in physical form or function articles commonly recognized as appealing to or intended for use by children under 5 years of age. This includes, but is not limited to, lighters that depict or resemble cartoon characters, toys, guns, watches, musical instruments, vehicles, toy animals, food or beverages, or that play musical notes or have flashing lights or other entertaining features. A novelty lighter may operate on any fuel, including butane or liquid fuel.

(e) *Successful operation* means one signal of any duration from a surrogate lighter within either of the two 5-minute test periods specified in §1210.4(f).

(f) *Surrogate lighter* means a device that: approximates the appearance, size, shape, and weight of, and is identical in all other factors that affect child resistance (including operation and the force(s) required for operation), within reasonable manufacturing tolerances, to, a lighter intended for use by consumers; has no fuel; does not produce a flame; and produces an audible or visual signal that will be clearly discernible when the surrogate lighter is activated in each manner that would normally produce a flame in a production lighter. (This definition does not require a lighter to be modified with electronics or the like to produce a signal. Manufacturers may use a lighter without fuel as a surrogate lighter if a distinct signal such as a "click" can be heard clearly when the mechanism is operated in each manner that would produce a flame in a production lighter and if a flame cannot be produced in a production lighter without the signal. *But see* §1210.4(f)(1).)

(g) *Model* means one or more cigarette lighters from the same manufacturer or importer that do not differ in design or other characteristics in any manner that may affect child-resistance. Lighter characteristics that may affect child-resistance include, but are not limited to, size, shape, case material, and ignition mechanism (including child-resistant features).

§1210.3 Requirements for cigarette lighters.

(a) A lighter subject to this part 1210 shall be resistant to successful operation by at least 85 percent of the child-test panel when tested in the manner prescribed by §1210.4.

(b) The mechanism or system of a lighter subject to this part 1210 that makes the product resist successful operation by children must:

(1) Reset itself automatically after each operation of the ignition mechanism of the lighter,

(2) Not impair safe operation of the lighter when used in a normal and convenient manner,

(3) Be effective for the reasonably expected life of the lighter, and

(4) Not be easily overriden or deactivated.

§1210.4 Test protocol.

(a) *Child test panel.* (1) The test to determine if a lighter is resistant to successful operation by children uses a panel of children to test a surrogate lighter representing the production lighter intended for use. Written informed consent shall be obtained from a parent or legal guardian of a child before the child participates in the test.

(2) The test shall be conducted using at least one, but no more than two, 100-child test panels in accordance with the provisions of §1210.4(f).

(3) The children for the test panel shall live within the United States.

(4) The age and sex distribution of each 100-child panel shall be:

(i) 30 +or- 2 children (20 +or- 1 males; 10 +or- 1 females) 42 through 44 months old;

(ii) 40 +or- 2 children (26 +or- 1 males; 14 +or- 1 females) 45 through 48 months old;

(iii) 30 +or- 2 children (20 +or- 1 males; 10 +or- 1 females) 49 through 51 months old.

Note:

To calculate a child's age in months:

1. Subtract the child's birth date from the test date.

	Month	Day	Year
Test Date	8	3	94
Birth Date	6	23	90
Difference	2	-20	4

2. Multiply the difference in years by 12 months.

4 years × 12 months = 48 months.

3. Add the difference in months.

48 months + 2 months = 50 months.

4. If the difference in days is greater than 15 (e.g. 16, 17), add 1 month.

If the difference in days is less than -15 (e.g., -16, -17) subtract 1 month.

50 months - 1 month = 49 months.

If the difference in days is between -15 and 15 (e.g., -15, -14, ... 14, 15), do *not* add or subtract 1 month.

(5) No child with a permanent or temporary illness, injury, or handicap that would interfere with the child's ability to operate the surrogate lighter shall be selected for participation.

(6) Two children at a time shall participate in testing of surrogate lighters. Extra children whose results will not be counted in the test may be used if necessary to provide the required partner for test subjects, if the extra children are within the required age range and a parent or guardian of each such child has signed a consent form.

(7) No child shall participate in more than one test panel or test more than one surrogate lighter. No child shall participate in both child-resistant package testing and surrogate lighter testing on the same day.

(b) *Test sites, environment, and adult testers.* (1) Surrogate lighters shall be tested within the United States at 5 or more test sites throughout the geographical area for each 100-child panel if the sites are the customary nursery schools or day care centers of the participating children. No more than 20 children shall be tested at each site. In the alternative, surrogate lighters may be tested within the United States at one or more central locations, provided the participating children are drawn from a variety of locations within the geographical area.

(2) Testing of surrogate lighters shall be conducted in a room that is familiar to the children on the test panel (for example, a room the children frequent at their customary nursery school or day care center). If the testing is conducted in a room that initially is unfamiliar to the children (for example, a room at a central location), the tester shall allow at least 5 minutes for the children to become accustomed to the new environment before starting the test. The area in which the testing is conducted shall be well-lighted and isolated from distractions. The children shall be allowed freedom of movement to work with their surrogate lighters, as long as the tester can watch both children at the same time. Two children at a time shall participate in testing of surrogate lighters. The children shall be seated side by side in chairs approximately 6 inches apart, across a table from the tester. The table shall be normal table height for the children, so that they can sit up at the table with their legs underneath and so that their arms will be at a comfortable height when on top of the table. The children's chairs shall be "child-size."

(3) Each tester shall be at least 18 years old. Five or 6 adult testers shall be used for each 100-child test panel. Each tester shall test an approximately equal number of children from a 100-child test panel (20 +or- 2 children each for 5 testers and 17 +or- 2 children each for 6 testers).

Note:

When a test is initiated with five testers and one tester drops out, a sixth tester may be added to complete the testing. When a test is initiated with six testers and one tester drops out, the test shall be completed using the five remaining testers. When a tester drops out, the requirement for each tester to test an approximately equal number of children does not apply to that tester. When testing is initiated with five testers, no tester shall test more than 19 children until it is certain that the test can be completed with five testers.

(c) *Surrogate lighters.* (1) Six surrogate lighters shall be used for each 100-child panel. The six lighters shall represent the range of forces required for operation of lighters intended for use. All surrogate lighters shall be the same color. The surrogate lighters shall be labeled with sequential numbers beginning with the number one. The same six surrogate lighters shall be used for the entire 100-child panel. The surrogate lighters may be used in more than one 100-child panel test. The surrogate lighters shall not be damaged or jarred during storage or transportation. The surrogate lighters shall not be exposed to extreme heat or cold. The surrogate lighters shall be tested at room temperature. No surrogate lighter shall be left unattended.

(2) Each surrogate lighter shall be tested by an approximately equal number of children in a 100-child test panel (17 +or- 2 children).

Note:

If a surrogate lighter is permanently damaged, testing shall continue with the remaining lighters. When a lighter is dropped out, the requirement that each lighter be tested by an approximately equal number of children does not apply to that lighter.

(3) Before each 100-child panel is tested, each surrogate lighter shall be examined to verify that it approximates the appearance, size, shape, and weight of a production lighter intended for use.

(4) Before and after each 100-child panel is tested, force measurements shall be taken on all operating components that could affect child resistance to verify that they are within reasonable operating tolerances for a production lighter intended for use.

(5) Before and after testing surrogate lighters with each child, each surrogate lighter shall be operated outside the presence of any child participating in the test to verify that the lighters produce a signal. If the surrogate lighter will not produce a signal before the test, it shall be repaired before it is used in testing. If the surrogate lighter does not produce a signal when it is operated after the test, the results for the preceding test with that lighter shall be eliminated. The lighter shall be repaired and tested with another eligible child (as one of a pair of children) to complete the test panel.

(d) *Encouragement*. (1) Prior to the test, the tester shall talk to the children in a normal and friendly tone to make them feel at ease and to gain their confidence.

(2) The tester shall tell the children that he or she needs their help for a special job. The children shall not be promised a reward of any kind for participating, and shall not be told that the test is a game or contest or that it is fun.

(3) The tester shall not discourage a child from attempting to operate the surrogate lighter at any time unless a child is in danger of hurting himself or another child. The tester shall not discuss the dangers of lighters or matches with the children to be tested prior to the end of the 10-minute test.

(4) Whenever a child has stopped attempting to operate the surrogate lighter for a period of approximately one minute, the tester shall encourage the child to try by saying "keep trying for just a little longer."

(5) Whenever a child says that his or her parent, grandparent, guardian, etc., said never to touch lighters, say "that's right — never touch a real lighter — but your [parent, etc.] said it was OK for you to try to make a noise with this special lighter because it can't hurt you."

(6) The children in a pair being tested may encourage each other to operate the surrogate lighter and may tell or show each other how to operate it. (This interaction is *not* considered to be disruption as described in paragraph (e)(2) below.) However, neither child shall be allowed to operate the other child's lighter. If one child takes the other child's surrogate lighter, that surrogate lighter shall be immediately returned to the proper child. If this occurs, the tester shall say "No. He(she) has to try to do it himself(herself)."

(e) *Children who refuse to participate*. (1) If a child becomes upset or afraid, and cannot be reassured before the test starts, select another eligible child for participation in that pair.

(2) If a child disrupts the participation of another child for more than one minute during the test, the test shall be stopped and both children eliminated from the results. An explanation shall be recorded on the data collection record. These two children should be replaced with other eligible children to complete the test panel.

(3) If a child is not disruptive but refuses to attempt to operate the surrogate lighter throughout the entire test period, that child shall be eliminated from the test results and an explanation shall be recorded on the data collection record. The child shall be replaced with another eligible child (as one of a pair of children) to complete the test panel.

(f) *Test procedure*. (1) To begin the test, the tester shall say "I have a special lighter that will not make a flame. It makes a noise like this." Except where doing so would block the child's view of a visual signal, the adult tester shall place a 8 1/2 by 11 inch sheet of cardboard or other rigid opaque material upright on the table in front of the surrogate lighter, so that the surrogate lighter cannot be seen by the child, and shall operate the surrogate lighter once to produce its signal. The tester shall say "Your parents [or other guardian, if applicable] said it is OK for you to try to make that noise with your lighter." The tester shall place a surrogate lighter in each child's hand and say "now *you* try to make a noise with your lighter. Keep trying until I tell you to stop."

(2) The adult tester shall observe the children for 5 minutes to determine if either or both of the children can successfully operate the surrogate lighter by producing one signal of any duration. If a child achieves a spark without defeating the child-resistant feature, say "that's a spark — it won't hurt you — try to make the noise with your lighter." If any child successfully operates the surrogate lighter during this period, the surrogate lighter shall be taken from that child and the child shall not be asked to try to operate the lighter again. The tester shall ask the successful child to remain until the other child is finished.

(3) If either or both of the children are unable to successfully operate the surrogate lighter during the 5-minute period specified in §1210.4(f)(2), the adult tester shall demonstrate the operation of the surrogate lighter. To conduct the demonstration, secure the children's full attention by saying "Okay, give me your lighters now." Take the lighters and place them on the table in front of you out of the children's reach. Then say, "I'll show you how to make the noise with your lighters. First I'll show you

with (child's name)'s lighter and then I'll show you with (child's name)'s lighter." Pick up the first child's lighter. Hold the lighter approximately two feet in front of the children at their eye level. Hold the lighter in a vertical position in one hand with the child-resistant feature exposed (not covered by fingers, thumb, etc.) Orient the child-resistant mechanism on the lighter toward the children. (This may require a change in your orientation to the children such as sitting sideways in the chair to allow a normal hand position for holding the lighter while assuring that both children have a clear view of the mechanism. You may also need to reposition your chair so your hand is centered between the children.) Say "now watch the lighter." Look at each child to verify that they are looking at the lighter. Operate the lighter one time in a normal manner according to the manufacturer's instructions. Do not exaggerate operating movements. Do not verbally describe the lighter's operation. Place the first child's lighter back on the table in front of you and pick up the second child's lighter. Say, "Okay, now watch this lighter." Repeat the demonstration as described above using the second child's lighter.

Note:

Testers shall be trained to conduct the demonstration in a uniform manner, including the words spoken to the children, the way the lighter is held and operated, and how the tester's hand and body is oriented to the children. All testers must be able to operate the surrogate lighters using only appropriate operating movements in accordance with the manufacturer's instructions. If any of these requirements are not met during the demonstration for any pair of children, the results for that pair of children shall be eliminated from the test. Another pair of eligible children shall be used to complete the test panel.

(4) Each child who fails to successfully operate the surrogate lighter in the first 5 minutes is then given another 5 minutes in which to attempt the successful operation of the surrogate lighter. After the demonstrations give their original lighters back to the children by placing a lighter in each child's hand. Say "Okay, now you try to make the noise with your lighters - keep trying until I tell you to stop." If any child successfully operates the surrogate lighter during this period, the surrogate lighter shall be taken from that child and the child shall not be asked to try to operate the lighter again. The tester shall ask the successful child to remain until the other child is finished.

(5) At the end of the second 5-minute test period, take the surrogate lighter from any child who has not successfully operated it.

(6) After the test is over, ask the children to stand next to you. Look at the children's faces and say: "These are special lighters that don't make fire. Real lighters can burn you. Will you both promise me that you'll never try to work a real lighter?" Wait for an affirmative response from each child; then thank the children for helping.

(7) Escort the children out of the room used for testing.

(8) After a child has participated in the testing of a surrogate lighter, and on the same day, provide written notice of that fact to the child's parent or guardian. This notification may be in the form of a letter provided to the school to be given to the parents or guardian of each child. The notification shall state that the child participated, shall ask the parent or guardian to warn the child not to play with lighters, and shall remind the parent or guardian to keep all lighters and matches, whether child resistant or not, out of the reach of children. For children who operated the surrogate lighter, the notification shall state that the child was able to operate the child-resistant lighter. For children who do not defeat the child-resistant feature, the notification shall state that, although the child did not defeat the child-resistant feature, the child may be able to do so in the future.

(g) *Data collection and recording*. Except for recording the times required for the children to activate the signal, recording of data should be avoided while the children are trying to operate the lighters, so that the tester's full attention is on the children during the test period. If actual testing is videotaped, the camera shall be stationary and shall be operated remotely in order to avoid distracting the children. Any photographs shall be taken *after* actual testing and shall simulate actual test procedure(s) (for example, the demonstration). The following data shall be collected and recorded for each child in the 100-child test panel:

(1) Sex (male or female).

(2) Date of birth (month, day, year).

(3) Age (in months, to the nearest month, as specified in §1210.4(a)(4)).

(4) The number of the lighter tested by that child.

(5) Date of participation in the test (month, day, year).

(6) Location where the test was given (city, state, country, and the name of the site or an unique number or letter code that identifies the test site).

(7) The name of the tester who conducted the test.

(8) The elapsed time (to the nearest second) at which the child achieved any operation of the surrogate signal in the first 5-minute test period.

(9) The elapsed time (to the nearest second) at which the child achieved any operation of the surrogate signal in the second 5-minute test period.

(10) For a single pair of children from each 100-child test panel, photograph(s) or video tape to show how the lighter was held in the tester's hand, and the orientation of the tester's body and hand to the children, during the demonstration.

(h) *Evaluation of test results and acceptance criterion*. To determine whether a surrogate lighter resists operation by at least 85 percent of the children, sequential panels of 100 children each, up to a maximum of 2 panels, shall be tested as prescribed below.

(1) If no more than 10 children in the first 100-child test panel successfully operated the surrogate lighter, the lighter represented by the surrogate lighter shall be considered to be resistant to successful operation by at least 85 percent of the child test panel, and no further testing is conducted. If 11 through 18 children in the first 100-child test panel successfully operate the surrogate lighter, the test results are inconclusive, and the surrogate lighter shall be tested with a second 100-child test panel in accordance with this §1210.4. If 19 or more of the children in the first 100-child test panel successfully operated the surrogate lighter, the lighter represented by the surrogate shall be considered not resistant to successful operation by at least 85 percent of the child test panel, and no further testing is conducted.

(2) If additional testing of the surrogate lighter is required by §1210.4(h)(1), conduct the test specified by this §1210.4 using a second 100-child test panel and record the results. If a total of no more than 30 of the children in the combined first and second 100-child test panels successfully operated the surrogate lighter, the lighter represented by the surrogate lighter shall be considered resistant to

successful operation by at least 85 percent of the child test panel, and no further testing is performed. If a total of 31 or more children in the combined first and second 100-child test panels successfully operate the surrogate lighter, the lighter represented by the surrogate lighter shall be considered not resistant to successful operation by 85 percent of the child test panel, and no further testing is conducted.

Table 1_Evaluation of Test Results_§ 1210.4(e)

Test panel	Cumulative Number of Children	Successful Lighter Operations		
		Pass	Continue	Fail
1	100	0-10	11-18	19 or more
1	200	11-30	_	31 or more

§1210.5 Findings.

Section 9(f) of the Consumer Product Safety Act, 15 U.S.C. 2058(f), requires the Commission to make findings concerning the following topics and to include the findings in the rule.

(a) *The degree and nature of the risk of injury the rule is designed to eliminate or reduce*. The standard is designed to reduce the risk of death and injury from accidental fires started by children playing with lighters. From 1988 to 1990, an estimated 160 deaths per year resulted from such fires. About 150 of these deaths, plus nearly 1,100 injuries and nearly $70 million in property damage, resulted from fires started by children under the age of 5. Fire-related injuries include thermal burns — many of high severity — as well as anoxia and other, less serious injuries. The annual cost of such fires to the public is estimated at about $385 million (in 1990 dollars). Fires started by young children (under age 5) are those which the standard would be most effective at reducing.

(b) *The approximate number of consumer products, or types or classes thereof, subject to the rule*. The standard covers certain flame-producing devices, commonly known as lighters, which are primarily intended for use in lighting cigarettes and other smoking materials. Lighters may be gas- or liquid-fueled, mechanical or electric, and of various physical configurations. Over 600 million lighters are sold annually to consumers in the U.S.; over 100 million are estimated to be in use at any given time. Over 95 percent of all lighters sold are pocket-sized disposable butane models; of the remaining 5 percent, most are pocket refillable butane models. A small proportion of refillables is comprised of pocket liquid-fuel models; still smaller proportions are represented by table lighters and by "novelty" lighters, that is, those having the physical appearance of other specific objects. Approximately 600 million pocket butane disposables (nonrefillable), 15-20 million pocket butane refillables, 5-10 million pocket liquid-fuel refillables, and 1-3 million novelty and other lighters were sold to consumers in 1991. The standard covers disposable lighters, including inexpensive butane refillables, and novelty lighters. Roughly 30 million households have at least one lighter; ownership of more than one lighter is typical, especially among smoking households.

(c) *The need of the public for the consumer products subject to the rule, and the probable effect of the rule on the utility, cost, or availability of such products to meet such need*. Consumers use lighters primarily to light smoking materials. Most other lighting needs that could be filled by matches may also be filled by lighters. Disposable butane lighters are, chiefly by virtue of their low price and convenience, the closest available substitutes for matches. Although matches are found in far more households, lighters have steadily replaced matches since the 1960's as the primary light source among American consumers. The standard generally requires that lighters not be operable by most children under 52 months of age. This would likely be achieved by modifying products to incorporate additional-action switches, levers, or buttons, thereby increasing the difficulty of product activation. Depending on the method of compliance chosen by manufacturers, there could be some adverse effect on the utility of lighters. This may occur to the extent that operation of the products by adult users is made more difficult by the incorporation of child-resistant features. This may lead some consumers to switch to matches, at least temporarily, which could reduce the expected level of safety provided by the standard. In addition, some "novelty" lighters will probably be discontinued, due to the technical difficulty of incorporating child-resistant features or designs. Some loss of utility derived from those products by collectors or other users may result, though many novelty models will probably remain on the market. The cost of producing lighters subject to the standard is expected to increase due to manufacturers' and importers' expenditures in the areas of research and development, product redesign, tooling and assembly process changes, certification and testing, and other administrative activities. Total per-unit production costs for the various lighter types may increase by 10-40 percent, with an average of less than 20 percent. Cost increases will likely be passed on to consumers in the form of higher retail prices. Disposable lighters may increase in price by 10-40 cents per unit; prices of other lighters may increase by as much as $1-3. The estimated average per-unit price increase for all lighters subject to the standard is about 20 cents. The total annual cost of the standard to consumers is estimated at about $90 million. The estimated cost of the standard per life saved is well under $1 million after considering the benefits of reduced injuries and property damage; this is well below the consensus of estimates of the statistical value of life. A wide range of lighter types and models will continue to be available to consumers. As noted above, some models of novelty lighters — all of which account for less than 1 percent of lighters sold — will likely be discontinued; this should not have a significant impact on the overall availability of lighters to consumers.

(d) *Any means of achieving the objective of the order while minimizing adverse effects on competition or disruption or dislocation of manufacturing and other commercial practices consistent with the public health and safety.* The Commission considered the potential effects on competition and business practices of various aspects of the standard, and, as noted below, incorporated some burden-reducing elements into the proposal. The Commission also encouraged and participated in the development of a draft voluntary standard addressing the risk of child-play fires. A draft voluntary safety standard was developed by members of an ASTM task group (now a subcommittee) to address much of the risk addressed by the proposed CPSC rule. This draft voluntary standard contained performance requirements similar, but not identical, to those in the CPSC proposal. Development work on the voluntary standard ceased in 1991; industry representatives requested that the Commission issue the draft ASTM provisions in a mandatory rule. One possible alternative to this mandatory standard would be for the Commission to rely on voluntary conformance to this draft standard to provide safety to consumers. The expected level of conformance to a voluntary standard is uncertain, however; although some of the largest firms may market some child-resistant lighters that conform to these requirements, most firms (possibly including some of the largest) probably would not. Even under generous assumptions about the level of voluntary conformance, net benefits to consumers would be substantially lower under this alternative than under the standard. Thus, the Commission finds that reliance on voluntary conformance to the draft ASTM standard would not adequately reduce the unreasonable risk associated with lighters.

(e) *The rule (including its effective date) is reasonably necessary to eliminate or reduce an* *unreasonable risk.* The Commission's hazard data and regulatory analysis demonstrate that lighters covered by the standard pose an unreasonable risk of death and injury to consumers. The Commission considered a number of alternatives to address this risk, and believes that the standard strikes the most reasonable balance between risk reduction benefits and potential costs. Further, the amount of time before the standard becomes effective will provide manufacturers and importers of most products adequate time to design, produce, and market safer lighters. Thus, the Commission finds that the standard and its effective date are reasonably necessary to reduce the risk of fire-related death and injury associated with young children playing with lighters.

(f) *The benefits expected from the rule bear a reasonable relationship to its costs.* The standard will substantially reduce the number of fire-related deaths, injuries, and property damage associated with young children playing with lighters. The cost of these accidents, which is estimated to be about $385 million annually, will also be greatly reduced. Estimated annual benefits of the standard are $205-$270 million; estimated annual costs to the public are about $90 million. Expected annual net benefits would therefore be $115-$180 million. Thus, the Commission finds that a reasonable relationship exists between potential benefits and potential costs of the standard.

(g) *The rule imposes the least burdensome requirement which prevents or adequately reduces the risk of injury for which the rule is being promulgated.* (1) In the final rule, the Commission incorporated a number of changes from the proposed rule in order to minimize the potential burden of the rule on industry and consumers. The Commission also considered and rejected several alternatives during the development of the standard to reduce the potential burden on industry (especially small importers) and on consumers. These alternatives involve different performance and test requirements and different definitions determining the scope of coverage among products. Other alternatives generally would be more burdensome to industry and would have higher costs to consumers. Some less burdensome alternatives would have lower risk-reduction benefits to consumers; none has been identified that would have higher expected net benefits than the standard.

(2) The scope of this mandatory standard is limited to disposable lighters and novelty lighters; it does not apply to "luxury" lighters (including most higher priced refillable butane and liquid-fuel models). This is similar but not identical to the scope of a draft voluntary industry standard developed in response to the Commission's advance notice of proposed rulemaking of March 3, 1988 (53 FR 6833). This exclusion significantly reduces the potential cost of the standard without significantly affecting potential benefits.

(3) The Commission narrowed the scope of the final rule with respect to novelty lighters, and considered limiting the scope further to exclude all nondisposable novelty lighters. Though further limiting the scope would ease the potential burden of the standard on manufacturers and importers slightly, inherently less safe non-child-resistant lighters that are considered to be especially appealing to children would remain on the market, thereby reducing the potential safety benefits to the public. The Commission finds that it would not be in the public interest to exclude novelty lighters.

(4) The Commission considered the potential effect of alternate performance requirements during the development of the standard. A less stringent acceptance criterion of 80 percent (rather than the standard's 85 percent) might slightly reduce costs to industry and consumers. The safety benefits of this alternative, however, would likely be reduced disproportionately to the potential reduction in costs. A higher (90 percent) acceptance criterion was also considered. This higher performance level is not commercially or technically feasible for many firms, however; the Commission believes that this more stringent alternative would have substantial adverse effects on manufacturing and

competition, and would increase costs disproportionate to benefits. The Commission believes that the requirement that complying lighters not be operable by at least 85 percent of children in prescribed tests strikes a reasonable balance between improved safety for a substantial majority of young children and other potential fire victims and the potential for adverse competitive effects and manufacturing disruption.

(5) The Commission believes that the standard should become effective as soon as reasonably possible. The standard will become effective 12 months from its date of publication in the *Federal Register*. The Commission also considered an effective date of 6 months after the date of issuance of the final rule. While most lighters sold in the U.S. could probably be made child resistant within 6 months, some disruptive effects on the supply of some imported lighters would result; this could have a temporary adverse impact on the competitive positions of some U.S. importers. The 12-month period in the standard would tend to minimize this potential effect, and would allow more time for firms to design, produce, and import complying lighters. The Commission estimates that there would be no significant adverse impact on the overall supply of lighters for the U.S. market.

(h) *The promulgation of the rule is in the public interest.* As required by the CPSA and the Regulatory Flexibility Act, the Commission considered the potential benefits and costs of the standard and various alternatives. While certain alternatives to the final rule are estimated to have net benefits to consumers, the adopted rule maximizes these net benefits. Thus, the Commission finds that the standard, if promulgated on a final basis, would be in the public interest.

Subpart B—Certification Requirements

Authority:

15 U.S.C. 2063, 2065(b), 2066(g), 2076(e), 2079(d).

§1210.11 General.

Section 14(a) of the Consumer Product Safety Act (CPSA), 15 U.S.C. 1263(a), requires every manufacturer, private labeler, or importer of a product that is subject to a consumer product safety standard and that is distributed in commerce to issue a certificate that such product conforms to the applicable standard and to base that certificate upon a test of each item or upon a reasonable testing program. The purpose of this subpart B of part 1210 is to establish requirements that manufacturers, importers, and private labelers must follow to certify that their products comply with the Safety Standard for Cigarette Lighters. This subpart B describes the minimum features of a reasonable testing program and includes requirements for labeling, recordkeeping, and reporting pursuant to sections 14, 16(b), 17(g), and 27(e) of the CPSA, 15 U.S.C. 2063, 2065(b), 2066(g), and 2076(e).

§1210.12 Certificate of compliance.

(a) *General requirements*—(1) *Manufacturers (including importers).* Manufacturers of any lighter subject to the standard must issue the certificate of compliance required by section 14(a) of the CPSA and this subpart B, based on a reasonable testing program or a test of each product, as required by §§1210.13-1210.14 and 1210.16. Manufacturers must also label each lighter subject to the standard as required by paragraph (c) of this section and keep the records and make the reports required by §§1210.15 and 1210.17. For purposes of this requirement, an importer of lighters shall be considered the "manufacturer."

(2) *Private labelers*. Because private labelers necessarily obtain their products from a manufacturer or importer that is already required to issue the certificate, private labelers are not required to issue a certificate. However, private labelers must ensure that the lighters are labeled in accordance with paragraph (c) of this section and that any certificate of compliance that is supplied with each shipping unit of lighters in accordance with paragraph (b) of this section is supplied to any distributor or retailer who receives the product from the private labeler.

(3) *Testing on behalf of importers*. If the required testing has been performed by or for a foreign manufacturer of a product, an importer may rely on such tests to support the certificate of compliance, provided that the importer is a resident of the United States or has a resident agent in the United States, the records are in English, and the records and the surrogate lighters tested are kept in the United States and can be provided to the Commission within 48 hours (§1210.17(a)) or, in the case of production records, can be provided to the Commission within 7 calendar days in accordance with §1210.17(a)(3). The importer is responsible for ensuring that the foreign manufacturer's records show that all testing used to support the certificate of compliance has been performed properly (§§1210.14-1210.16), the records provide a reasonable assurance that all lighters imported comply with the standard (§1210.13(b)(1)), the records exist in English (§1210.17(a)), (4) the importer knows where the required records and lighters are located and that records required to be located in the United States are located there, arrangements have been made so that any records required to be kept in the United States will be provided to the Commission within 48 hours of a request and any records not kept in the United States will be provided to the Commission within 7 calendar days (§1210.17(a)), and the information required by §1210.17(b) to be provided to the Commission's Division of Regulatory Management has been provided.

(b) *Certificate of compliance*. A certificate of compliance must accompany each shipping unit of the product (for example, a case), or otherwise be furnished to any distributor or retailer to whom the product is sold or delivered by the manufacturer, private labeler, or importer. The certificate shall state:

(1) That the product "complies with the Consumer Product Safety Standard for Cigarette Lighters (16 CFR 1210),"

(2) The name and address of the manufacturer or importer issuing the certificate or of the private labeler, and

(3) The date(s) of manufacture and, if different from the address in paragraph (b)(2) of this section, the address of the place of manufacture.

(c) *Labeling*. The manufacturer or importer must label each lighter with the following information, which may be in code.

(1) An identification of the period of time, not to exceed 31 days, during which the lighter was manufactured.

(2) An identification of the manufacturer of the lighter, unless the lighter bears a private label. If the lighter bears a private label, it shall bear a code mark or other label which will permit the seller of the lighter to identify the manufacturer to the purchaser upon request.

[58 FR 37584, July 12, 1993, as amended at 59 FR 67621, Dec. 30, 1994]

§1210.13 Certification tests.

(a) *General.* As explained in §1210.11 of this subpart, certificates of compliance required by section 14(a) of the CPSA must be based on a reasonable testing program.

(b) *Reasonable testing programs*—(1) *Requirements.* (i) A reasonable testing program for lighters is one that demonstrates with a high degree of assurance that all lighters manufactured for sale or distributed in commerce will meet the requirements of the standard, including the requirements of §1210.3. Manufacturers and importers shall determine the types and frequency of testing for their own reasonable testing programs. A reasonable testing program should be sufficiently stringent that it will detect any variations in production or performance during the production interval that would cause any lighters to fail to meet the requirements of the standard.

(ii) All reasonable testing programs shall include qualification tests, which must be performed on surrogates of each model of lighter produced, or to be produced, to demonstrate that the product is capable of passing the tests prescribed by the standard (see §1210.14), and production tests, which must be performed during appropriate production intervals as long as the product is being manufactured (see §1210.16).

(iii) Corrective action and/or additional testing must be performed whenever certification tests of samples of the product give results that do not provide a high degree of assurance that all lighters manufactured during the applicable production interval will pass the tests of the standard.

(2) *Testing by third parties.* At the option of the manufacturer or importer, some or all of the testing of each lighter or lighter surrogate may be performed by a commercial testing laboratory or other third party. However, the manufacturer or importer must ensure that all certification testing has been properly performed with passing results and that all records of such tests are maintained in accordance with §1210.17 of this subpart.

§1210.14 Qualification testing.

(a) *Testing.* Before any manufacturer or importer of lighters distributes lighters in commerce in the United States, surrogate lighters of each model shall be tested in accordance with §1210.4, above, to ensure that all such lighters comply with the standard. However, if a manufacturer has tested one model of lighter, and then wishes to distribute another model of lighter that differs from the first model only by differences that would not have an *adverse* effect on child resistance, the second model need not be tested in accordance with §1210.4.

(b) *Product modifications.* If any changes are made to a product after initial qualification testing that could adversely affect the ability of the product to meet the requirements of the standard, additional qualification tests must be made on surrogates for the changed product before the changed lighters are distributed in commerce.

(c) *Requalification.* If a manufacturer or importer chooses to requalify a lighter design after it has been in production, this may be done by following the testing procedures at §1210.4.

§1210.15 Specifications.

(a) *Requirement.* Before any lighters that are subject to the standard are distributed in commerce, the manufacturer or importer shall ensure that the surrogate lighters used for qualification testing under §1210.14 are described in a written product specification. (Section 1210.4(c) requires that six surrogate lighters be used for testing each 100-child panel.)

(b) *Contents of specification.* The product specification shall include the following information:

(1) A complete description of the lighter, including size, shape, weight, fuel, fuel capacity, ignition mechanism, and child-resistant features.

(2) A detailed description of all dimensions, force requirements, or other features that could affect the child-resistance of the lighter, including the manufacturer's tolerances for each such dimension or force requirement.

(3) Any further information, including, but not limited to, model names or numbers, necessary to adequately describe the lighters and any child-resistant features.

§1210.16 Production testing.

(a) *General.* Manufacturers and importers shall test samples of lighters subject to the standard as they are manufactured, to demonstrate that the lighters meet the specifications, required under §1210.15, of the surrogate that has been shown by qualification testing to meet the requirements of the standard.

(b) *Types and frequency of testing.* Manufacturers, private labelers, and importers shall determine the types of tests for production testing. Each production test shall be conducted at a production interval short enough to provide a high degree of assurance that, if the samples selected for testing pass the production tests, all other lighters produced during the interval will meet the standard.

(c) *Test failure*—(1) *Sale of lighters.* If any test yields results which indicate that any lighters manufactured during the production interval may not meet the standard, production and distribution in commerce of lighters that may not comply with the standard must cease until it is determined that the lighters meet the standard or until corrective action is taken. (It may be necessary to modify the lighters or perform additional tests to ensure that only complying lighters are distributed in commerce. Lighters from other production intervals having test results showing that lighters from that interval comply with the standard could be produced and distributed unless there was some reason to believe that they might not comply with the standard.)

(2) *Corrective actions.* When any production test fails to provide a high degree of assurance that all lighters comply with the standard, corrective action must be taken. Corrective action may include changes in the manufacturing process, the assembly process, the equipment used to manufacture the product, or the product's materials or design. The corrective action must provide a high degree of assurance that all lighters produced after the corrective action will comply with the standard. If the corrective action changes the product from the surrogate used for qualification testing in a manner that could adversely affect its child resistance, the lighter must undergo new qualification tests in accordance with §1210.14, above.

§1210.17 Recordkeeping and reporting.

(a) *Records.* Every manufacturer and importer of lighters subject to the standard shall maintain the following records in English on paper, microfiche, or similar media and make such records available to any designated officer or employee of the Commission in accordance with section 16(b) of the Consumer Product Safety Act, 15 U.S.C. 2065(b). Such records must also be kept in the United States and provided to the Commission within 48 hours of receipt of a request from any employee of the Commission, except as provided in paragraph (b)(3) of this section. Legible copies of original records may be used to comply with these requirements.

(1) Records of qualification testing, including a description of the tests, photograph(s) or a video tape for a single pair of children from each 100-child test panel to show how the lighter was held in the tester's hand, and the orientation of the tester's body and hand to the children, during the demonstration, the dates of the tests, the data required by §1210.4(d), the actual surrogate lighters tested, and the results of the tests, including video tape records, if any. These records shall be kept until 3 years after the production of the particular model to which such tests relate has ceased. If requalification tests are undertaken in accordance with §1210.14(c), the original qualification test results may be discarded 3 years after the requalification testing, and the requalification test results and surrogates, and the other information required in this subsection for qualifications tests, shall be kept in lieu thereof.

(2) Records of procedures used for production testing required by this subpart B, including a description of the types of tests conducted (in sufficient detail that they may be replicated), the production interval selected, the sampling scheme, and the pass/reject criterion. These records shall be kept until 3 years after production of the lighter has ceased.

(3) Records of production testing, including the test results, the date and location of testing, and records of corrective actions taken, which in turn includes the specific actions taken to improve the design or manufacture or to correct any noncomplying lighter, the date the actions were taken, the test result or failure that triggered the actions, and the additional actions taken to ensure that the corrective action had the intended effect. These records shall be kept for 3 years following the date of testing. Records of production testing results may be kept on paper, microfiche, computer tape, or other retrievable media. Where records are kept on computer tape or other retrievable media, however, the records shall be made available to the Commission on paper copies upon request. A manufacturer or importer of a lighter that is not manufactured in the United States may maintain the production records required by paragraph (a)(3) of this section outside the United States, but shall make such records available to the Commission in the United States within 1 week of a request from a Commission employee for access to those records under section 16(b) of the CPSA, 15 U.S.C. 2065(b).

(4) Records of specifications required under §1210.15 shall be kept until 3 years after production of each lighter model has ceased.

(b) *Reporting*. At least 30 days before it first imports or distributes in commerce any model of lighter subject to the standard, every manufacturer and importer must provide a written report to the Division of Regulatory Management, Consumer Product Safety Commission, Washington, D.C. 20207. Such report shall include:

(1) The name, address, and principal place of business of the manufacturer or importer,

(2) A detailed description of the lighter model and the child-resistant feature(s) used in that model,

(3) A description of the qualification testing, including a description of the surrogate lighters tested, the specification of the surrogate lighter required by §1210.15, a summary of the results of all such

tests, the dates the tests were performed, the location(s) of such tests, and the identity of the organization that conducted the tests,

(4) An identification of the place or places that the lighters were or will be manufactured,

(5) The location(s) where the records required to be maintained by paragraph (a) of this section are kept, and

(6) A prototype or production unit of that lighter model.

(c) *Confidentiality.* Persons who believe that any information required to be submitted or made available to the Commission is trade secret or otherwise confidential shall request that the information be considered exempt from disclosure by the Commission, in accordance with 16 CFR 1015.18. Requests for confidentiality of records provided to the Commission will be handled in accordance with section 6(a)(2) of the CPSA, 15 U.S.C. 2055(a)(2), the Freedom of Information Act as amended, 5 U.S.C. 552, and the Commission's regulations under that act, 16 CFR part 1015.

§1210.18 Refusal of Importation.

(a) *For noncompliance with reporting and recordkeeping requirements.* The Commission has determined that compliance with the recordkeeping and reporting requirements of this subpart is necessary to ensure that lighters comply with this part 1210. Therefore, pursuant to section 17(g) of the CPSA, 15 U.S.C. 2066(g), the Commission may refuse to permit importation of any lighters with respect to which the manufacturer or importer has not complied with the recordkeeping and reporting requirements of this subpart. Since the records are required to demonstrate that production lighters comply with the specifications for the surrogate, the Commission may refuse importation of lighters if production lighters do not comply with the specifications required by this subpart or if any other recordkeeping or reporting requirement in this part is violated.

(b) *For noncompliance with this standard and for lack of a certification certificate.* As provided in section 17(a) of the CPSA, 15 U.S.C. 2066(a), products subject to this standard shall be refused admission into the customs territory of the United States if, among other reasons, the product fails to comply with this standard or is not accompanied by the certificate required by this standard.

Subpart C—Stockpiling

Authority:

15 U.S.C. 2058(g)(2), 2079(d).

§1210.20 Stockpiling.

(a) *Definition. Stockpiling* means to manufacture or import a product that is subject to a consumer product safety rule between the date of issuance of the rule and its effective date at a rate which is significantly greater than the rate at which such product was produced or imported during a base period.

(b) *Base Period.* For purposes of this rule, *base period* means, at the option of the manufacturer or importer, any 1-year period during the 5-year period prior to July 12, 1993.

(c) *Prohibited act*. Manufacturers and importers of disposable and novelty cigarette lighters shall not manufacture or import lighters that do not comply with the requirements of this part between July 12, 1993 and July 12, 1994, at a rate that is greater than the rate of production or importation during the base period plus 20 per cent of that rate.

Child-Resistant Lighters

A decision was made on 11th May 2006 by the European Commission to introduce a measure to ensure that only child-resistant cigarette lighters are placed on the market and to prohibit the sale of novelty lighters.

What are the important dates?

There will be a two stage removal of these lighters from the market. From 11th March 2007, manufacturers will be prohibited from placing non-child-resistant lighters onto the European Market. A further decision will then be made to prohibit the sale of these lighters to consumers from 11th March 2008. This allows a twelve-month window for businesses to clear non-compliant stock.

What is a child-resistant lighter?

A child-resistant lighter means one that is designed and manufactured in such a way that it cannot, under normal conditions of use, be operated by children younger than 51 months, because of the force needed to operate or because of its design or the protection of its ignition mechanism or the complexity or sequence of operations required for the ignition.

What certification is required?

A lighter can be deemed child-resistant in the EU if it has certification for either EN 3689:2002 or the US Consumer Product Safety Standard for Cigarette Lighters given in 16, CFR, Chapter 11 of 12 July 1993.

How will I know if the lighters I purchase are child-resistant?

Manufacturers must supply a declaration of compliance to accompany each supply unit of lighters to both distributors and retailers. This must state that the product complies with the standard, the name and address of the producer, the time period the lighter was produced and the distributor if different to the manufacturer. Each lighter must also be marked with the manufacturer and the time period produced, this can be in code.

All KTWO lighters will also feature a child-resistant symbol on the outer pack and on the warning label on the reverse of each lighter.

What is KTWO's position on child-resistant lighters?

KTWO has been involved in the consultation process with the DTI and fully supports the EU Directive. Our KTWO lighters are available in child-resistant format from December 2006.

What is important about the mechanism for KTWO?

Our patented child-resistant mechanism has been available in the US and Canada for over 10 years. Furthermore, our child-resistant lighter is market proven in the UK, because we have been in successful supply to a major UK "C" store operator

for more than two years. This experience has been invaluable, enabling us to confidently plan for this major development.

What is important about Single Stage Mechanisms?

KTWO disposable lighters have a single stage lighting mechanism which ensures they remain consumer friendly. In the US the CPSC found that smokers faced with difficult to use double stage mechanisms were put off and turned to the more consumer-friendly designs.

However, although our lighters are smoker-friendly, they are not easy to light by children. Our lighters have a new "slip wheel" in addition to the existing "strike wheel". The slip wheel acts as a mechanical barrier preventing a child's thumb access to the "strike wheel". The "slip wheel" can freely rotate independently of the "strike wheel" which actually ignites the lighter.

The "slip wheel" makes the ignition of the lighter difficult by increasing the requisite amount of force and manual dexterity required to ignite the lighter. The feature is also intended to take advantage of the smaller anatomical size of a child's finger to hinder a child's ability to operate the lighter. The "slip wheels" are larger in radius than the prior "strike wheels". We also believe the complexity of the lighting process means that additional analytical steps are required to the child's mental process of understanding the operation of the lighter, which further hinders the ability of small children to use the lighter.

What should I do now?

Contact the KTWO Sales Team for further information on 01992 814786. We will also update our website as new information becomes available.

KTWO Limited, Auction House
Market Place, Abridge, Essex RM4 1UA
Tel: 01992 814786, Sales Tel: 01992 813828
Fax: 01992 814872, Web: www.ktwo.uk.com
Email: http://www.ktwo.uk.com/mailto:enquiries@ktwo.uk.com

The General Product Safety Regulations 2005

Notification guidance for producers and distributors

September 2005

CONTENTS

1. INTRODUCTION

The General Product Safety Regulations 2005 ("the Regulations") implement Directive 2001/95/EC on general product safety ("the GPSD") and came into force on 1st October 2005 (when they replaced the 1994 Regulations). They have the aim of ensuring that non-food consumer products placed on the market are safe.

One of the new duties placed on producers and distributors by the Regulations (Regulation 9) is to notify their local authorities (or other appropriate bodies – see section 4.2) when they become aware that a product they have placed on the market, or have supplied, "poses risks to the consumer that are incompatible with the general safety requirement" – see Regulation 5.

This guide has been produced by the DTI to help producers and distributors understand this requirement and how they should make notifications when necessary. Users of the guide might also find it helpful to read the general guidance on the Regulations[1] and the EC Guidelines on producer/distributor notifications[2].

In most areas the guidance applies to both producers and distributors, but where requirements are different the following definitions of *producer* and *distributor* should help readers decide what action is relevant to them.

The Regulations define a *producer* as:

(a) The manufacturer of a product, when he is established in a Member State and any other person presenting himself as the manufacturer by affixing to the product his name, trade mark or other distinctive mark, or the person who reconditions the product;

(b) When the manufacturer is not established in a Member State –

(i) If he has a representative established in a Member State, the representative,

(ii) In any other case the importer of the product from a state that is not a Member State into a Member State;

(c) Other professionals in the supply chain, insofar as their activities may affect the safety properties of a product.

A *distributor* is defined as a professional in the supply chain whose activity does not affect the safety properties of a product. But a distributor or retailer is also a producer if it carries out any of the activities in (a) and (b) above.

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1 Available on the DTI website - http://www.dti.gov.uk/ccp/topics1/safety.htm#gpsr

2 http://europa.eu.int/comm/consumers/cons_safe/prod_safe/gpsd/guidelines_en.htm

2. SUMMARY OF THE PROVISIONS IN THE GENERAL PRODUCT SAFETY REGULATIONS 2005 ON NOTIFICATION BY PRODUCERS AND DISTRIBUTORS

2.1. Obligation to inform enforcement authorities

Producers and distributors are required to inform the enforcement authorities if they know or ought to know, on the basis of the information in their possession and as professionals, that a product they have placed on the market is not a safe product (see section 3.2).

"Isolated" circumstances or products do not need to be notified.

Producers and distributors could give the enforcement authority preliminary information about a potential product risk as soon as they become aware of it. With this information the authorities may be able to help producers and distributors assess the risk and the appropriate response and to carry out their notification duty correctly. There is no requirement to give the enforcement authority preliminary information, but it is desirable.

2.2. Why this provision has been introduced

The obligation to inform the authorities about dangerous products is an important element for improved market surveillance and risk management.

Producers and distributors, within the limits of their respective activities, are responsible in the first instance for preventing/removing risks from consumer products. However, they may not have taken (or may not be in a position to take) all the measures necessary to do this. There is also the possibility that other products of the same type (made by other producers) may pose similar risks and may require similar measures to be taken.

The main purpose of the notification procedure is to enable the enforcement authority to monitor whether the company has taken appropriate action to address the risks posed by a product already on the market and to require (or take) additional action if necessary to prevent risks. When passed on by the DTI to the authorities in other Member States in which the product has been marketed, this information also allows those authorities to take appropriate action for their domestic markets.

3. NOTIFICATION CRITERIA

3.1. Application and Scope

For the notification obligation to apply the following criteria must be satisfied:

- the product is within the scope of regulation 2 – i.e. it is a product intended for or likely to be used by consumers (including in the context of providing a service and second-hand products);

- the product is on the market;

- the producer or distributor has evidence (from monitoring activities, testing, quality control or from other sources) that the product is dangerous as defined by the Regulations, or that it does not satisfy the safety requirements of the relevant sectoral legislation;

- the nature and level of risk requires preventative and corrective action, including removing the products form the market, recalling the product from consumers, modifying the product, issuing warnings etc., depending on the specific circumstances.

Where consumer products are subject to sector-specific legislation dealing with aspects of their safety, and where that legislation does not have similar notification obligations, the notification requirements of the Regulations apply. Examples of such products include (but are not limited to):

Toys
Electrical equipment
Cosmetics
Personal protective equipment
Construction products
Machinery
Motor vehicles

The notification requirements of the Regulations do not however extend to consumer products falling under sector specific legislation with separate notification obligations (e.g. medical devices, medicinal products etc).

3.2. General safety requirement and conformity criteria

Producers and distributors are obliged to supply or to place on the market only products that are safe. Regulation 2 defines a safe product as one that:

"under normal or reasonably foreseeable conditions of use (including duration) and, where applicable, putting into service, installation and maintenance requirements, does not present any risk or only the minimum risks compatible with the product's use, considered to be acceptable and consistent with a high level of protection for the safety and health of persons. In determining the foregoing, the following shall be taken into account in particular:

(a) the characteristics of the product, including its composition, packaging, instructions for assembly and, where applicable, instructions for installation and maintenance,

(b) the effect of the product on other products, where it is reasonably foreseeable that it will be used with other products,

(c) the presentation of the product, the labelling, any warnings and instructions for its use and disposal and any other indication or information regarding the product, and

(d) the categories of consumers at risk when using the product, in particular children and the elderly."

Any product that does not meet this definition is regarded as dangerous.

Regulation 6 describes how conformity with this requirement is assessed with reference to national legislation, European standards and other reference material. Where suitable European standards do not exist the Regulations allow other elements to be taken into account in assessing the safety of a product - e.g. national standards, codes of good practice, etc.

In addition to the above, the Regulations also refer to serious risk, which is defined in regulation 2 as *"a serious risk, including one the effects of which are not immediate, requiring rapid intervention."*

Nevertheless, the Regulations recognise that the feasibility of obtaining higher levels of safety, or the availability of other products presenting a lesser degree of risk, do not on their own constitute grounds for considering a product to be "dangerous". It should also be borne in mind that non-compliance with a relevant standard (where compliance was not made mandatory by legislation) would not necessarily mean that a product was unsafe.

The level of risk could depend on a number of factors, e.g. the type and vulnerability of the user and the extent to which the producer had taken precautions to guard against the hazard and warn the user. The level of risk which is characteristic of the product and regarded as acceptable by consumers also has to be taken into account. Society accepts higher risks in some circumstances (e.g. such as motoring), than in others (e.g. such as children's toys). A knife has to be sharp in order to be able to cut and therefore presents a risk, but the product is not regarded as dangerous because the risk is an obvious one and a characteristic of the product that consumers accept.

A risk could be the result of a manufacturing or production error or it could result from the design of, or the materials used in, the product. A risk could also arise from a product's contents, construction, finish, packaging, warnings or instructions.

In determining whether a product is dangerous under the terms of the GPSD several issues should be analysed: the utility of the product, the nature of the risk, the population groups exposed, previous experience with similar products, etc. A safe product must have no risk or only present the minimum risk compatible with the product's use and needed in order to ensure useful operation of the product. Producers are expected to undertake a risk assessment of their products before they are marketed. This will form both the basis of their conclusion that the product satisfies the general safety obligation and can be marketed, and also provide a reference for subsequent reassessment of further risk information and whether the product continues to satisfy the definition of "safe product" or corrective action or notification needs to be undertaken.

If producers or distributors become aware of information or new evidence showing that a product may be dangerous they should determine whether such information leads to the conclusion that a product is actually dangerous.

The European Commission's guidance on risk assessment at Annex I is one approach to risk assessment that producers and distributors can use to decide if a specific situation caused by a consumer product justifies a notification to the competent authorities. It represents a methodological framework intended to promote consistency across the EU and does not take account of all possible factors, but should facilitate consistent, reasoned professional judgements on the risks posed by specific consumer products. Some industry sectors have proven risk assessment procedures to assist producers to come to a conclusion; but they should always be used only as an indicator of appropriate action. In all cases, the producer must take responsibility for the decision. Producers or distributors should analyse the information collected and decide whether a particular hazardous situation should be notified to the authorities taking into account:

- the gravity of the outcome of a hazard, depending on the severity and probability of the damage to human health and safety. Combining the severity and probability gives an assessment of the gravity of the risk. The accuracy of this assessment will depend upon the quality of the information available to the producer or distributor.

- The severity of health/safety damage for a given hazard should be that for which there is reasonable evidence that the health/safety damage attributable to the product could occur under foreseeable use. This could be the worst case from health/safety damages that have occurred with similar products.

- The probability of damage to human health and safety resulting from an exposure corresponding to the intended or reasonably expected use of the product has also to be considered as well as the probability of the product being or becoming dangerous in normal or reasonably foreseeable use including duration.

- The decision to notify should not be influenced by the number of products on the market or by the number of people who could be affected by a dangerous product. These factors may, however, be taken into account when deciding on the type of action to be taken to solve the problem, and the data concerned is essential to conduct a risk assessment.

- the factors which affect the level of the risk such as the type of user and, for non-vulnerable adults, whether the product has adequate warnings and safeguards and whether the hazard is sufficiently obvious.

It is considered that among the important factors affecting the level of risk are the vulnerability of the type of person affected and, for non-vulnerable adults, the knowledge of the risk and the possibility of taking precautions against it.

It follows therefore that any risk assessment should take into account the type of person likely to use a product and if the product is likely to be used by vulnerable people (such as children, the elderly) the level of acceptable risk be set at a lower level.

Producers and distributors are encouraged to contact the enforcement authority if they are in any doubt as to whether evidence of a potential problem in their possession should be notified. The enforcement authority is responsible for assisting and helping them to correctly fulfil their notification obligation.

3.3. Criteria for non-notification

Subject to the final sub paragraph of 3.2 above, there are certain circumstances where a notification is specifically not required.

The objective is to prevent a burden to business and a proliferation of notifications of measures, actions or decisions related to "isolated circumstances or products" which do not require any verification, monitoring or action by the authorities and do not provide information useful for risk assessment and consumer protection. This may happen when it is clear that the risk is related to a limited number of well identified products or batches only, and the producer or distributor has solid evidence to conclude that the risk has been fully controlled and its cause is such that knowledge of the incident does not represent useful information for the authorities (such as the malfunctioning of a production line, errors in handling or packaging, etc.).

Producers and distributors do not need to notify under these Regulations:

- products that are not within the scope of regulation 3 or the definition of "product" in Regulation 2, or products that are covered by regulation 4;
- products that are covered by specific notification procedures under sector-specific legislation (e.g. medical devices and medicinal products);
- products for which the manufacturer has been able to take immediate corrective action for all the items concerned. The defect is limited to well identified items or batches of items and the producer has withdrawn the items in question;
- problems related to the functional quality of the product, not to its safety;
- when the producer/distributor knows that the authorities have already been informed and have all the required elements of information.

4. NOTIFICATION PROCEDURE

4.1. Who must notify

The obligation to notify applies to both producers and distributors, within the limits of their respective activities and in proportion to their responsibilities – but they should not duplicate notifications.

If notification policy (e.g. who should notify) has not already been agreed within the supply chain, it may be sensible for such a discussion to take place following a risk becoming known and before a notification is made. At this stage, the producer may inform the TSD. If the producer subsequently concludes that notification, on the basis of a risk assessment showing that the product is incompatible with the GSR, is required, he must do this within 10 calendar days. This gives an opportunity for discussion with the TSD on the corrective action it is undertaking or planning. It should also be understood that the duty to notify rests with the party first becoming aware of the risk, and it is they who must make the notification unless they can be sure that another party will notify within the original 10-day period. If retailers receive information on a dangerous product from their producer/distributor, they should not inform the authorities if they know that the producer or distributor has already informed the authorities.

Producers and distributors are encouraged to hold discussions with everyone involved in the supply of an individual product before the need for notification arises. The benefit will be that in the event of a notification becoming necessary the various operators will know what to do in advance and unnecessary double notifications will be avoided.

In general, when a notification does become necessary we expect the following procedures to be followed:

If it is the producer that first becomes aware that its product is incompatible with the general safety requirement it should inform the home authority[3] and forward a copy of the information to its distributors stating the date of the notification, to whom it was made and the action to be taken in respect of the product (i.e. remove it from sale). A distributor receiving such information from a producer may reasonably assume that a notification has been made. If a distributor is uncertain whether a notification has been made it should clarify the situation with the producer before taking any further steps.

If it is a distributor that first becomes aware that a product is incompatible with the general safety requirement, it should as a first step withdraw the product from

[3] The Local Authorities Coordinators of Regulatory Services (LACORS) promotes the "Home Authority" principle, under which the local authority for the area where the decision-making function of a business is located accepts the primary responsibility for offering advice and preventative guidance on safety to the business. Other local authorities should liaise with the relevant home authority on any safety matters arising from the products supplied by that business and before implementing any measures. Businesses are encouraged to make contact with, and seek advice on any particular matter from their home local authority.

sale and then inform the producer of its concerns. Where the producer is in the UK, it is expected that it will make the notification – this will prevent multiple and unnecessary distributor notifications. But if the distributor cannot be certain that a notification will be made by the producer or another distributor it should advise the relevant enforcement authority by completing as much of the notification form as it can within the 10-day deadline and copy this to the producer for further completion of any gaps in the information. The producer should then send the updated form to its home authority for onward submission to the DTI (the local authority will have consulted the home authority following the distributor's notification). Communication with the producer is important so as to be able to determine whether the event recorded is an isolated circumstance and whether and to the authorities of which other member states the notification needs to be promulgated and the nature and scope of any necessary corrective actions.

Producers may only become aware of hazard situations as a result of an aggregated assessment of individual communications received from different retailers or distributors. The producer has the responsibility of assessing the information in order to determine the exact origin of the possible hazard, to assess the risk to consumers, and to take the measures that appear to be necessary, including notification of the authorities.

A company should assign responsibility for notifications to someone sufficiently senior in the organisation who has decision-making powers.

4.2. To whom the notification should be presented

Producers and distributors are required by the Regulations to submit their notifications to the appropriate market surveillance/enforcement authority, which in most instances will be the local authority (or the home authority for producers), who will then pass this information on to the DTI for onward transmission to the Commission and other Member States as necessary. For new motor vehicles and automotive products, notifications should be made to the Vehicle and Operator Services Agency (VOSA). See Annex III for information on how to identify local/home authorities and for VOSA contact details.

When a local authority receives a notification from a producer or distributor it will assess the risk for itself and advise on the nature and scale of the corrective actions undertaken or proposed. If the risk is deemed to be non-"serious" and not requiring urgent intervention the notification will be passed on to the DTI for onward transmission to the Commission and other Member States in which the product has been marketed. If the risk is deemed to be serious the local authority will generate a serious risk notification under the Rapid Alert Notification System (RAPEX) for the DTI to formally submit to the European Commission. In both cases the producer or distributor will be notified by the DTI when this information is being submitted for European circulation.

If the enforcement authorities conclude or obtain evidence that a product placed on the market is dangerous and that the producer and/or distributor was aware of this but had not made a notification, the authority may apply the sanctions that are provided for under the Regulations.

4.3. How to notify

A company should notify by filling in the form presented in Annex I and submitting it without delay to the relevant enforcement authority. The operator notifying must provide the information required in the form. However, no company should delay a notification because part of the information is not yet available.

It may be helpful to divide the form into two parts. The first part should be filled in and submitted immediately (Sections 1 to 5) and the second part (Section 6) should be completed as the information becomes available (a timetable for providing the missing information should be provided). This will assist the rapid notification process in the event of a serious risk being identified.

The Regulations require that the appropriate authorities be informed immediately. A company must therefore inform them without delay, as soon as the relevant information has became available, and in any case within 10 calendar days of it obtaining reportable information. When there is a serious risk companies are required to inform the authority immediately and in no case later than three calendar days after they have obtained notifiable information.

In an emergency situation, such as where immediate corrective action is taken by a company, the company should inform the local authority immediately and by the fastest means possible.

5. CONTENTS OF NOTIFICATIONS

5.1. Background to notifications (obligation of post-marketing monitoring)

In addition to the duty to comply with the general safety requirement for their products, producers and distributors have the obligation, as professionals and within the limits of their activities, to ensure an adequate follow-up of the safety of products they supply. The obligations established by the Regulations in that respect (Regulations 7(3) and 8 in particular), such as providing information to consumers, post-marketing monitoring of product risks, withdrawing dangerous products, etc, have been mentioned elsewhere.

Various types of evidence may become available to operators within the framework of their post-marketing responsibilities which may lead to a notification, such as:

– reports or other information on accidents involving the company's products;

– safety-related complaints or other feedback received from consumers, directly or through distributors or consumer or other safety organisations;

– insurance claims or legal actions concerning dangerous products;

– safety-related non-compliance reported via the company's quality control procedures;

– any information relevant for identifying non-compliances with safety requirements that is brought to the company's attention by other organizations such as market surveillance authorities (including in other member states), consumer organisations or other companies including component or sub assembly suppliers;

– scientific reports or developments that have an impact on the assessment of risk of the product concerned.

5.2. Notification form

The information required has been classified under the following sections:

1. Details of Authority(ies)/Company(ies) receiving the notification form: the person completing the form is requested to identify the authoritv(ies) and company(ies) that will receive the notification and the role that these companies have in the marketing of the product.

2. Details of the producer (as defined in regulation 2) / distributor completing the notification form: the person filling in the form must enter complete details of their identity, that of the company and its role in the marketing of the product.

3. Details of the product involved: a precise identification of the product is required including its brand, model, etc., supported by photographs or drawings in order to avoid confusion.

4. Details of the hazard (type and nature) including accidents and health/safety effects and conclusions of the risk estimation and evaluation that has been carried out in accordance with section 3 (Notification criteria) and in light of the risk assessment criteria at Annex I (or some other suitable assessment model).

5. Details of corrective actions that have been taken or are planned to reduce or eliminate the risk to consumers, e.g. recall or withdrawal, modification, informing consumers, etc. and of where responsibility for these actions lays.

6. Details of companies in the supply chain who hold affected products (including approximate numbers of products in the hands of businesses and consumers). The amount of detail required should be discussed with the local/home authority. When identifying product availability in other Member States (needed only when the notifier has made the product available in those countries) only the main distribution point(s) in those countries needs to be indicated.

In the event of serious risk producers and distributors are required to include all the available information relevant for tracing the product. The information required for Section 6 of the notification form (see Annex I) may take longer to collect than the other sections, because it may be necessary to collect it from several organisations. Companies should complete and send Sections 1 to 5 as soon as possible and send Section 6 as soon as the information is available.

6. FOLLOW-UP TO NOTIFICATIONS

After a notification is sent it is generally assumed that where the producer or distributor is already taking the action considered by the authority necessary to remove the risk to consumers it will not be necessary for the enforcement authorities to serve a safety notice. Voluntary action is specifically encouraged as an alternative to formal enforcement.

Having said that various developments are possible. In particular:

– the authority that has received the notification may, if appropriate, reply by asking for additional information or request the producer or distributor to take further action or measures;

– producers and distributors may have to provide additional information at their own initiative or on request from the authorities on any new developments or findings and/or success or problems with any action taken;

– the authority should decide where appropriate to take enforcement action and/or require producers and distributors to ensure cooperation on market surveillance or to inform the public about product identification, the nature of the risk and the measures taken, taking into account professional secrecy;

– if the requirements of a RAPEX notification are fulfilled (serious risk, product marketed in several Member States), the local authority must send a RAPEX notification to the DTI for onward transmission to the Commission, which will then send this to all the Member States.

– The enforcement authority may have recourse to the various sanctions e.g. for placing an unsafe product on the market provided by the Regulations.

ANNEX I - METHODOLOGICAL FRAMEWORK FOR FACILITATING CONSISTENT RISK ESTIMATION AND EVALUATION

The following risk assessment procedures are currently being revised. They are included in this Guidance, but may be replaced in a future edition by a revised version. The DTI website should be checked regularly for updates on this. Attention is also drawn to the existence of more product-specific Risk Assessment procedures in some sectors.

The following text is based on the framework developed for the RAPEX Guidelines and is presented here in order to assist companies in assessing the level of a risk and deciding whether a notification to the authorities is necessary. The guidelines in this Annex II are not exhaustive and do not attempt to take into account all possible factors. The companies should judge each individual case on its merits taking into account the criteria set out in these guidelines as well as their own experience and practice, other relevant considerations and appropriate methods.

A consumer product may present one or more intrinsic hazards. The hazard may be of various types (chemical, mechanical, electrical, heat, radiation, etc.). The hazard represents the intrinsic potential of the product to damage the health and safety of users under certain conditions.

The severity of each type of hazard may be given a rating, based on qualitative and sometimes quantitative criteria related to the type of damage that it is liable to produce.

It may happen that not all individual products present the hazard in question, but only some of the items placed on the market. The hazard may in particular be related to a defect that appears only in some of the products of a certain type (brand, model, etc.) placed on the market. In such cases the probability of the defect/hazard being present in the product should be considered.

The potential of a hazard to materialise as an actual negative effect on health/safety will depend on the degree to which the consumer is exposed to it when using the product as intended or as could reasonably be expected during its lifetime. In addition the exposure to certain hazards may in some cases involve more than one person at a time. Finally when determining the level of the risk presented by a product by combining the severity of the hazard with the exposure, consideration should be given also to the ability of the exposed consumer to prevent or react to the hazardous situation. This will depend on the evidence of the hazard, the warnings given and the vulnerability of the consumer who may be exposed to it.

Taking into account the above considerations, the following conceptual approach may assist businesses when deciding whether a specific hazardous situation caused by a consumer product requires a notification to the competent authorities.

It is recommended that assessments be carried out by a small team who have knowledge and experience of the product and its hazards. Assessors may have to make subjective judgements if objective data is not available and it is hoped this procedure will help them to make consistent and reasoned judgements about actual or potential risks.

The assessor should analyse the information collected and use the risk assessment table as follows:

1. As a first step, use Table A to determine the gravity of the outcome of a hazard, depending on both its severity and the probability of it occurring under the conditions of use considered, and of the possible health/safety effect related to the intrinsic hazardous characteristics of the product.

2. As a second step, use Table B to further assess the gravity of the outcome depending on the type of consumer and, for non-vulnerable adults, whether the product has adequate warnings and safeguards and whether the hazard is sufficiently obvious to make it possible to grade the risk level qualitatively.

Table A - Risk estimation: severity and probability of health/safety damage

In Table A the two main factors affecting the risk estimation, namely the severity and probability of health/safety damage, are combined. The following definitions of severity and probability have been drawn up to assist in the selection of appropriate values.

Severity of injury

The assessment of severity is based on consideration of the potential health/safety consequences of the hazards presented by the product considered. A grading should be established specifically for each type of hazard[4].

The assessment of severity should also take into account the number of people who could be affected by a dangerous product. This means that the risk from a product which could pose a risk to more than one person at a time (e.g. fire or

4 As an example, for certain mechanical risks the following definitions of the severity classifications may be proposed, with typical corresponding injuries:

Slight	Serious	Very Serious
<2% incapacity usually reversible and not requiring hospital treatment.	2 – 15% incapacity usually irreversible requiring hospital treatment	>15% incapacity usually irreversible
Minor cuts	Serious cuts	Serious injury to internal organs
	Fractures	Loss of limbs
	Loss of finger or toe	Loss of sight
	Damage to sight	Loss of hearing
	Damage to hearing	

gas poisoning from a gas appliance) should be classified as more severe than a hazard which can only affect one person.

The initial risk estimation should refer to the risk to any person exposed to the product and should not be influenced by the size of the population at risk. However, it may be legitimate for the companies to take account of the total number of people exposed to a product in deciding on the type of action to be taken.

For many hazards it is possible to envisage unlikely circumstances that could lead to very serious injury, e.g. tripping over a cable, falling and banging one's head, leading to death, although a less serious outcome is more likely. The assessment of the severity of the hazard should be based on reasonable evidence that the effects selected for characterizing the hazard could occur during foreseeable use. This could be the worst-case experience involving similar products.

Overall Probability

This refers to the probability of negative health/safety effects to a person exposed to the hazard. It does not take into account the total number of people at risk. Where the guide refers to the probability of a product being defective, this should not be applied if it is possible to identify each one of the defective samples. In this situation, the users of the defective products are exposed to the full risk and the users of the other products to no risk.

The overall probability is the combination of all the contributing probabilities such as:

- the probability of the product being or becoming defective (if all products carry the defect then this probability would be 100%);

- the probability of the negative effect materialising for a normal user who has an exposure corresponding to the intended or reasonably expected use of the defective product.

These two probabilities are combined in the following table to give an overall probability, which is entered into Table A.

Overall Probability of Health/Safety Damage		Probability of hazardous product		
		1%	10%	100% (All)
Probability of health/safety damage from regular exposure to hazardous product	Hazard is always present and health/safety damage is likely to occur in foreseeable use	Medium	High	Very High
	Hazard may occur under one improbable or two possible conditions	Low	Medium	High
	Hazard only occurs if several improbable conditions are met	Very Low	Low	Medium

Combining the severity and overall probability in Table A gives an estimation of the gravity of the risk. The accuracy of this assessment will depend upon the quality of the information available to the company. However, this assessment needs to be modified to take account of society's perception of the acceptability of the risk.

Society accepts much higher risks in some circumstances such as motoring, than in others, such as children's toys. Table B is used to input this factor.

Table B – Grading of Risk: type of person, knowledge of the risk and precautions

Society accepts higher risks in some circumstances than in others. It is considered that the main factors affecting the level of risk are the vulnerability of the type of person affected and for non-vulnerable adults, the knowledge of the risk and the possibility of taking precautions against it.

Vulnerable people

The type of person using a product should be taken into account. If the product is likely to be used by vulnerable people, the level of risk which should be notified should be set at a lower level. Two categories of vulnerable people are proposed below, with examples:

Very vulnerable	Vulnerable
Blind	Partially sighted
Severely Disabled	Partially disabled
Very old	Elderly
Very young (<3 years)	Young (3-11 years)

Normal adults

The adjustment of the seriousness of risk for non-vulnerable adults should only apply if the hazard is obvious and necessary for the function of the product. For non-vulnerable adults the level of risk should be dependent on whether the hazard is obvious and whether the manufacturer has taken adequate care to make the product safe and to provide safeguards and warnings, especially if the hazard is not obvious. For example, if a product has adequate warnings and safeguards and the hazard is obvious, a high gravity of outcome may not be serious in terms of grading the risk (Table B), although some action may be needed to improve the safety of the product. Conversely, if the product does not have adequate safeguards and warnings, and the hazard is not obvious, a moderate gravity of outcome is serious in terms of grading the risk (Table B).

Risk Assessment of consumer products for the GPSD

This procedure is proposed to assist companies when deciding whether a specific hazardous situation caused by a consumer product requires notification to the authorities

Table A - Risk Estimation

Probability of Health/Safety Damage	Severity of Health/Safety Damage: Slight	Serious	Very Serious	Overall Gravity of Outcome
		Very High	High	Very High
Very High		High	Medium	High
High		Medium	Low	Moderate
Medium		Low	Very Low	Low
Low		Very Low		Very low

Table B – Grading of Risk

Vulnerable people		Non-vulnerable adults				
Very vulnerable	Vulnerable	No	Yes	No	Yes	Adequate warnings and safeguards?
		No	No	Yes	Yes	Obvious hazard?

SERIOUS RISK – Notification required

Moderate risk – Notification required

Low risk Notification unlikely

Table A is used to determine the gravity of the outcome of a hazard, depending on the severity and probability of the possible health/safety damage (see tables in notes)

Table B is used to determine the rating of the gravity of risk depending on the type of user and, for non-vulnerable adults, whether the product has adequate warnings and safeguards and whether the hazard is sufficiently obvious

<u>**Example**</u> **(Indicated by the arrows above)**
A chain saw user has suffered a badly cut hand and it is found that the chain saw has an inadequately designed guard which allowed the user's hand to slip forward and touch the chain. The company's assessor makes the following risk assessment.

Table A - The assessment of probability is High because the hazard is present on all products and may occur under certain conditions. The assessment of severity is **Serious** so the overall gravity rating is **High.**

Table B – The chain saw is for use by non-vulnerable adults, presents an obvious hazard but with inadequate guards.

The **High** gravity is therefore intolerable so a **serious risk** exists.

ANNEX II - NOTIFICATION FORM FOR THE NOTIFICATION OF DANGEROUS PRODUCTS TO THE AUTHORITIES BY PRODUCERS OR DISTRIBUTORS

Section 1: Details of AUTHORITY(IES)/COMPANY(IES) receiving the notification form	
Authority/Contact name/Address/Telephone/Fax/ E-mail/Website	
Identification of the companies notified and their role in the marketing of the product	
Section 2: Details of PRODUCER/DISTRIBUTOR	
Producer or Producer 's representative/Distributor completing the form	
Contact name, responsibility, Address/Telephone/Fax/Email/ Website	
Section 3: Details of PRODUCTS involved	
Category. Brand or trademark. Model name(s)or Bar code/CN Tariff. Country of origin	
Description/Photograph	
Section 4: Details of HAZARD	
Description of the hazard and possible health/safety damages and conclusions of the risk estimation and evaluation carried out	
Record of accident(s)	
Section 5: Details of corrective ACTIONS already taken	
Types/Scope/Duration of action(s) and precautions taken and identification of the company responsible	

<u>COMPANIES SHOULD COMPLETE AND SEND SECTION 6 IN CASE OF A SERIOUS RISK OR WHEN THE PRODUCER/DISTRIBUTOR OPTS TO SUBMIT THE NOTIFICATION ONLY TO THE AUTHORITY OF THE MEMBER STATE IN WHICH THEY ARE ESTABLISHED</u>

Section 6: Details of other COMPANY(IES) in the supply chain which hold affected products	
List of Manufacturers/ Importers or Authorised representatives by Member State: Name/Address/ Tel/Fax/E-mail/Website.	
List of Distributors/Retailers by Member State: Name/Address/ Tel/Fax/E-mail/Website	
Number of products (serial numbers or date codes) held by producer/importer/ distributor/retailer/consumers by Member State	

ANNEX III – ENFORCEMENT AUTHORITY CONTACT DETAILS

How to find local/home authorities:

Producers and distributors who do not already have this information can find the contact details for their local/home authority by visiting the Trading Standards Central website - http://www.tradingstandards.gov.uk/

Contact details for motor vehicle notifications:

Producers and distributors who need to make notifications concerning motor vehicle safety, or who want to discuss the possibility of doing this, should contact:

The Vehicle & Operator Services Agency
Vehicle Safety Branch
Room 101
Berkeley House
Croydon Street
Bristol
BS5 0DA

Tel: 0117 9543249
Email: Alison.martin@vosa.gsi.gov.uk

Consumer & Competition Policy Directorate
DTI
September 2005

URN 05/1457

ew parents and others who care for babies and small children need to pay special attention to fire safety.

When it comes to your family's smallest members, remember:

Love alone won't save them. Practicing fire safety will.

FEMA

U.S. Fire Administration

UNITED STATES FIRE ADMINISTRATION
16825 South Seton Avenue
Emmitsburg, MD 21727
www.usfaparents.gov

IN PARTNERSHIP WITH

American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN

NFPA

National SAFE KIDS Campaign

ZERO TO THREE

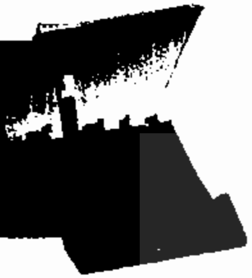
Love alone didn't save her

Practicing fire safety did.

PARENTS' GUIDE

to Fire Safety for Babies and Toddlers

My child is curious about fire. Should I be concerned? What can I do?



Yes, you should be concerned—and you can do a lot. Children do not understand the dangers of fire. In fact, children playing with matches and lighters start many of the home fires that kill children.

- ❑ Calmly but firmly explain to your child that matches and lighters are tools for adults to use carefully. Teach young children to tell an adult if they see matches or lighters.
- ❑ Always store matches and lighters out of children's reach and sight, preferably in a locked cabinet.
- ❑ Purchase only child-*resistant* lighters. Remember: no lighter is child *proof!*
- ❑ Never use lighters or matches as a source of amusement. Children may imitate what you do.
- ❑ Always supervise young children closely.
- ❑ Prevent fires by practicing and teaching fire safe behaviors in your home. Keep children 3 feet away from the stove when cooking, don't overload outlets, have your heating systems checked annually and use deep ashtrays and soak the ashes in water, if you smoke.

FACT: Matches, lighters, and other heat sources are the leading causes of fire-related deaths for children under age 5.

FACT: Two thirds of home fires that kill children occur in homes without a working smoke alarm.

How effective are smoke alarms? Should I put one near my baby's room?

When children die in home fires, it is most often in homes where there are no working smoke alarms. When fire breaks out, you have only seconds to escape its heat, black smoke and deadly gases. Working smoke alarms help you get out in time. Smoke alarms save lives.

- ❑ Put working smoke alarms on each floor of your home, outside sleeping areas, and inside bedrooms where the doors are often closed.
- ❑ If you keep the door to your infant's room closed, keep a working smoke alarm inside the room and use a baby monitor so that you can hear the alarm sound.
- ❑ As soon as you know children are ready, familiarize them with the sound of your smoke alarms. Teach them that if one goes off, they must crawl on the floor under the smoke, leave the home, and meet at a designated place outside.
- ❑ Smoke alarms must be maintained. Test the batteries in your smoke alarms monthly. Replace the batteries at least once a year.

What can we do to help make sure that our family, especially the little ones, can escape a fire safely?

A fire can engulf your home in a matter of seconds. You'll need to react quickly. Be prepared with a detailed fire escape plan. Practice it with your children, as often as you can and at least twice a year. Children who have practiced an escape plan are less likely to panic and hide and more likely to get out safely.

- ❑ Your fire escape plan begins with a basic diagram of your home. Mark all windows and doors, and plan two routes out of each room.
- ❑ Consider several fire scenarios, such as a fire starting in the kitchen, basement or bedroom.
- ❑ Figure out the best way for you to help babies and toddlers get out. How will you get to them? Carry them? You may want to keep a baby harness near the crib, to carry the baby and leave your hands free for another child. If you have older children too, have them practice crawling, touching doors, or going to the window, according to your escape plan.
- ❑ Prepare an alternate fire escape plan so that you can escape safely with young children even if one parent or guardian is away when a fire occurs.
- ❑ When practicing the fire escape plan, show children how to cover their nose and mouth to reduce smoke inhalation.
- ❑ Keep home exits clear of toys and debris.
- ❑ Have a safe meeting place outside the home and teach children never to go back inside.

2004

Number 7

AAMI

AAMI FIRESCREEN

This is the seventh annual *AAMI Firescreen Index*. It is published to raise awareness about the common locations and causes of fires in the home and the steps to take if fire breaks out.

This Index is based on an independent study into Australians' attitudes and experiences of fire in the home. A survey of 1460 adults was conducted by Sweeney Research in the following areas:

- Sydney
- Newcastle
- Coffs Harbour
- Port Macquarie
- Wagga Wagga
- Dubbo
- Batemans Bay
- Melbourne
- Ballarat, Bendigo, Shepparton
- Geelong
- Brisbane
- North Queensland
- Fraser Coast
- Central Coast
- Sunshine Coast
- Gold Coast
- Adelaide
- Hobart
- Launceston
- Canberra

This research is supported by an in-depth analysis of insurance claims lodged in 2003 by AAMI policyholders in New South Wales, Victoria, Queensland, South Australia, Tasmania and the Australian Capital Territory.

KEY FINDINGS

- **Children at risk:** one-quarter of Australians (25 per cent) say their children would not know what to do in the event of a fire in the home.
- **Fire at home:** one in five Australians (22 per cent) has experienced a fire at home.
- **Renters vulnerable:** one in two renters (48 per cent) has no home contents insurance.
- **Could be better prepared:** three-quarters of Australians (73 per cent) agree that it would probably be sensible for them to have more fire equipment in their home.
- **Hoping it won't happen:** one in seven Australians (14 per cent) has no insurance for their home.
- **Not fully covered:** one-quarter of Australians (26 per cent) say they are not insured for the full cost of replacing their home if it were destroyed by fire.
- **Danger in the kitchen:** half of all fires (51 per cent) start in the kitchen and 43 per cent of fires are cooking-related.
- **Weekends a hazard:** Almost one-third of homes fires (30 per cent) occur on a Saturday.

Children at risk

One in 20 Australians (5 per cent) has experienced a fire-related incident involving their children. The causes of fire incidents involving children were varied:

- 24 per cent were the result of children playing with matches or lighters
- 18 per cent involved oil-related or cooking fires
- 10 per cent involved families threatened by bushfires
- 7 per cent were the result of children sitting too close to an open fire
- 5 per cent resulted from careless behaviour by children
- 3 per cent involved clothing catching alight from a heater or radiator.

Fire education

Despite the dangers, one in eight parents (13 per cent) has not talked to their children (5-15 years) about the dangers of fire. This figure was highest in Tasmania, where one in six people (17 per cent) had not talked with their children about fire danger. One-quarter of Australians (25 per cent) said their children would not know what to do in the event of a fire.

TWO-THIRDS OF AUSTRALIANS BELIEVE MOST BUSHFIRES ARE DELIBERATELY LIT.

Having a fire escape plan

A home fire escape plan is an important part of educating children about home fire safety. An escape plan should identify all exits and a meeting point outside the house for all family members. By involving children in the preparation of an escape plan, parents can ensure that all members of the family will know what to do in the event of a fire that cannot be extinguished.

One-third of survey respondents (34 per cent) admitted they do not have a fire escape plan for their home. Two-thirds of people in regional areas (67 per cent) have a fire escape plan, compared with only half of metropolitan residents (52 per cent).

Experience of home fire

One in five Australians (22 per cent) had experienced a fire in their home sometime in their lives. This figure was highest in New South Wales and Victoria. One-quarter of women (25 per cent) had experienced a fire in their home compared with 18 per cent of men. Three-quarters of home fires were confined to just the area where the fire started. In six per cent of cases, the fire destroyed the entire home.

Experience of home fire

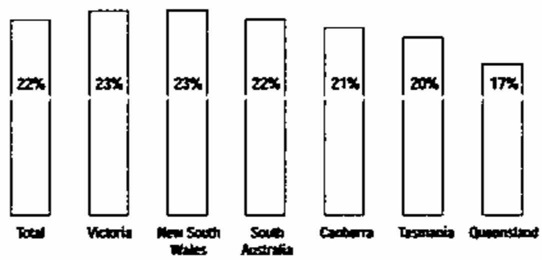
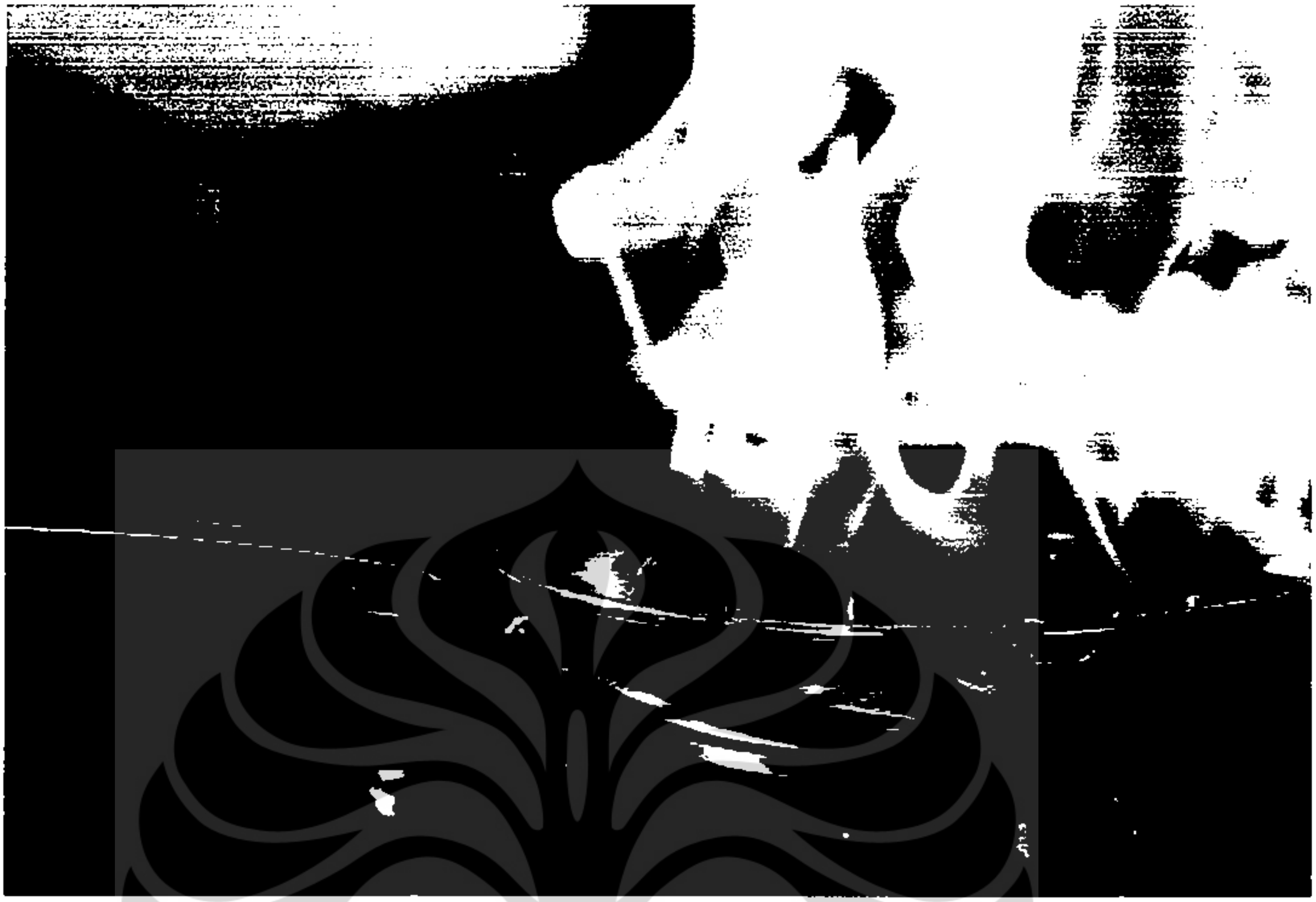


Figure 1. Percentage of people by State who have experienced a fire at home

Source: Sweeney Research survey, 2004



Arson linked with bushfire

Two-thirds of Australians believe most bushfires are deliberately lit. This figure was particularly high among New South Wales respondents, of which 78 per cent believed bushfires were mostly caused by arson.

Saturday evening: danger time

In more than half of all home fire insurance claims lodged with AAMI, the claimants did not know when the fire had started in their home. Of those claims that did have an approximate start time, almost one in four (37 per cent) started in the early evening between 4 pm and 8 pm. The riskiest day of the week for fire was Saturday, on which almost one-third of all fires (30 per cent) started.

Cooking the biggest cause of fire

Cooking remains the single biggest cause of fire in the home: half of all fires (51 per cent) began in the kitchen. Faulty electrical appliances were the second major cause, while bushfires accounted for six per cent of all home fires nationally.

ONE-THIRD OF RESPONDENTS ADMITTED THEY DO NOT HAVE A FIRE ESCAPE PLAN.

Fire safety equipment

Ownership of fire safety equipment is at its highest since 2001: nine in 10 Australians (90 per cent) now have some kind of fire equipment in their home. However, three-quarters of Australians (73 per cent) agree that it would probably be sensible for them to have more fire safety equipment.

Eighty-six per cent of people have smoke alarms installed and 87 per cent of them said their alarms are checked regularly to ensure they are working. One survey response highlighted the life-saving potential of correctly functioning smoke

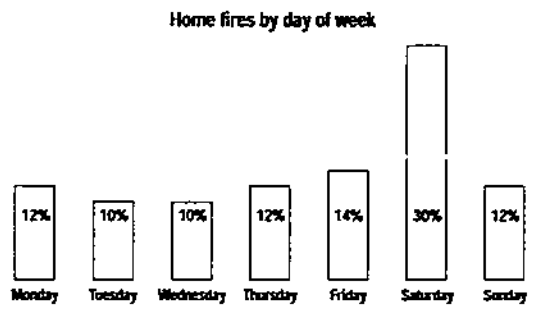


Figure 2. Percentage of home fires started on each day

Source: AAMI claims data, 2003

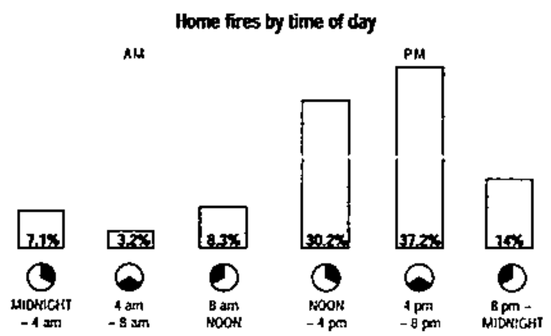


Figure 3. Percentage of fires started by time of day

Source: AAMI claims data, 2003

alarms when a home fire broke out. "We were all very lucky to get out. It was the smoke alarm that saved us that night."

Smoke alarm ownership is highest in Victoria, where 97 per cent of homes had at least one, and lowest in New South Wales where just 79 per cent of homes had at least one installed. Smoke alarms, fire extinguishers and fire blankets were more common among homeowners and people who live in newer homes (up to 10 years old).

Fire prevention a low priority

Planning for a fire event remains low on the agendas of many Australians. Almost half of those surveyed (47 per cent) admitted they did not leave their keys in deadlocked doors to make escape easier in case of a fire.

One-sixth (16 per cent) does not regularly clean their roof gutters, in order to protect against build-up of debris. Still, most people (85 per cent) were confident they would know the best response to a fire that started in their home.

People who live in bushfire-prone areas vulnerable

Around one in seven people (15 per cent) believed they live in a bushfire-prone area. This figure was highest among Canberra residents, of which 31 per cent said they live in a bushfire-prone area. An overwhelming 95 per cent of people agreed that bushfire was a serious concern for people living in regional and rural Australia.

According to AAMI's claims data, less than 22 per cent of all fires nationally were attributed to bushfire during 2003, yet bushfire damage accounted for more than half of the claims costs (54 per cent) associated with fires in the home.

Hoping it won't happen

Despite the risks, many people remain uninsured for home fires. Surprisingly, people who live in bushfire-prone areas, or those who had already experienced a fire, were no more likely to be fully insured than the rest of the population. Fourteen per cent of people in bushfire-prone areas were completely uninsured compared with 15 per cent of people living in non-bushfire-prone areas.

Of those who *were* insured, one-quarter (26 per cent) was consciously underinsured for their home building and one-third (31 per cent) were underinsured for their contents. The most common reasons for being underinsured were, 'Haven't got around to updating' (22 per cent for building insurance and 14 per cent for contents); 'House prices keep going up' (21 per cent); and 'Too expensive' (19 per cent for building insurance and 21 per cent for contents).

Renters more likely to be uninsured

People who live in rental properties were far less likely to be insured for their belongings than people who owned their home or had a mortgage. Nine in 10 homeowners (93 per cent) said they had home contents cover, while only half of renters (52 per cent) said they were covered.

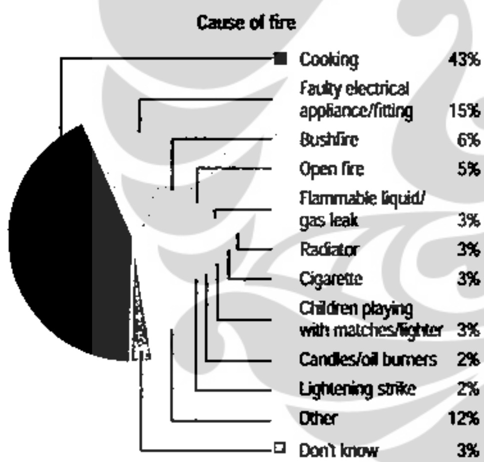


Figure 4. How fires were started in the home

Source: Sweeney Research survey, 2004

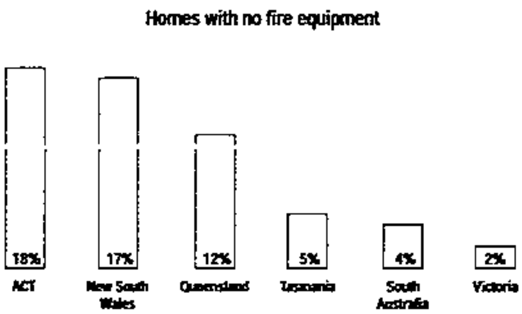


Figure 5. Percentage of homes that have no fire equipment by State

Source: Sweeney Research survey, 2004

STAY ALERT: A MOMENT'S DISTRACTION CAN LEAD TO A FIRE EMERGENCY

Dave Nicholson, Assistant Chief Fire Officer and Director of Community Safety, Metropolitan Fire Brigade, Melbourne

Statistics demonstrate that in a staggering nine out of 10 home fires, the occupants were at home when the fire started. Many fires in the home are linked to the use of stoves, heaters and candles, and these fires are often caused by a moment's distraction, when householders have been called away to tend to children, answer phones or hang out the washing.

When stoves, heaters and other sources of ignition are left unattended, the unexpected happens. By the time you return from the distraction, you are faced with a real-life emergency requiring immediate life-saving actions to protect yourself, your family and your home.

Last year's statistics also revealed a 16 per cent increase in home fires during winter in Victoria compared to summer. As we head into these cooler months, it is important that we keep reinforcing the messages to never leave cooking unattended, to keep clothes and other combustibles at least one metre from heaters, and to emphasise the safe use of naked flames, including candles, incense and oil burners. Candles should never be used near combustible materials like curtains or bed linen, and people are advised to always follow the manufacturer's instructions when using oil burners.

Most house fires occur in the kitchen, followed by bedrooms and then lounge rooms. Not only do residents need to be extremely careful to prevent fire, they need to be prepared in case fire breaks out.

The installation of a fire blanket or fire extinguisher is highly recommended, but more importantly, people should be prepared to use them effectively by reading the instructions or seeking advice from their local fire service. A home escape plan needs to be developed and practised by the entire family.

On the issues of safety and security, we advise householders to strike an even balance between the two. The current practices employed by householders of using deadlocks, window-shutters and external grills to provide a more secure environment for their family may pose a threat to their safety in the event of a fire. These devices limit the occupants' means of escape and also limit entry by emergency personnel to effect rescues. People should ensure that windows and security grills can be easily opened from the inside. If installing deadlocks, choose brands that meet Australian Standards, or deadlocks that can be opened without keys.

We urge all householders to check their smoke alarms are working, and to prepare themselves for the winter fire season.

JUVENILE FIRE AWARENESS AND INTERVENTION PROGRAMS AROUND AUSTRALIA

What are juvenile fire programs?

Juvenile Fire Awareness and Intervention Programs are designed to help families solve the problem of children lighting fires deliberately. Approximately 12 per cent of all fires attended by the Melbourne Fire and Emergency Services Board are caused by children.

The aim of these programs is to reduce the number of deaths, injuries and millions of dollars of property damage caused by fire-play and fire-setting.

What is involved?

The content and approaches in the program(s) vary according to the age and maturity of the child.

The child is visited at home by the practitioner over a number of weeks. In partnership, the practitioner, child and parents develop an awareness of fire safety issues in the home.

Through the use of role plays, discussions and enjoyable activities, the practitioner develops within the child a greater respect for fire and awareness of its consequences. Participants are referred to the programs from concerned parents, fire personnel, doctors, child welfare agencies, juvenile justice, community policing, Children's Hospital Accident Prevention Centres and other family welfare sources.

What do the statistics show?

Since the inception of the program in 1986 in Victoria, the Melbourne Metropolitan Fire Brigade has been able to draw a profile of the juvenile fire lighter.

- 84 per cent of participants are male
- 80 per cent of the fires involve inappropriate use of cigarette lighters
- 78 per cent are from single parent families
- 59 per cent have a smoker in the family
- 21 per cent are believed to have Attention Deficit Disorder or some level of hyperactivity
- The average age of fire lighters is 8.4 years of age
- The average age when the child first showed interest in fire is 4 years of age.

South Australia Juvenile Fire Lighters Intervention Program: (08) 8204 3611

Tasmania Juvenile Fire Lighters Intervention Program: 1800 000 699

Queensland Fight Fire Fascination Program: (07)3247 8366

New South Wales Child Fire Fascination: 1800 600 700

Victoria Juvenile Fire Awareness and Intervention Program: (03) 9662 2311

Reasons	Approx.	Age Association
Curiosity/fascination	3–16 years	Attraction to the colour, light and energy release by flames
Attention-seeking	6–12 years	A change in the family situation, e.g. parental separation, new baby, learning or social difficulties
Peer pressure	10–14 years	Learning difficulties or low self-esteem
Anger/revenge	8–14 years	Difficulty relating to peers, or experiencing family problems
Malicious mischief	13–16 years	Family and social difficulties

Tips to reduce fire risks with children:

1. **Keep lighters, matches and candles out of reach of children**

   Even child-safe lighters can be dangerous in the hands of children. Whether inside the home or outdoors, matches and lighters can cause injuries to children or start fires. One response to the *AAMI Firescreen* survey highlighted the danger of children playing with matches when their child was, "playing with fire in bedroom and set alight a shoe box."

2. **Never dry clothing or bedding directly in front of heaters or open fires**

   Even damp clothing can heat up quickly if left too close to a heater or open fire. Some fabrics are more combustible than others and should never be left unattended beside a heat source.

3. **Don't allow children to stand or sleep too close to heaters or fires**

   A sleeping child may move and cause their bedding or clothing to come into contact with a fire or heater if they are sleeping close by. Heat can cause fabric to combust even without contact, so it is important to ensure a safe distance. One person interviewed had experienced this when their, "child was sleeping in front of the radiator with a doona."

4. **Install guards around fires and heaters**

   Allowing open access to fires can be dangerous for a number of reasons. Not only can children hurt themselves when guards are absent, as experienced by one person whose "child fell into the fire place and burnt his arm", but coals can fall out onto carpet, rugs or other flammable material and start a fire.

5. **Closely supervise children in the kitchen**

   Cooking is the number one cause of home fires. Never leave children alone in the kitchen while they are cooking, as they can be easily distracted and hot oils and tea-towels can easily catch alight. One response highlighted the dangers of children in the kitchen: "I was at work, and one of my older children was cooking dinner, then the phone rang, therefore distracting the child, causing the cooking to burn and causing a fire."

6. **Ensure children know what to do in case of a fire**

   Teach your children about fire safety in the home. Ensure they know what your fire escape plan is and what to do if a fire starts and you are not in the room. Also, ensure they know how to call the fire brigade and program the telephone number into your home phone and your mobile.

General tips for fire safety:

1. Don't leave cooking unattended in the kitchen: hot oils can catch alight in minutes.
2. Don't use volatile liquids to start fires or BBQs: using highly flammable liquids can lead to fires that spread quickly and are difficult to extinguish.
3. Install and regularly check smoke alarms: once you have alarms in every room of your home, ensure you maintain them.
4. Don't overload power points.
5. Be aware of fire restrictions: know when you can use BBQs and open fires safely and when you cannot.
6. Clean roof gutters regularly: in case of bushfire, or if a neighbouring home catches alight, you can reduce the risk of your home being affected.

Cover photograph by Derek Brown. All other photographs courtesy of the Metropolitan Fire Brigade, Melbourne

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Towards a realistic biomechanical model of the thumb: the choice of kinematic description may be more critical than the solution method or the variability/uncertainty of musculoskeletal parameters

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Abstract

A biomechanical model of the thumb can help researchers and clinicians understand the clinical problem of how anatomical variability contributes to the variability of outcomes of surgeries to restore thumb function. We lack a realistic biomechanical model of the thumb because of the variability/uncertainty of musculoskeletal parameters, the multiple proposed kinematic descriptions and methods to solve the muscle redundancy problem, and the paucity of data to validate the model with in vivo coordination patterns and force output. We performed a multi-stage validation of a biomechanical computer model against our measurements of maximal static thumbtip force and fine-wire electromyograms (EMG) from 8 thumb muscles in each of five orthogonal directions in key and opposition pinch postures. A low-friction point-contact at the thumbtip ensured that subjects did not produce thumbtip torques during force production. The 3-D, 8-muscle biomechanical thumb model uses a 5-axis kinematic description with orthogonal and intersecting axes of rotation at the carpometacarpal and metacarpophalangeal joints. We represented the 50 musculoskeletal parameters of the model as stochastic variables based on experimental data, and ran Monte Carlo simulations in the "inverse" and "forward" directions for 5000 random instantiations of the model. Two inverse simulations (predicting the distribution of maximal static thumbtip forces and the muscle activations that maximized force) showed that: the model reproduces at most 50% of the 80 EMG distributions recorded (eight muscle excitations in 5 force directions in two postures); and well-directed thumbtip forces of adequate magnitude are predicted only if accompanied by unrealistically large thumbtip torques (0.64 ± 0.28 N m). The forward simulation (which fed the experimental distributions of EMG through random instantiations of the model) resulted in misdirected thumbtip force vectors (within $74.3 \pm 24.5°$ from the desired direction) accompanied by doubly large thumbtip torques (1.32 ± 0.95 N m). Taken together, our results suggest that the variability and uncertainty of musculoskeletal parameters and the choice of solution method are not the likely reason for the unrealistic predictions obtained. Rather, the kinematic description of the thumb we used is not representative of the transformation of net joint torques into thumbtip forces/torques in the human thumb. Future efforts should focus on validating alternative kinematic descriptions of the thumb.

Keywords: Hand; Thumb; Muscle coordination; EMG; Biochemical model; Monte Carlo simulation

Abbreviations: ADD, adductor pollicis muscle; APB, abductor pollicis brevis muscle; APL, abductor pollicis longus muscle; CMC, carpometacarpal; DIO, first dorsal interosseous muscle; EMG, electromyographic recordings; EPB, extensor pollicis brevis muscle; EPL, extensor pollicis longus muscle; FPB, flexor pollicis brevis muscle; FPL, flexor pollicis longus muscle; IP, interphalangeal; LP, linear programming; MP, metacarpophalangeal; OPP, opponens pollicis muscle; SD, standard deviation; PIP, proximal interphalangeal joint; DIP, distal interphalangeal joint; PCSA, physiological cross-sectional area.

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URLs: http://www.mae.cornell.edu/valero.

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1. Introduction

Impairment of the thumb can severely diminish pinch function and manipulation ability. Surgeries that restore thumb function for pinch grasps should have consistent and predictable outcomes despite anatomical variations across individuals. In practice, improvements in pinch force magnitude and pinch ability vary following surgical treatment of orthopedic (Glickel et al., 1992; Tomaino et al., 1995; Freedman et al., 2000) and neurological (Ramselaar, 1970; McFarlane, 1987; Brandsma and Ottenhoff-De Jonge, 1992; Hentz et al., 1992) conditions of the thumb. Understanding the source of outcome variability can improve the treatment of pinch force deficits.

It is difficult to understand the sources of outcome variability due to the complex mechanics and muscle coordination of the thumb, and anatomical variability. One way to address this clinical question is to create biomechanical computer models to predict how musculoskeletal and kinematic variables affect thumb function. Unfortunately, today there is no validated and realistic model of the thumb that predicts even simple mechanical output, such as maximal static force and the muscle coordination that achieves it. We believe the validity of biomechanical computer models of the thumb remains questionable for four reasons. First, the choice of kinematic description of the thumb remains debatable (Cooney and Chao, 1977; Chao and An, 1978; Giurintano et al., 1995). Second, the predictions of biomechanical models can be sensitive to both the musculoskeletal parameter values (Valero-Cuevas et al., 1998) and the choice of mathematical solution method. Third, there is much uncertainty in published musculoskeletal parameter values for the thumb (e.g., coefficients of variance >40% are common (Smutz et al., 1998)). And fourth, to our knowledge no biomechanical thumb model has been validated by comparing predictions of both mechanical output and muscle coordination patterns to experimental measurements (i.e., inverse *and* forward validation).

Creating realistic biomechanical models of the thumb requires that we understand the consequences of the choice of musculoskeletal parameters. Three of the four reasons above are associated with the challenge of measuring and assigning musculoskeletal parameters compatible with the kinematic description adopted and representative of the individuals modeled. Most biomechanical models of the digits (Chao et al., 1976; Cooney and Chao, 1977; An et al., 1979, 1985) and the thumb (Cooney and Chao, 1977; Chao and An, 1978; Giurintano et al., 1995) assign average experimental values to each parameter. This approach does not address the potential effects of intersubject variability, which could be a critical factor in predicting surgical outcomes. To explore the biological question of whether including intersubject variability suffices to realistically predict maximal thumbtip forces and their associated coordination patterns, we investigated which factor is most critical (to represent well) in developing a biomechanical model of the thumb: kinematic description, musculoskeletal and kinematic parameters, or solution method. Our results clarify whether future efforts to create realistic models should focus on obtaining more reliable values for musculoskeletal parameters vs. improving kinematic descriptions or solution methods.

2. Methods

We measured thumbtip forces and recorded electromyograms (EMG) from individual thumb muscles with methods reported for the forefinger (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000) and thumb (Johanson et al., 2001). Briefly, seven participants (5 female, 2 male, 28.6±6.5 yr) produced maximal voluntary thumbtip force against a smooth, rigidly held 6-axis dynamometer with the distal phalanx of their right-dominant thumb in five orthogonal directions (palmar, distal, lateral, dorsal and medial) defined with respect to the distal phalanx in two thumb postures (key and opposition, Fig. 1). Key posture (Fig. 1 and Table 1) was defined as the thumbtip touching the radial aspect of the forefinger between the DIP and the PIP joints corresponding to the recommended posture for surgical arthrodesis (House, 1985; Hentz et al., 1992). Opposition posture (Fig. 1 and Table 1) is defined with the tip of the thumb in contact with the tip of the forefinger with the joints of the thumb and forefinger in enough flexion and abduction so the two digits formed a ring. These postures placed all joints away from their extremes of range of motion. A custom molded thimble fit snuggly over the distal phalanx and had five 5-mm spherical brass beads embedded on its outer surface in locations corresponding to each force direction. Each bead defined a low-friction point-contact between a polished aluminum plate and the thumbtip requiring participants to produce well-directed force (i.e., within 16° of the perpendicular to the surface) with negligible thumbtip torque, or else the bead would slip and/or rotate (Valero-Cuevas et al., 1998), because a low-friction point-contact cannot transmit torque because of its tendency to slip and roll (Murray et al., 1994). We instructed participants to produce maximal voluntary thumbtip force in three 10-s trials by either ramping to maximal force (ramp trial) or by increasing force in two steps (step trial) (Fig. 2). Visual and auditory feedback motivated the participants to produce their maximal voluntary thumbtip force in each posture. A computer screen displayed either their maximal or their maximal and 50% maximal force output in a stair-step pattern.

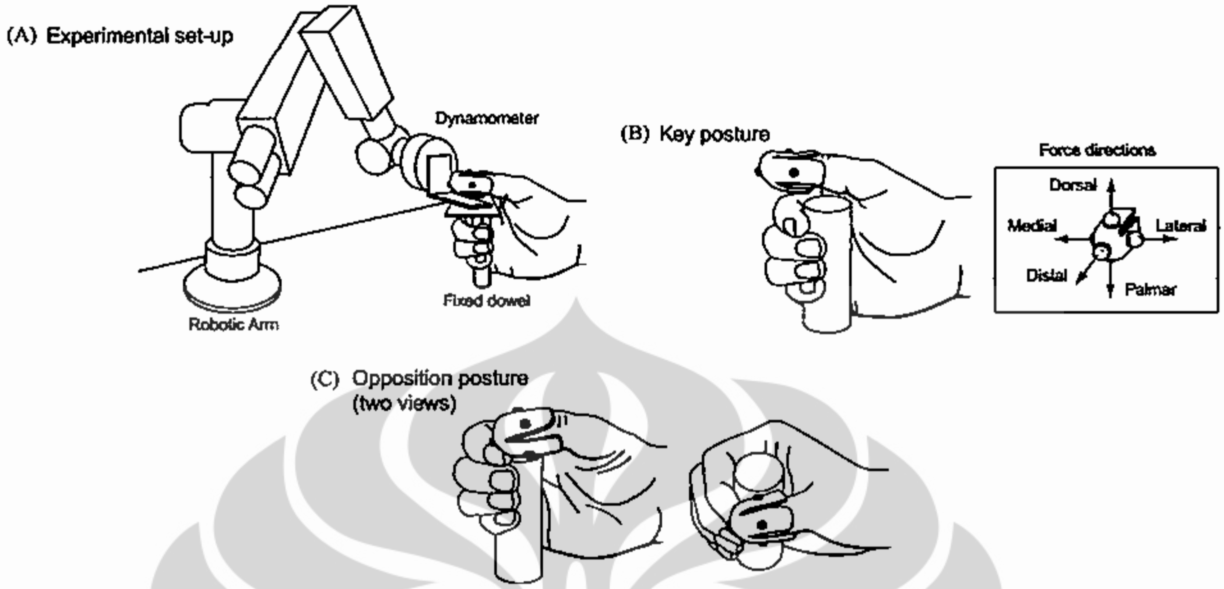

Fig. 1. We used a methodology developed to study forefinger force production (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000), which was recently adapted to study thumb force production (Johanson et al., 2001). (A) Participants were seated with their right dominant arm supported by a trough in elbow flexion and neutral forearm rotation, and wrapped their fingers around a fixed dowel similar to a joystick which placed the wrist in 45° extension, and 0° of ulnar deviation, prevented thumb–forefinger contact and isolated thumb force production. We instructed the participants to maximize isometric thumbtip forces against a dynamometer (6-axis force/torque sensor, Gamma F/T transducer, ATI Industrial Automation, Gardner, NC) mounted on a robotic arm (Stäubli-Unimate Puma 260 programmable robot, Stäubli Corporation, Duncan, SC). The position and orientation of the force plate was pre-programmed for each participant. A computer (PowerMacintosh 7200, Apple Computer, Inc., Cupertino, CA) with data acquisition hardware/software (NB-MIO-16 card and LabView, National Instruments, Austin, TX) collected and stored force data as well as EMG signals processed by BAK model MDA-3 amplifiers. The positioning of the dynamometer was programmed to oppose the thumb in reproducible thumb postures used in key and opposition pinch. Participants wore custom thimbles made of thermoplastic splinting material (MaxD, North Coast Medical, Inc.) with 5 mm brass balls that defined the directions of force production. The few (<5%) cases in which the thimble slipped or rotated were repeated. One-minute rest between trials prevented fatigue (Enoka and Stuart, 1992). Participants had no history of neurological or musculoskeletal hand pathologies or injuries, and read, understood and signed a consent form approved by the Medical Committee for Protection of Human Participants in Research at Stanford University prior to participation. (B) Key posture is defined as the thumbtip touching the radial aspect of the forefinger between the DIP and the PIP joints (Table 1), with the thumb MP and IP joints in moderate flexion, and the CMC joint extended 30° (so that the first metacarpal was extended with respect to the long axis of the radius in the plane of the palm) and aligned with the long axis of the radius in the plane transverse to the palm (neutral abduction) corresponding to the recommended posture for surgical arthrodesis (House, 1985; Hentz et al., 1992). (C) Opposition posture is defined with the tip of the thumb in contact with the tip of the forefinger (requiring pronation of the metacarpal to align the nail-beds) with the joints of the thumb and forefinger in enough flexion and abduction so the two digits formed a ring (Table 1).

Preliminary trials provided the initial targets. For the step force pattern, participants targeted their 50% maximal level, then proceeded to maximal force, and reduced the force to repeat the 50% level of force. For the ramp force pattern, participants increased force monotonically at their chosen speed. We included ramp trials because some subjects could reach higher forces when increasing force at self-selected speed. We randomized the order of thumb postures and force directions within each posture. We simultaneously recorded thumbtip force and EMG using fine-wire electrodes placed in all nine muscles of the thumb (see Fig. 2 for details; Johanson et al., 2001). We excluded the DIO muscle from EMG recordings and the model because others (Brand and Hollister, 1999; Kaufman et al., 1999) and we (Johanson et al., 2001) could only record activity from DIO when both the thumb and forefinger were used to pinch. The DIO was inactive when producing thumb force while relaxing the forefinger. The participants performed three trials: two ramp and one step force pattern. The third trial was always designated as a ramp and the order of the first two trials were randomized for step or ramp. A fourth ramp trial was done without the thimble to insure maximal EMG was recorded without the precariousness of the point-contact for each direction/posture. This additional ramp trial was used only for EMG normalization purposes, and was not used in the force or coordination pattern analysis.

Consistent with biomechanical models of static force production, thumbtip force/torque at a given thumb posture was expressed as a system of linear equations in the activation level of each muscle (Chao and An, 1978; Valero-Cuevas et al., 1998). The model consists of a

Table 1
Musculoskeletal parameters

	Key pinch			Opposition pinch	
	Tendon/Joint	Mean	SD	Mean	SD
Moment arms (mm) (Smutz et al., 1998)					
CMC flexion	FPB	13.50	7.56	12.50	8.50
(flexion +)	ADD	32.00	10.56	26.00	8.50
(extension −)	APB	3.93	3.10	4.20	3.40
	OPP	12.90	3.87	12.80	4.90
	FPL	14.30	4.00	13.60	2.80
	EPB	−13.00	2.47	−14.40	2.20
	EPL	−8.07	2.58	−9.89	3.60
	APL	−7.17	3.44	−7.92	3.00
CMC abduction	FPB	10.50	6.83	6.40	4.90
(abduction +)	ADD	−18.80	15.42	−22.40	13.90
(adduction −)	APB	16.50	6.93	13.20	7.50
	OPP	4.80	4.99	−1.50	4.50
	FPL	0.20	4.90	0.10	2.80
	EPB	3.20	6.69	4.50	2.30
	EPL	−9.50	7.13	−5.70	4.40
	APL	10.50	3.26	7.30	2.70
MP flexion	FPB	5.30	1.59	5.30	1.59
(flexion +)	ADD	4.90	4.12	4.90	4.12
(extension −)	APB	0.70	2.90	0.70	2.90
	FPL	10.90	1.74	10.90	1.74
	EPB	−8.60	0.69	−8.60	0.69
	EPL	−9.30	1.12	−9.30	1.12
MP abduction	FPB	8.70	3.31	7.20	3.30
(abduction +)	ADD	−5.00	4.90	−5.45	5.50
(adduction −)	APB	11.10	4.44	10.00	4.10
	FPL	−0.10	2.40	−1.20	2.10
	EPB	1.40	0.90	1.30	0.90
	EPL	−4.40	1.80	−4.50	1.70
IP flexion	FPL	8.00	1.52	6.60	1.60
(flexion +)	EPL	−5.20	0.52	−4.40	0.40
(extension −)					
Extensor mechanism angles (deg)					
α, projection angle of tendon of ADP's oblique head onto EPL tendon	35.00				
γ, projection angle of tendon of ABPB's medial slip onto EPL tendon	30.00				
θ, medial bifurcation angle of APB	15.00				
β, lateral bifurcation angle of APB	25.00				
PCSA (cm^2) (Lieber et al., 1992; Jacobson et al., 1992; Brand et al., 1981)					
	FPB	0.66	0.20	0.66	0.20
	ADD	4.00	0.80	4.00	0.80
	APB	0.68	0.58	0.68	0.58
	OPP	1.02	0.35	1.02	0.35
	FPL	2.08	0.23	2.08	0.23
	EPB	0.47	0.32	0.47	0.32
	EPL	0.98	0.13	0.98	0.13
	APL	1.93	0.60	1.93	0.60
Bone segment lengths (cm) (measured in participants)					
	Metacarpal	5.29	0.90		
	Prox. phalanx	4.03	0.62		
	Dist. phalanx	3.07	0.31		

Table 1 (*continued*)

	Key pinch			Opposition pinch	
	Tendon/Joint	Mean	SD	Mean	SD
Joint angles (deg) (measured in participants)					
	CMC flexion	−30.00	8.50	−24.00	12.70
	CMC abduction	0.00	0.00	19.00	8.20
	MP flexion	17.00	10.40	24.00	12.90
	MP abduction	0.00	0.00	6.00	2.80
	IP flexion	23.00	11.70	51.00	14.00

Note on model implementation: As was previously described (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000), the isometric force production of each muscle was modeled by scaling its maximal force fo_i by its excitation level e_i ($0 \leqslant e_i \leqslant 1$). Fo_i is calculated by multiplying PCSAs times maximal muscle stress (35.4 N/cm^2; Close, 1972; Brand et al., 1981; Powell et al., 1984; Zajac, 1989). We assumed muscles were at optimal fiber length due to lack of published values, with pennation angles (Jacobson et al., 1992; Lieber et al., 1992; Brand and Hollister, 1999) small enough not to affect Fo_i (i.e., $<10°$; Zajac, 1989). The parameter-based computer model is a matrix equation where a 5×8 matrix embodies the static force production properties of the digit. This matrix includes the nominal Fo_i values (to scale the excitation level of each muscle into muscle force), the moment arm and extensor mechanism values (to calculate the net torque at all joints), and the inverse transpose Jacobian matrix of the three-segment/5-DOF thumb (calculates the thumbtip output produced any net joint torque vector). For each thumb posture, this matrix is a constant non-invertible matrix representing an under constrained system where several coordination patterns can produce a given sub maximal thumbtip force. The linear programming optimization predicted the unique coordination pattern that produces the maximal biomechanically feasible magnitude of thumbtip force in each direction in each posture.

fixed trapezium, a metacarpal and two phalanges articulated by five pin joints (Fig. 3) actuated by eight independent muscles, plus an extensor mechanism at the MP joint (Fig. 4). The CMC and MP joints have orthogonal and intersecting axes of rotation. The static fingertip force production properties of the thumb are represented by a 5×8 matrix **M**. **M** maps a rank-8 input vector of muscle activation into a rank-5 output vector containing three forces and two torque components. If rigidly coupled to an object, the distal phalanx can impart torques independently of fingertip forces because it has five DOFs (Valero-Cuevas et al., 1998). **M** is the concatenation of three matrices ($\mathbf{M} = \mathbf{J}^{-\mathrm{T}}\mathbf{R}\mathbf{F}_0$; Valero-Cuevas et al., 1998; Valero-Cuevas, 2000): the 8×8 $\mathbf{F}_0$ diagonal matrix of maximal muscle force values, which scales the excitation level of each muscle into muscle force; the 5×8 **R** moment arm and extensor mechanism interaction matrix, which superimposes the joint torque vector produced by each muscle force to obtain the net joint torque vector; and the 5×5 $\mathbf{J}^{-\mathrm{T}}$ inverse transpose Jacobian matrix corresponding to the chosen kinematic description, which calculates the output force/torque vector produced by the net joint torque vector. The 50 musculoskeletal parameters of the model (Table 1) were either measured by us: in the study participants (3 bone segment lengths and 5 joint angles for key and opposition posture); or in one cadaver thumb (4 angles of the extensor mechanism), or obtained from cadaveric studies: 8 PCSA (Jacobson et al., 1992; Lieber et al., 1992; Brand and Hollister, 1999); and 30 moment arms measured assuming the same kinematic description as our model (Smutz et al., 1998). We measured bone lengths as the distance between the palpable grooves between bones (e.g., metacarpal length was the distance between the CMC and MP grooves). Flexion-extension joint angles were defined between the longitudinal axes of bones, as typically done in the clinic. Total thumb abduction in opposition posture was the angle between the first and second metacarpal bones. This angle was apportioned to the CMC and MP in the ratio of 3:1, consistent with the notion that most thumb abduction occurs at the CMC than at the MP joint (Smutz et al., 1998). All 50 musculoskeletal parameters were described as uniformly distributed pseudo-random variables in a Mathematica® computational package (Wolfram Research, Inc., Champaign, IL) using a G3 Powerbook computer (Apple Computer, Inc., Cupertino, CA) with the bounds set to their mean value ± 1 standard deviation (SD) (Table 1). In no case were these parameter ranges anatomically unrealistic.

We performed three Monte Carlo simulations to predict the distribution of maximal thumbtip forces in the five directions studied in each thumb posture. Each simulation consisted of 5000 iterations (i.e., random instantiations) of the model in each thumb posture. The first two simulations used linear programming (LP) to solve the "inverse" (or muscle redundancy) problem of finding the unique optimal coordination pattern that maximized thumbtip force within 10° of the desired directions for each model instantiation. The objective was to maximize the force vector component in the desired direction while constraining muscle activations to be $\geqslant 0$ and $\leqslant 1$ (see caption to Table 1) (Valero-Cuevas et al., 1998). The directional accuracy constraint was achieved iteratively by progressively adjusting the linear constraints on the components of force perpendicular to the desired direction until their magnitudes were at or below 17% of the magnitude of the component

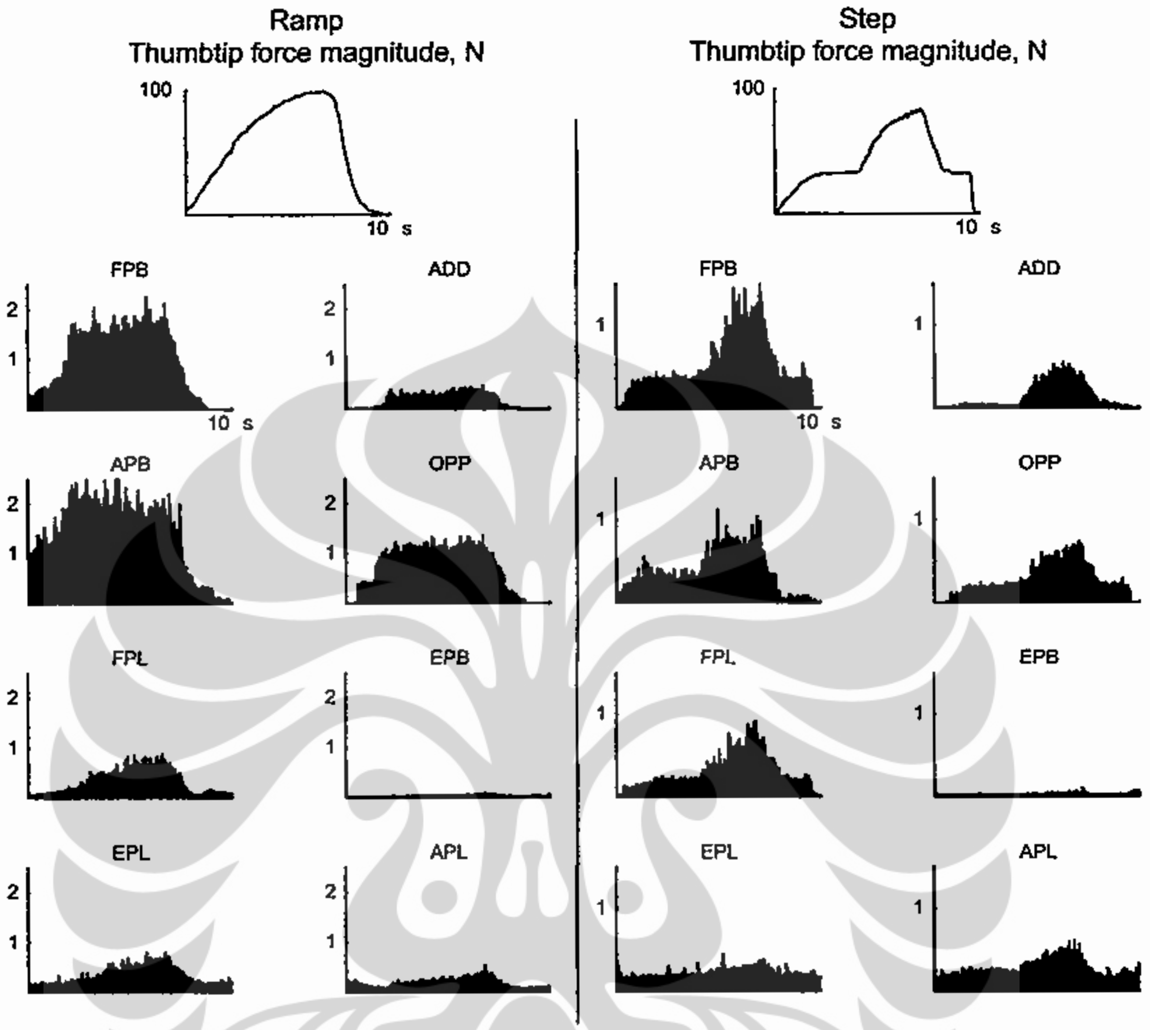

Fig. 2. Representative samples of simultaneous force and EMG recordings for force production in the distal direction in opposition posture for one subject. Participants were instructed to maximize force by ramping to maximal force (ramp trial) and by increasing force in two steps (step trial). In the ramp trials, participants simply increased force at their chosen speed attempting to exceed the 100% target within 10 s. In the step trial, participants targeted their 50% maximum level, proceeded to exceed their previous maximum level, and returned to the 50% level of force. Both ramp and step trials were used because preliminary tests showed individual preference for ramp or step trial to maximize force. For each force direction/thumb posture condition, only the trial with the largest force magnitude was analyzed. Sterile, paired 50 μm wire electrodes with approximately 1 mm recording surface were inserted into flexors pollicis longus (FPL) and brevis (FPB), extensors pollicis longus (EPL) and brevis (EPB), abductors pollicis longus (APL) and brevis (APB), opponens pollicis (OPP), adductor pollicis (ADD) and the first dorsal interosseus (DIO) muscles. Muscle locations were identified by palpation and/or by using monopolar electrodes (Burgar et al., 1997; Johanson et al., 2001). Electrode placement was confirmed using mild electrical stimulation to the target muscle through the wires and by isolated contraction of each muscle. Raw and filtered signals were recorded (band-pass 10–10,000 Hz) and amplified (gain 500–2000). Raw EMG was sampled at 2000 Hz and displayed after each trial to review signals for noise prior to processing. Filtered signals were full-wave rectified and smoothed (50 ms time constant) using custom analog circuits to produce a linear envelope and sampled at 500 Hz. For each participant, the EMG data for each muscle in each trial was that within a 750 ms window centered on peak force as described previously (Valero-Cuevas et al., 1998). EMG data were normalized in each participant for each posture to the highest EMG activity recorded for each muscle within a 750 ms window centered on peak force production in a maximum voluntary contraction in manual muscle testing positions (Kendall and Kendall, 1993) or during thumbtip force production, whichever value was greater. We excluded the DIO muscle from EMG recordings and the model because it adds little to thumb movement and force (Brand and Hollister, 1999; Kaufman et al., 1999), and our EMG recordings have shown activity exclusively with forefinger force production (Johanson et al., 2001).

maximized (equivalent to 10° of misdirection). The first simulation constrained output torque components to $\leqslant 0.05$ N m (a negligible non-zero constraint which is compatible with the experimental conditions). The second simulation did not constrain thumbtip torque. The third Monte Carlo simulation was in the "forward" direction where matrix multiplication calculated the thumbtip output force/torque when EMG was input to the model without applying any constraints. A non-parametric model determined if the predicted activation

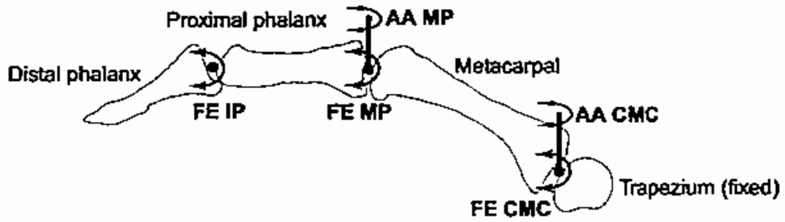

Fig. 3. Kinematic description of the thumb. The kinematics of the thumb were described using 5 hinge-type DOFs with perpendicular and intersecting axes of rotation at the CMC and MP joints, and a single axis of rotation at the IP joint. All flexion-extension axes of rotation were parallel, as were the ad-abduction axes. The radial aspect of a right thumb is shown.

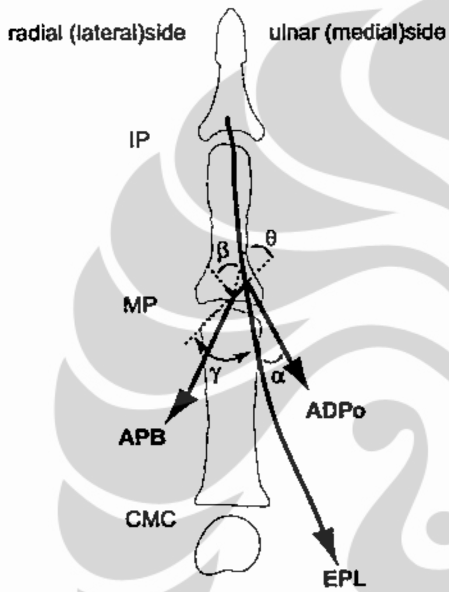

Fig. 4. Extensor mechanism on dorsal aspect of right thumb. Arrows represent the muscles involved, and the angles among them (see Table 1) The extensor mechanism model was based on thumb anatomy (Kendall and Kendall, 1993), cadaver dissections, and personal communications with a hand surgeon (Hentz and Chase, 1999). For a given set of angles, tendon forces are combined as if the mechanism were a flat, floating net (Valero-Cuevas et al., 1998).

range for each muscle was compatible with EMG in each test condition. We required that ≥50% of EMG data lay within the predicted central 50th percentile. Due to the small number of EMG values, we were conservative to avoid type I errors by requiring that all EMG data lay within the predicted central 90th percentile (Sokal and Rohlf, 1995).

3. Results

The number of valid instantiations in each posture was sufficient for convergence of thumbtip force magnitudes. The mean and coefficient of variance (100∗SD/mean) of all thumbtip force magnitudes were within 2% of the final mean and coefficient of variance, respectively, for the last 10% of valid instantiations (Table 2) (Fishman, 1996). An instantiation was considered valid if it resulted in non-zero thumbtip forces in all five directions, and the Euclidean magnitude of the palmar, dorsal, lateral and medial forces normalized by the distal force were within the range seen experimentally.

The first inverse simulation produced unrealistically low thumbtip force magnitudes in both postures. The model consistently underestimated the magnitude of maximal thumbtip force by a mean ratio of 4.1 ± 2.9 (Fig. 5, Tables 2 and 3). The predicted distribution of activation levels were compatible with EMG measurements in 40 out of 80 muscle activations studied ($8 \times 5 \times 2$: eight muscle excitations in each of 5 force directions in each of two postures; Fig. 6). Activity in ≥5 muscles was compatible with EMG in only three force directions (palmar, distal and ulnar directions for key posture). All inverse simulations produced thumbtip forces directed within 10° of the desired direction because of the constraints imposed.

The second inverse simulation (unconstrained thumbtip torque) predicted higher thumbtip force magnitudes than the first simulation, but still predicted unrealistic coordination patterns for all directions in both postures. The ratio of measured to predicted thumbtip force magnitudes 1.96 ± 1.28. The predicted distribution of activation level was statistically compatible with EMG measurements in 29 out of 80 muscle activations studied. Predicted muscle activity was compatible with EMG in 5 out of 8 muscles only for the medial force direction in opposition posture. The average magnitude of the thumbtip torque was 0.64 ± 0.28 N m, which is an unrealistic amount because the thimble worn by the participants precluded the production of thumbtip torque.

The third simulation (forward method) predicted thumbtip force magnitudes comparable to the second simulation, but the thumbtip force vectors were misdirected and accompanied by unrealistically high thumbtip torques. The ratio of measured to predicted thumbtip force magnitudes was 2.32 ± 1.82. On average, thumbtip force vectors were deviated $74.3 \pm 24.5°$ from the desired direction, and the accompanying average thumbtip torque was 1.32 ± 0.95 N m (Table 2).

Table 2
Results summary

		Modeling approach		
Methods	Type	Inverse	Inverse	Forward
	Technique	Linear programming	Linear programming	Matrix multiplication
	Goal	Maximize thumbtip force	Maximize thumbtip force	Calculate thumbtip force
	Stochastic variables	Musculoskeletal parameters	Musculoskeletal parameters	Musculoskeletal parameters and EMG inputs
	Constraints	Force direction and fingertip torques	Force direction only	—
Predictions	Min. valid sols. per posture	1620	2250	2460
	Convergence	Within 2%	Within 2%	Within 2%
	Fingertip force magnitude	Unrealistically low	OK	OK
	Force direction	OK	OK	Very misdirected
	Fingertip torques	OK	Unrealistically high	Unrealistically high
	Coordination patterns	Unrealistic	Unrealistic	—
Possible model flaw	Kinematic model	Yes	Yes	Yes
	Solution method	Yes	Yes	No
	PCSA	Yes	No	No

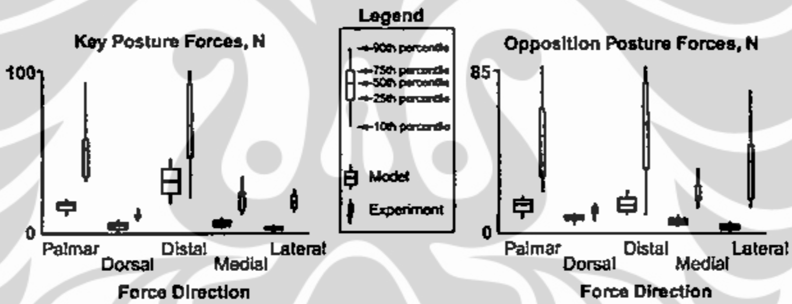

Fig. 5. Comparison of maximal thumbtip force distributions in each direction for both postures. The maximal voluntary thumbtip forces measured in the participants are shown in the narrow gray box plots. The maximal predicted thumbtip forces from the valid solutions from the first inverse Monte Carlo simulation are shown in the wide white box plots. Note that the predicted maximal thumbtip forces were lower than the thumbtip forces measured in the subjects.

4. Discussion

This study evaluated the validity of a 5-axis, 8-muscle biomechanical computer model of the thumb by comparing the predicted ranges of maximal static force production and muscle activity to experimental measurements of maximal voluntary thumbtip force and EMG. We will argue that, when taken together (Table 2), our results suggest that the musculoskeletal parameters and solution methods are sound; but the chosen kinematic description may not represent the transformation of net joint torques into thumbtip forces/torques in the anatomical thumb. We do not argue that the model's predictions would become entirely realistic if we used an alternative, perfectly realistic kinematic model. Rather, we conclude that, in this particular model of the thumb, the kinematic description appears to be the dominant factor in preventing realistic predictions of isometric force production and the coordination patterns that achieve them.

The choice of individual musculoskeletal parameter values is not the likely reason for the underestimation of thumbtip force or discrepancies in coordination patterns. Monte Carlo simulations explicitly calculate the sensitivity of model predictions to parameter variability and uncertainty, and mitigate the limitations associated with adopting average or subject-specific musculoskeletal parameters (Fishman, 1996). Because all simulations converged, running additional iterations (i.e., different parameter values) would not change the distribution of the thumbtip forces reported here.

Table 3
Measured thumbtip force magnitudes and predicted magnitudes for first Monte Carlo simulation (N)

Direction	Key posture			Opposition posture		
		Mean	SD		Mean	SD
Dorsal	Experiment	11.0	2.2	Experiment	11.5	2.7
	Model	4.7	2.6	Model	7.7	2.1
ratio Exp:Model		2.3			1.5	
Palmar	Experiment	51.9	20.4	Experiment	47.8	27.2
	Model	16.9	3.7	Model	14.1	4.1
ratio Exp:Model		3.1			3.4	
Distal	Experiment	65.0	27.9	Experiment	56.0	34.1
	Model	32.6	10.3	Model	15.1	4.8
ratio Exp:Model		2.0			3.7	
Medial	Experiment	21.3	7.8	Experiment	20.7	6.9
	Model	6.2	2.4	Model	6.1	2.2
ratio Exp:Model		3.4			3.4	
Lateral	Experiment	19.5	4.8	Experiment	36.6	21.5
	Model	3.0	1.4	Model	3.1	1.9
ratio Exp:Model		6.6			11.7	
Mean Exp:Model		3.5			4.7	

The underestimation of thumbtip force and discrepancies in coordination patterns in the first inverse simulation could result from inappropriate PCSA values, solution method, and/or kinematic description (Table 2). PCSA values set the baseline strength of the model, and affect the prediction of coordination patterns by specifying relative muscle strengths. Because PCSAs are generally measured from specimens belonging to older individuals, they likely underestimate the thumb strength of the young participants we studied. This may explain some "weakness" in biomechanical models (Valero-Cuevas et al., 1998), but it is unlikely that it would explain force under-prediction of a factor of 4, or the discrepancies of the predicted coordination patterns. PCSA values may, nevertheless, be adequate because the other simulations produced higher thumbtip forces. As argued previously (Valero-Cuevas et al., 1998), we do not feel justified in increasing the value for maximal muscle stress from 35.4 N/cm^2 because this is already the larger of the two generally accepted (Close, 1972; Brand et al., 1981; Powell et al., 1984; Zajac, 1989) (the other being 22.5 N/cm^2). For recent detailed reviews supporting this range of values see (Zajac, 1989; Lieber, 1992; Brown et al., 1998).

The kinematic description specifies the transformation of net joint torques into thumbtip forces/torques (Yoshikawa, 1990). Thus, an inappropriate kinematic description could contribute to both the underestimation of thumbtip force and discrepancies in coordination patterns of the first simulation. Removing the constraints on the thumbtip torque in the second simulation doubled the magnitude of the thumbtip forces and produced unrealistically large thumbtip torques suggesting that the model is not inherently weak. Agreement between measured to predicted force magnitudes (i.e., a ratio of 1) is already within $\pm$0.75 SD of the mean ratios for the last two simulations, and can be further improved by doubling PCSA values—a reasonable adjustment compatible with weakness in older adults (Mathiowetz et al., 1985).

All Monte Carlo simulations have the limitation that assuming parameter independence can broaden the predicted distributions. This increases the likelihood of false-positive matches with the experimental data because we were, in fact, simulating a wider variety of thumbs than are likely to exist in reality. Additional limitations include: The moment arms of Smutz et al. (1998), and the ranges we used (based on their reported standard deviations), should not be taken as definitive as they note their data do differ at times from other reports of muscle moment arms. We assumed the extensor mechanism apportions tendon tensions by acting as a floating net (as in Valero-Cuevas et al., 1998) were unaffected by thumb posture. We also approximated the fan-shaped ADD muscle as a single line of action. Variability in the experimental muscle coordination patterns was most likely due to the force–EMG relationship that can change with different muscles, force magnitude, muscle fiber type (Lawrence and De Luca, 1983; Basmajian and De Luca, 1985) and excitation history (Burke et al., 1976; Zajac and Young, 1980; Bigland-Ritchie et al., 1983). Although EMG artifacts and possible cross-talk cumulatively can increase signal variability, cross-talk from wire

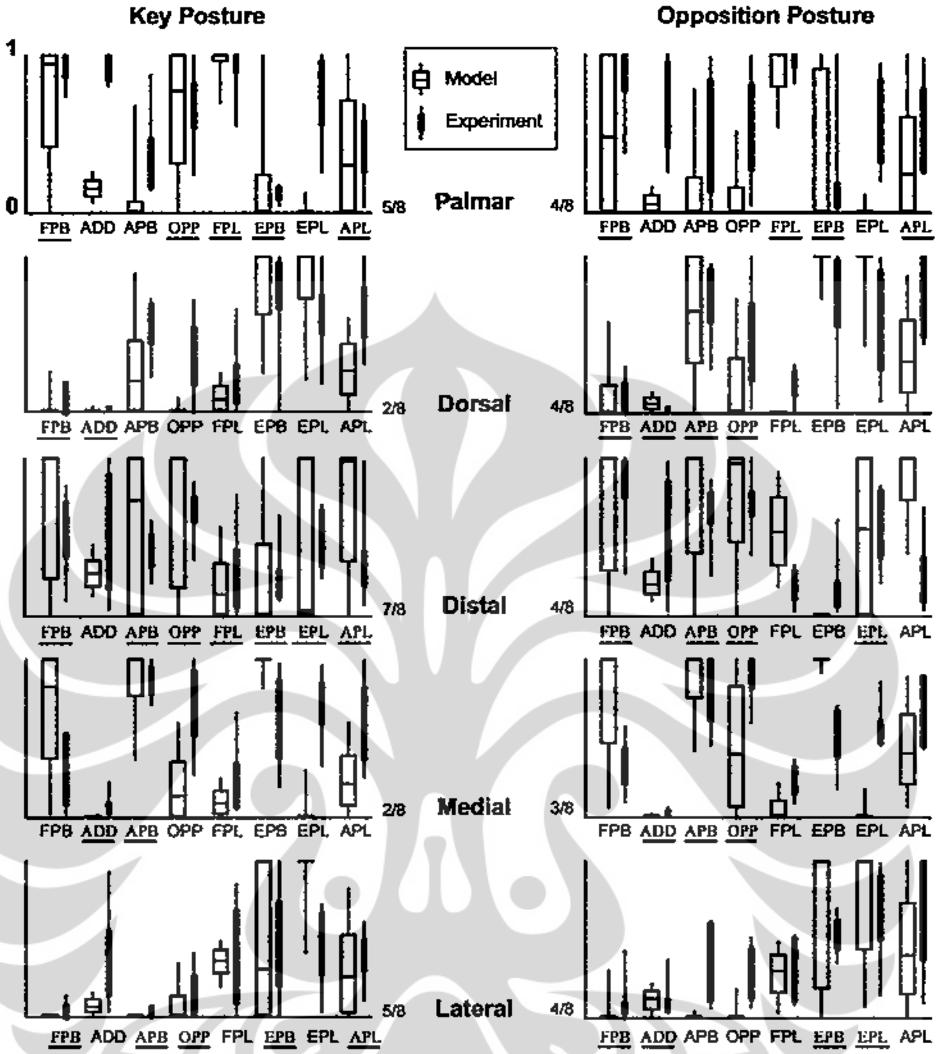

Fig. 6. Comparison of distributions of activation levels during maximal thumbtip force production in each direction for both postures. The normalized EMG during maximal voluntary thumbtip forces measured in the participants is shown in the narrow gray box plots. The maximal predicted thumbtip forces from the valid solutions from the first inverse Monte Carlo simulation are shown in the wide white box plots. The fraction next to each force direction indicates the number of muscles for which the predicted distribution includes the measured EMG, and the matching muscles have their labels in bold. We used a non-parametric statistical test to determine if the predicted activation range for each muscle was compatible with EMG for each force direction at each posture. To accept compatibility with 90% confidence, we required that ≥50% of EMG data lay within the central 50th percentile of the predicted distribution, and all EMG data lay within the central 90th percentile.

electrodes has been reported to be insignificant at around 2% of their maximal value (Solomonow et al., 1994). To control for intersubject variability, all of the EMG signals were normalized within each posture since joint position has been shown to have an effect on EMG magnitude (Onishi et al., 2002). Regarding the advantages and limitations of LP, this optimization method predicts the maximal possible output of linear systems because it finds the system's boundary of performance (Chvátal, 1983). The coordination patterns predicted by LP reflect the mechanical consequences of the model and state the muscular interactions necessary to maximize well-directed thumbtip forces. If anything, LP tends to overestimate thumbtip force because we assumed independence of muscle activations and placed no constraints on muscle activation other than the production of well-directed thumbtip force. Reformulating the optimization to include possible, but not currently known, muscle synergies could only weaken the model further. Similarly, alternative non-linear cost functions or optimization methods would affect the coordination patterns predicted, but could not improve upon the force magnitudes found here. The limitations of LP to predict realistic coordination patterns are related to conjectures from EMG studies that thumb muscle may at times act to stabilize joints via co-contraction instead of contributing to output force (Chao et al., 1989). In contrast, LP assumes all muscle activity optimally contributes to the output force. Even if subjects did co-contract to stabilize joints, this would not imply the system is not linearizable or solvable with LP. Rather, it would mean the thumb has additional DOFs, such as sliding at the incongruous CMC joint, whose control may depend on joint configuration and active/passive loading—much like the knee. If such DOFs were present, kinematic descriptions using fixed hinge-type joints would be inappropriate to describe the interactions among joint contact geometry, passive structures, muscle forces and thumbtip forces/torques. Non-linearities in the transmission of tendon tension are also possible.

The third (forward) and last simulation suggests that LP was not responsible for the model's underestimation of thumbtip force and the discrepancies in coordination patterns. The results of the forward simulation again suggested that PCSA values are likely appropriate because the model was able to produce thumbtip forces within a factor of 2 of the experimental values. Moreover, both the direction of thumbtip forces and the magnitude of the thumbtip torques were unrealistic (Tables 2 and 3). These results, together with the first two simulations, strongly suggest the adopted kinematic description does not accurately represent the transformation of muscle forces to thumbtip output in the human thumb. All available kinematic descriptions of the thumb idealize articulations as invariant hinge-type joints (Cooney and Chao, 1977; Chao and An, 1978; Giurintano et al., 1995), but it is conceivable that in vivo muscle forces affect thumb kinematics and that more elaborate descriptions may be necessary to replicate the biomechanical complexity of articulations.

In light of our results, future efforts to create realistic biomechanical computer models of the thumb should explore alternative kinematic descriptions. In this study we used a straightforward 5-DOF kinematic description in the spirit of Occam's Razor, and because experimental moment arm data compatible with this description exist (Smutz et al., 1998). An inverse model of the thumb using a more elaborate 5-DOF description with non-orthogonal and non-intersecting axes (Giurintano et al., 1995) found coordination patterns for palmar force in the key posture that were less compatible than our predictions. In our model, 5/8 muscles agreed with our EMG data vs. 2/8 muscles in theirs. However, it is unclear how the choice of optimization method, musculoskeletal parameters, and/or kinematic description in their model affected their results. The lack of DIO in our model is immaterial to this comparison because DIO was inactive in their prediction. Future work should explore how the number, location, orientation and type of DOFs affect the biomechanical predictions of mechanical output and the muscle coordination that achieves it in the presence of parameter variability.

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The fundamental thumb-tip force vectors produced by the muscles of the thumb

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Abstract

A rigorous description of the magnitude and direction of the 3D force vector each thumb muscle produces at the thumb-tip is necessary to understand the biomechanical consequences to pinch of a variety of paralyses and surgical procedures (such as tendon transfers). In this study, we characterized the 3D force vector each muscle produces at the thumb-tip, and investigated if these thumb-tip force vectors scaled linearly with tendon tension. In 13 cadaver specimens, we measured the output 3D thumb-tip force vector produced by each tendon acting on the thumb, plus two common tendon transfers, as a function of input tendon tension. After fixing the hand to a rigid frame, we mounted the thumb by configuring it in standardized key or opposition pinch posture and coupling the thumb-tip to a rigidly held 6 degree-of-freedom force/torque sensor. Linear actuators applied tension to the distal tendons of the four extrinsic thumb muscles, and to six Nylon cords reproducing the lines of action of (i) the four intrinsic thumb muscles and (ii) two alternative tendon transfers commonly used to restore thumb opposition following low median nerve palsy. Each computer-controlled linear actuator ramped tendon tension from zero to 1/3 of predicted maximal muscle force expected at each tendon, and back to zero, while we measured the 3D force vector at the thumb-tip. In test/re-test trials, we saw thumb-tip force vectors were quite sensitive to mounting procedure, but also sensitive to variations in the seating of joint surfaces. We found that: (i) some thumb-tip force vectors act in unexpected directions (e.g., the *opponens* force vector is parallel to the distal phalanx), (ii) the two tendon transfers produced patently different force vectors, and (iii) for most muscles, thumb-tip force vectors do not scale linearly with tendon tension—likely due to load-dependent viscoelastic tendon paths, joint seating and/or bone motion. Our 3D force vector data provide the first quantitative reference descriptions of the thumb-tip force vectors produced by all thumb muscles and two tendon transfers. We conclude that it may not be realistic to assume in biomechanical models that thumb-tip force vectors scale linearly with tendon tensions, and that our data suggest the thumb may act as a "floating digit" affected by load-dependent trapezium motion.

Keywords: Hand; Finger; Thumb; Cadaveric; Surgical planning; Muscle coordination

Introduction

The force vectors produced at the thumb-tip by individual thumb muscles have not been previously quantified, even though these data would be instrumental in describing how muscle forces manifest themselves as thumb-tip force vectors in the healthy, paralyzed, and post-operative thumb. Available descriptions of the biomechanical function of thumb muscles and their tendons include quantitative measures of muscle parameters including moment arms (i.e., the perpendicular distance between the force line of action and the joint center) and muscle architecture (e.g., fiber length, physiological cross-sectional area (PCSA)) [3,5,14]. Unfortunately, muscle parameters do not translate directly or unequivocally into descriptions of the 3D force vector each muscle produces at the thumb-tip—where pinch forces occur and where force vectors need to be restored after low median nerve palsy, for example. Similarly, the graphical description of the lines of action of intact and transferred tendons at each joint has been of limited use

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to represent the biomechanical function of muscles at the thumb-tip, to predict deficit after paralysis, and to compare alternative tendon transfers. These Cartesian plots of the moment generating capacity of a muscle about each joint it crosses [3,14] are created by combining the lines of action of tendons with respect to the anatomical structures (e.g., joint axes, other tendons, etc.) with PCSA and moment arm data. These plots distill the complex anatomical lines of actions muscles into manageable diagrams describing the torque a muscle or tendon transfers could produce about specific joint axes. However, these plots cannot be unequivocally extrapolated to find the force vector a tendon transfer produces at the thumb-tip.

Importantly, the above descriptions of the biomechanical function of thumb muscles rely on accurate and realistic estimates of moment arms [2]—but the validity of moment arm measurements depends on technical skill and realistic assumptions about the number, location and orientation of the joint axes of the thumb, which remains debatable (cf. [9] vs. [5]). In addition, there may be inter-subject variability and load-dependent deformation of tendon paths or motion of the carpal bones, especially the trapezium [3], which are not accounted for in any kinematic model of the thumb or measurements of moment arms. Note that moment arms have been measured by applying tendon tension of at most 10% of the strength of thumb muscles (i.e., 2 N [14]), even though some thumb muscles can produce forces up to 100 N [5]. It is also important to note that the transformation from muscle forces to thumb-tip force vectors is assumed to be linear in biomechanical models [1,8,16], in spite of the deformation ligaments and tendons can undergo under physiologic loads [3,17] due to their viscoelastic properties.

In this study, we expand on a previously described system identification approach [15,18] to address two questions: (i) What is the 3D magnitude and direction of the force vector each muscle produces at the thumb-tip? (ii) Do thumb-tip force vectors scale linearly with tendon tension for realistic tension magnitudes? Unlike the available descriptions of the biomechanical function of thumb muscles, this approach does not make any assumptions about the kinematic structure of the thumb because it directly measures the thumb-tip force vectors that arise when known tensions are applied along the lines of action of the muscles of cadaveric thumbs. We also provide an example of a clinical application of this approach by measuring the thumb-tip force vectors produced by two tendon transfers.

Methods

As in previous studies of the index finger [15,18] and thumb [13], we began by dissecting the intrinsic and extrinsic muscles acting in the thumb of 13 fresh-frozen forearm specimens (7 males, 6 females, Age = 76 ± 9 years). Specimens were pre-screened for blood-borne pathogens and kept moist with a mixture of bovine serum (10%, product #C6278, Sigma Chemical Company, St. Louis, MO) and water during the entire dissection and experiment. We isolated and removed from their origins the extrinsic muscle bellies: (flexor pollicis longus (FPL), extensor pollicis longus (EPL), extensor pollicis brevis (EPB), and abductor pollicis longus (AbPL)). After excising the muscles bellies, we tied and glued (Vetbond Tissue Adhesive, 3M Inc., St. Paul, MN) 1-mm Nylon cords to the each tendon. Next, we isolated and removed from their origin the intrinsic muscles of the thenar eminence: abductor pollicis brevis (AbPB), flexor pollicis brevis (FPB), and opponens pollicis (OPP). We tied and glued Nylon cords to the AbPB and FPB at their insertions (Fig. 1h and j, respectively). The muscle belly of the OPP was completely excised, and an eyehook (3-mm ID) was screwed flush to the surface of the first metacarpal at the OPP insertion (Fig. 1f). Other eyehooks were screwed flush into the trapezium and trapezoid at the origins of the AbPB and OPP, respectively, and were used to route the Nylon cords (Fig. 1i and g, respectively). A floating 3-mm ring tied around the proximal end of the third metacarpal was used to represent the origin of the FPB (in the palmar fascia (Fig. 1k). After dissection of the thenar muscles, we excised the belly of the adductor pollicis (ADD). We screwed an eyehook into the proximal-ulnar aspect of the proximal phalanx at the ADD origin (Fig. 1a). Because of the fan-shape of the ADD, we represented the muscle with two Nylon cords. The ADD oblique (ADDo) cord was routed through an eyehook placed in the capitate (Fig. 1c), and the ADD transverse (ADDt) was routed through an eyehook placed in the distal end of the palmar aspect of the third metacarpal (Fig. 1b); these eyehooks were placed at the extreme proximal and distal locations of the ADD origin to represent all of the possible actions (by vector addition) of the fan-shaped ADD. The first dorsal interosseous (DIO) was isolated and excised and eyehooks were placed in the ulnar aspect of the first metacarpal (at mid-shaft) and in the radial aspect of the head of the second metacarpal at the origin and insertion of the DIO, respectively (Fig. 1d and e). We also routed two tendon transfers commonly used for low median nerve palsy [7]:

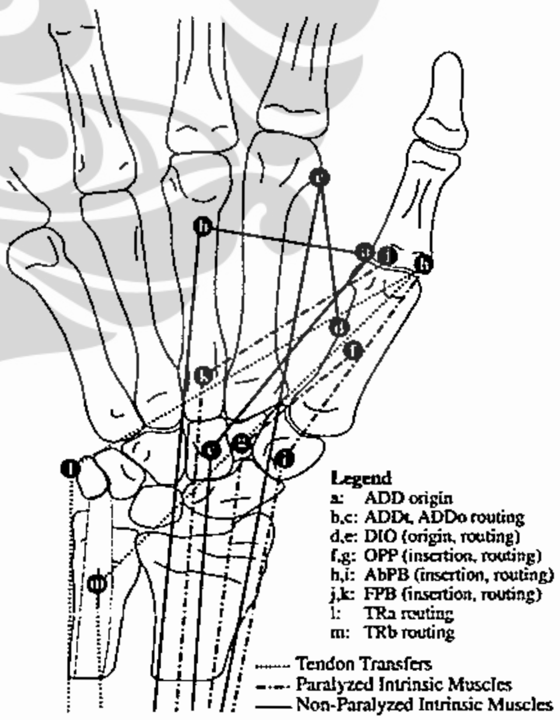


Fig. 1. Representative schematic dissection diagram showing the approximate eyehook location and lines of action of the intrinsic muscle and tendon transfer cords.

transfer A (TRa), attributed to Burkhalter et al., is performed by transferring the *extensor indicis proprius* muscle to the insertion of the failed AbPB via the pisiform bone, and transfer B (TRb), attributed to Riordan, is performed by transferring the flexor digitorum superficialis (FDS) of the ring finger to the insertion of the failed AbPB via a slip in the flexor carpi ulnaris (FCU) (Fig. 1l and m, respectively). In the cases where we used eyehooks to represent the origin of the muscles (ADD, OPP and DIO) we tied the Nylon cord to the base of the eyehook (rather than the eye itself) to ensure that the cord was in contact with the bone, mimicking the tendinous origin coming out of the bone. Tendon paths were left covered by skin to avoid drying out of the tendon sheaths.

After the dissection, we used an external fixation device (Agee-WristJack, Hand Biomechanics Lab, Inc., Sacramento, CA) to fix the second and third metacarpals to the radius and ulna in neutral wrist flexion/extension and radial/ulnar deviation [15,18]. We then configured the thumb in two functional postures using a manual goniometer: key pinch (10° interphalangeal (IP) flexion, 45° metacarpophalangeal (MP) flexion, and 0° carpometacarpal (CMC) abduction and flexion) and opposition pinch (45° IP flexion, 10° MP flexion, 45° CMC abduction, and 0° CMC flexion). We formed thermoplastic molds (Omega Max, North Coast Medical Inc., Morgan Hill, CA) for each of these postures to hold the thumb in position while it was mounted to a custom table-top load frame. The aluminum load frame housed ten linear actuators, each consisting of a stepper motor (model 801B-AM, American Scientific Instrument Corp., Palos Hills, IL) mounted in-line with a uniaxial load cell (SML series ±107.5 N or ±215 N, depending on the strength of the muscle simulated, InterfaceForce, Scottsdale, AZ) and an extension spring (to increase the resolution of force control). We mounted the specimen on the load frame by configuring it in standardized key or opposition pinch posture. As in our in vivo studies [10,16,19], the thumb interfaced with a rigidly held 6 degree-of-freedom force/torque sensor (F/T nano17, ATI/Industrial Automation, Garner, NC) via a thermoplastic thimble formed around the distal phalanx. The thimble was rigidly connected to the sensor and glued to the thumb pulp to keep the thumb-tip in the thimble (Fig. 2, inset). The mixed boundary conditions of the thimble-thumb interface (soft-tissue interface for palmar, radial, ulnar, and distal force production, and a rigid interface of the thumbnail and thimble during dorsal force production) are our well established method of noninvasively measuring 3D digit-tip force production in vivo [10,16,19] that allow for the natural compliance of soft-tissue.

A personal computer (Celeron, Dell Computer Corporation, Round Rock, Texas) with a data acquisition card (DAQ PCI 6021E, National Instruments Corporation, Austin, TX) running custom programs in LabVIEW (National Instruments Corporation, Austin, TX) controlled the linear actuators attached to each tendon's Nylon cord.

After mounting the specimen, we measured the output force vector at the thumb-tip when tension was applied to each tendon. We commanded each linear actuator to incrementally ramp tension up from zero to a desired value and back down to zero from that value in ten ramp-and-hold steps in each direction under force control (precision: ±0.05 N). We recorded thumb-tip output force vector during hold periods to exclude actuator vibrations. We did not analyze the torque vector produced at the thumb-tip because it is beyond the scope of this work. The maximum force for each muscle was based on the mass fraction reported in the literature [3] and was scaled so that each muscle reached approximately 1/3 of its maximal predicted force based on PCSA (Table 1, FMAX column; note, FMAX was assumed to be identical for both postures). Prior work showed that tendon tensions greater than 40 N would risk rupture of the attachment of the tendon to the Nylon cord [15,18].

We calculated two measures of *intra*-specimen reproducibility by calculating the percent magnitude difference and included angle between thumb-tip output force vectors for each muscle across two test/re-test trials. For the 1st reproducibility measure, we repeated ramp-up and down trials for all muscles after decoupling the thumb-tip from the dynamometer, moving the thumb randomly through its range of motion and re-coupling the thumb-tip *without moving the dynamometer*. This quantified the sensitivity of thumb-tip force vectors to any joint seating variations that may occur after articulating the thumb and reattaching the thimble in the *identical* position and orientation as the first trial. For the 2nd reproducibility measure, we repeated trials after re-doing the entire mounting procedure: we placed the posture mold on the thumb (holding it in the approximate desired key or opposition pinch posture), decoupled the dynamometer, and moved the dynamometer to a random location and back, intending to re-attach the thimble to the dynamometer at the same thumb posture and thimble position and orientation as the first trial. This quantified the sensitivity of thumb-tip force vectors to the mounting procedure, excluding the creation of the thermoplastic posture molds, but *including* joint seating variations that may have occurred due to changes in the spatial relationships between bones after reconnecting the thumb-tip to the repositioned dynamometer.

We used three measures to quantify the relationship between input tendon tensions and output thumb-tip force vectors. (i) We found the fundamental action of each muscle at the thumb-tip by calculating an average 3D thumb-tip force vector in both magnitude and direction across tension levels for each tendon for each specimen and averaged across specimens. (ii) We characterized the degree of association

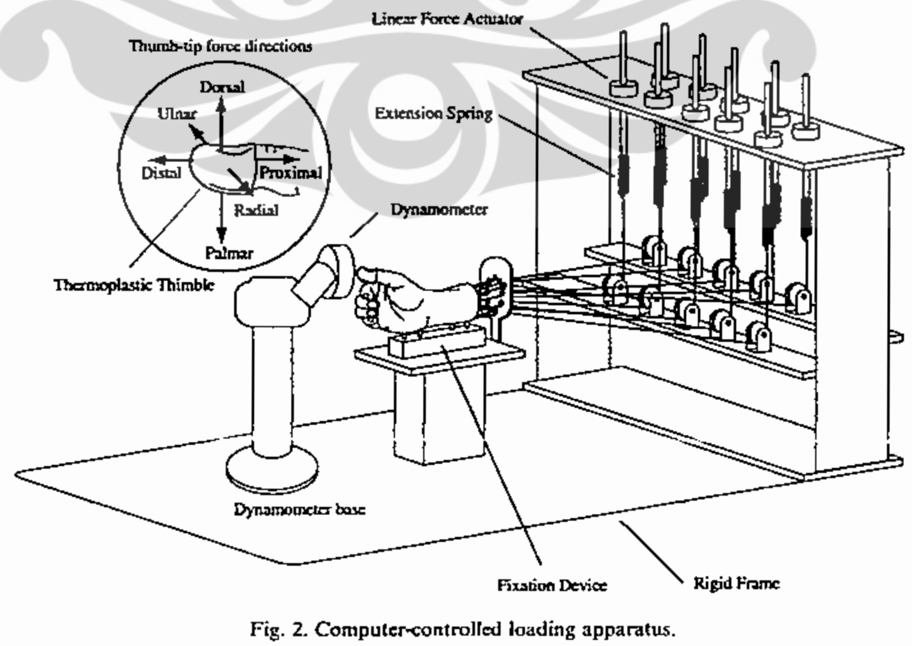
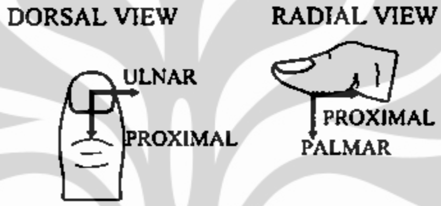


Fig. 2. Computer-controlled loading apparatus.

Table 1
Nonlinearity and average thumb-tip force vector results

Muscle	FMAX	Key pinch							Opposition pinch						
		%NL	PLM	ULN	PRX	$\|F\|$	DSL PRJ	RAD PRJ	%NL	PLM	ULN	PRX	$\|F\|$	DSL PRJ	RAD PRJ
AbPB	10.5	85	0.5	−1.5	0.5	1.7 (0.6)	44	30	85	0.4	−1.4	0.3	1.5 (0.9)	46	33
AbPL	30	91	0.1	−2.0	5.0	5.3 (1.5)	56	56	90	0.1	−0.8	3.1	3.2 (0.8)	56	57
ADDo	14.4	100	2.1	0.6	−1.9	2.9 (1.0)	55	50	100	2.5	0.4	−1.6	3.0 (0.9)	33	45
ADDt	14.4	100	1.3	1.3	−4.1	4.5 (1.8)	56	54	100	1.3	1.4	−3.3	3.9 (1.4)	55	55
DIO	12.6	100	−0.1	0.2	−1.4	1.4 (0.9)	56	53	100	0.0	0.5	−1.1	1.2 (0.7)	48	50
EPB	7.8	92	−0.9	−0.3	0.7	1.2 (0.3)	33	43	92	−1.0	−0.1	0.7	1.2 (0.4)	34	42
EPL	12.6	92	−0.9	1.6	0.2	1.9 (0.5)	50	35	75	−1.1	1.3	0.1	1.7 (0.5)	48	43
FPB	12.6	92	1.1	0.0	−1.3	1.7 (0.8)	27	43	100	0.7	−0.1	−1.4	1.6 (0.7)	38	44
FPL	26.1	50	5.6	−0.5	4.5	7.2 (0.9)	53	57	44	5.8	−0.9	3.9	7.0 (1.5)	55	57
OPP	18.3	92	−0.2	−0.3	−2.4	2.4 (1.2)	53	52	100	−0.1	−0.2	−2.3	2.3 (1.3)	51	50
TRa	9.6	100	0.1	−0.6	−3.2	3.3 (2.2)	56	54	100	−0.1	−0.7	−2.8	2.9 (2.1)	56	54
TRb	19.4	90	0.7	−2.0	−2.2	3.1 (1.7)	49	42	92	0.2	−2.1	−1.8	2.8 (1.7)	49	38



In all specimens, the tension in each tendon was ramped up from zero to its FMAX (N) level in ten equal steps, and then ramped down to zero in ten steps. The FMAX applied to each tendon was based on published PCSA values [3,4] and maximal muscle stress of 35.4 N/cm² [4,6,12,20]. %NL is the percentage of regression cases of tendon tensions against each of the three thumb-tip force components that were nonlinear. These thumb-tip force vector components (averaged across tension levels and specimens, and scaled to $\|F\|$) in the palmar (PAM), ulnar (ULN), and proximal (PRX) orthogonal directions (N) are reported as if all hands were right hands. $\|F\|$ is the magnitude (N) (mean(SD)) of the force vectors at their maximal force values (FMAX). PRJ columns indicate the orientation variability (SD in degrees) from the mean direction of the thumb-tip force vectors in the dorsal (DSL) and radial (RAD) views (see inset).

between input tendon tension and the Euclidean magnitude of the output thumb-tip force vector by calculating the square of their Pearson product-moment correlation coefficient (r^2). And (iii) we tested the linearity of the transformation from tendon tension to thumb-tip force magnitude by regressing the tendon tensions (X) against each of the three force components (in the palmar-ulnar-proximal reference frame; Fig. 2, inset) of the thumb-tip output vector (Y) using a quadratic model ($Y = a_0 + a_1 * X + a_2 * X^2$). An F-test ($\alpha = 0.05$) determined if the quadratic term (a_2) was significantly different from zero. Only if the null hypothesis ($H_0 : a_2 = 0$) could not be rejected in *all* three force directions would we conclude that the thumb-tip output force vector scaled linearly with tendon tension. Otherwise, we concluded that the response was significantly different from linear.

Results

The average 3D thumb-tip force vectors produced by all thumb muscles are shown in Fig. 3 and Table 1. See www.mae.cornell.edu/nmbl/thumb/avgvec.html for an interactive three-dimensional exploration of results for opposition posture.

The high degree of association between tendon tension and magnitude of the thumb-tip output force vector is shown by the box plots showing all r^2 values across postures and specimens across muscles (Fig. 3, box plots).

The output thumb-tip force vector was nonlinearly related to input tendon tension in most cases (Table 1, %NL column), suggesting that a quadratic or higher-order relationship is needed to describe how thumb-tip force vectors scale with tendon tension.

Regarding reproducibility of the experiment when we articulated the thumb (without moving the dynamometer), the thumb-tip output force changed in magnitude by 4 ± 18% and direction by 9 ± 10° compared to the initial trial. This suggests the experiment was sensitive to the seating of the joints. When remounting the thumb and re-positioning the dynamometer, the thumb-tip output force magnitude changed an average of 35% with respect to the first test (standard deviation (SD) = 77%), and vector direction changed by an average of 34° (SD = 34°). This suggests the experiment was highly sensitive to the combined effects of joint seating and mounting procedure.

Discussion

In multi-joint musculoskeletal systems such as the thumb, a muscle generates torque at each joint it crosses that is proportional to the muscle's force and moment arm. The force and torque output at a finger-tip in static pinch depends on the net torque at each joint produced

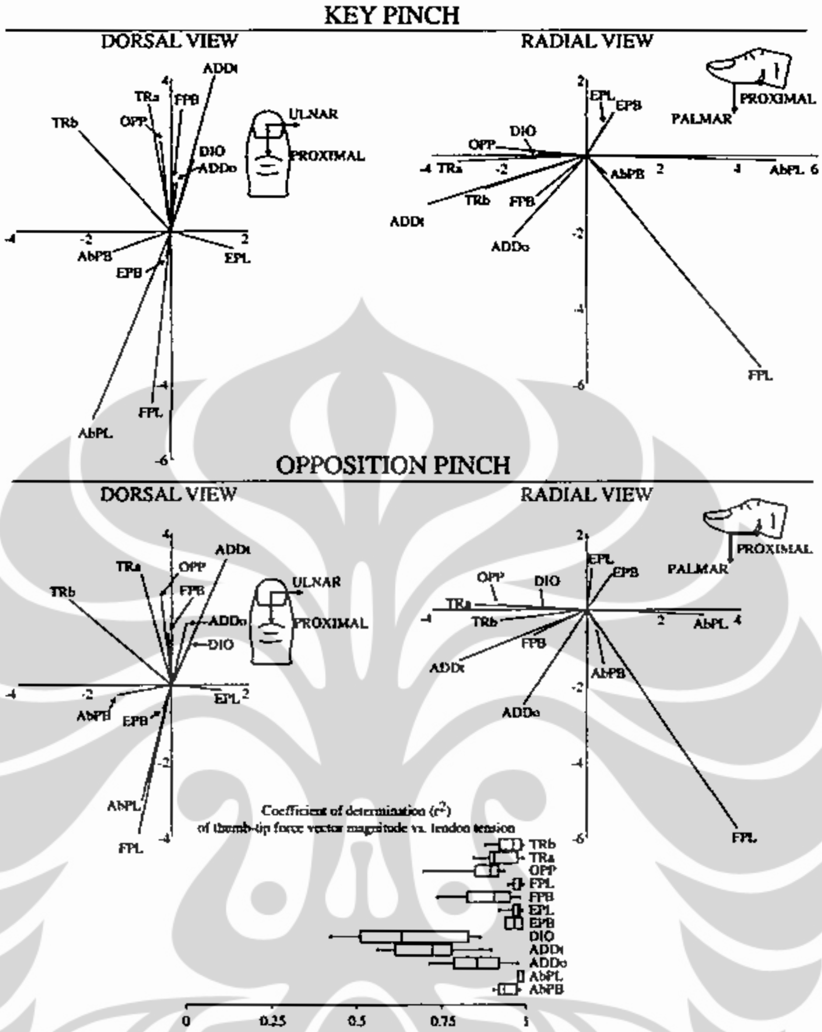


Fig. 3. Average thumb-tip output vectors (*N*) for each functional posture in anatomical projections. All data were rotated to a right hand. For an interactive three-dimensional exploration of results for opposition posture see www.mae.cornell.edu/nmbl/thumb/avgvec.html. We also show the r^2 values of thumb-tip force vector Euclidean magnitude vs. tendon tension for each muscle across postures and specimens.

by the combined action of all active muscles, and the geometry and configuration of the skeletal structure of the finger [16,19]. Because of the thumb's complex anatomy, it is difficult to predict with certainty the thumb-tip output each thumb muscle produces [16]. In this study, we characterized the thumb-tip force vectors produced by each muscle of the thumb and two tendon transfers by directly applying known tensions to the tendons of cadaver thumbs and measuring the resulting force output at the thumb-tip.

The average 3D thumb-tip force vectors describe how the actions of tendon tensions span the possible 3D force-producing directions at the thumb-tip without having made assumptions about the underlying biomechanical system (e.g. kinematic structure [15,18]); Fig. 3, Table 1, and www.mae.cornell.edu/nmbl/thumb/avgvec.html. These graphs, tables, and interactive website will complement the available descriptions of the actions of thumb muscles [3,11,14] by presenting the 3D description of the vector force produced by individual muscles at the thumb-tip. Additionally, we reported the actions of two common tendon transfers for low median palsy, allowing for easy comparison of their thumb-tip force vectors with respect to the available and paralyzed musculature.

Because we found that thumb-tip vectors are nonlinearly related to tendon tension, our study is limited in that these average force vectors are valid up to the 1/3 of maximum muscle force regime and extrapolating to higher tendon tensions may not be valid. Given that most functional manipulation occurs at sub-maximal force levels, our results are, nevertheless, representative of realistic requirements of thumb function. In addition, the routing of the Nylon cords, including the visual placement of eyehook screws, may not have accurately reproduced the paths of some muscles. Additionally, activity in one muscle may affect the line of action of another muscle, such as when the activity in the OPP may cause the AbPB to separate from the thumb CMC joint (increasing its moment arm [3]). Applying tension to multiple muscles simultaneously may result in increased nonlinearity. We are currently exploring the nonlinearity of thumb-tip force vectors when several tendons are loaded simultaneously. Lastly, our two measurements of *intra*-specimen reproducibility suggest thumb-tip output force vectors are sensitive to both joint seating and mounting procedure. The small changes in the force vectors (4 ± 18% and 9 ± 10° in magnitude and direction, respectively) when the thumb-tip was returned to the same position and orientation after moving the thumb (1st reproducibility measure) can be reasonably attributed to differences in the seating of thumb joints because the skeletal column of the thumb may have more than 6 degree-of-freedom due to the soft-tissue at the thumb pad, and the kinematic complexity and inherent laxity of the joints of the thumb. That is, fixing the position and orientation of the thimble and hand did not guarantee that all joints would be seated in the same way before and after moving the thumb. The much larger changes in the force vectors (35 ± 77% and 34 ± 34° in magnitude and direction, respectively) when re-positioned the thumb and dynamometer (2nd reproducibility measure) show the results to be highly sensitive to the compounded effects of joint seating and mounting procedure. In future, we will use robotic manipulators (as in [15,18]) and 3D motion analysis to improve thumb posture and mounting accuracy, but need to retain the use of the thimble to allow compatibility with in vivo studies.

Our results do demonstrate that the thumb-tip force vector magnitudes are strongly associated with tendon tension ($r^2 > 0.8$), with DIO and ADDt having lower r^2 values, but >0.5 (Fig. 3, box plots). Moreover, the correlation between the thumb-tip force vector direction and tendon tension is best modeled by a nonlinear function (Table 1, %NL column). The nonlinear behavior of the system, assuming negligible deformation of the bone, is likely due to load-dependent viscoelastic tendon paths, joint seating and/or bone motion. We were careful to use stiff 200 N test Nylon cord and rigid frames to eliminate the likelihood that our loading apparatus could introduce nonlinear deflection artifacts. The nonlinear relationships we found between input tendon tension and output thumb-tip force vectors challenges the common assumption used for biomechanical models of the thumb that this relationship is linear [1,8,16]. We are currently exploring the extent to which these nonlinearities affect the motor control of the thumb.

Load-dependent proximal motion of the trapezium is a likely contributor to the nonlinearity of thumb-tip force vector production. In our preliminary experiments, where we pinned the distal phalanx of the thumb to the dynamometer (as in [15,18]), we noticed thumb-tip force vectors progressively swung proximally and rapidly increased in magnitude as tendon tension increased. Careful examination showed that the trapezium migrated proximally when tendon tensions were applied, therefore causing the thumb-tip to "hang" from the dynamometer. We, thus, used a thimble to allow physiologic compliance at the thumb-tip-dynamometer coupling, as in our in vivo studies [10,16,19], to allow the joints to remain seated. While this may have added variability, thereafter the output force vectors no longer swung proximally.

Load-dependent motion has been reported elsewhere for the trapezium [3] and carpus in general [17], but no quantitative measures of this motion have been reported. Even though this study was not designed or equipped to reliably measure trapezial motion, we confirmed trapezial motion in two specimens (with a rigidly coupled thumb-tip) by measuring the displacement of a pin inserted in the trapezium (using digital video close-ups) as a function of FPL tension. We found this motion to be ~2.0 mm in the proximal direction at maximal FPL tension, which likely underestimates the trapezial motion compared to when more muscles are active. To exclude the possibility that our dissection of the intrinsic musculature led to trapezial laxity, we performed one additional experiment where we loaded FPL prior to the dissection of the intrinsic muscles, and noted a similar motion of a pin inserted in the trapezium. Thus we propose the thumb does not have a rigid base at the trapezium, but in reality acts as a "floating digit" affected by motion of the carpal bones when its tendons are loaded. This load-dependent displacement of the trapezium likely contributes to the nonlinear transmission of tendon tension by, at a minimum, affecting joint seating and configuration, which in turn affect the transformation of individual tendon tensions into thumb-tip force vectors. We are conducting additional in vivo Computed Tomography studies during static pinch to characterize the load-dependence of thumb kinematics, and quantify changes in joint kinematics, tendon paths and moment arms, if any.

Our work has several clinical implications. The nonlinearity of fingertip force production we found is clinically important because it calls into question the conventional method of quantifying the mechanical function of musculotendons. To describe the actions of muscles, researchers report tables of moment potentials [3,14], which reflect the mechanical advantage of the muscles about each joint they cross, and the maximum tendon tension predicted by PCSA. The nonlinearities in thumb-tip force production that we identified suggests that the moment potentials may be related to force level in the muscle, and that the moment potentials reported in the literature represent only an instance of a continuous response to force. Researchers have only recorded the mechanical advantage of a muscle under only nominal tendon tensions (e.g., 2 N in [14]), thus moment arm data may not be representative of physiologically loaded tendons.

In addition, our work underscores how standard anatomical nomenclature can be of little value in describing fingertip force production for clinical restoration of function. Conventional anatomical nomenclature describes finger muscle actions from the perspective of individual joint movements: abductors abduct a given joint, while flexors flex a given joint. These names simply specify the dominant motion of the digit with tendon excursion, often while other joints are held fixed, and have little value in describing thumb-tip force production even in the isometric case (e.g., pinch). Our work complements anatomical nomenclature by providing functional descriptions of 3D force vectors at the thumb-tip—where pinch forces occur and where force vectors need to be restored clinically. Using a reference frame fixed on the thumb tip (Fig. 2, inset) we note, for example, that the thumb-tip action of ADDo and ADDt is greater in the distal and palmar directions than in the ulnar ("adduction") direction, and that OPP acts almost purely in the distal direction (Fig. 3).

Lastly, our results demonstrate how alternative, but presumably equivalent, tendon transfers to restore thumb opposition can be compared and contrasted by analyzing the 3D thumb-tip output force they produce. When exploring the data interactively (see www.mae.cornell.edu/nmbl/thumb/avgvec.html), and in the Dorsal Views of Fig. 3, it is clear that transfer B (TRb: transferring the ring finger FDS via a slip in the FCU) better reproduces the radial component of force lost after low median nerve palsy (i.e., previously provided by AbPB). This is but one example of how tendon transfers can be compared. In the future, other surgical procedures could be rigorously evaluated in this way.

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An integrative approach to the biomechanical function and neuromuscular control of the fingers

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Abstract

The exquisite mechanical functionality and versatility of the human hand emerges from complex neuro–musculo–skeletal interactions that are not completely understood. I have found it useful to work within a theoretical/experimental paradigm that outlines the fundamental neuro–musculo–skeletal components and their interactions. In this integrative paradigm, the laws of mechanics, the specifications of the manipulation task, and the sensorimotor signals define the interactions among hand anatomy, the nervous system, and manipulation function. Thus, our collaborative research activities emphasize a firm grounding in the mechanics of finger function, insistence on anatomical detail, and meticulous characterization of muscle activity. This overview of our work on precision pinch (i.e., the ability to produce and control fingertip forces) presents some of our findings around three Research Themes: Mechanics-based quantification of manipulation ability; Anatomically realistic musculoskeletal finger models; and Neural control of finger muscles. I conclude that (i) driving the fingers to some limit of sensorimotor performance is instrumental to elucidating motor control strategies; (ii) that the cross-over of tendons from flexors to extensors in the extensor mechanism is needed to produce force in every direction, and (iii) the anatomical routing of multiarticular muscles makes co-contraction unavoidable for many tasks. Moreover, creating realistic and clinically useful finger models still requires developing new computational means to simulate the viscoelastic tendinous networks of the extensor mechanism, and the muscle–bone–ligament interactions in complex articulations. Building upon this neuromuscular biomechanics paradigm is of immense clinical relevance: it will be instrumental to the development of clinical treatments to preserve and restore manual ability in people suffering from neurological and orthopedic conditions. This understanding will also advance the design and control of robotic hands whose performance lags far behind that of their biological counterparts.

Keywords: Hand; Human; Manipulation; Muscle; EMG; Neural; Motor control; Robotics

1. Introduction

Static and dynamic manipulation of objects with the fingertips is essential to the activities of daily living. Manipulation ability is vulnerable to orthopedic/neurological disease and aging because it hinges upon the exquisite interaction between the complex anatomy of the hand and nervous system (Valero-Cuevas, 2000a). The restoration of manipulation ability is the subject of an entire medical field (Tubiana, 1981; MacKenzie and Iberall, 1994; Brand and Hollister, 1999; Green et al., 1999). In spite of these efforts, the legendary complexity of the hand has delayed a comprehensive understanding of biomechanical function and neuromuscular control of the hand.

Given that the neuro–musculo–skeletal complexity of the hand is not well understood, I have found it useful to define a conceptual paradigm to outline the fundamental neuro–musculo–skeletal components of the hand and their interactions (Valero-Cuevas, 2000a) (Fig. 1). Creating a fundamental understanding of manipulation necessitates an integrative paradigm firmly grounded on the mechanics of finger function, but equally devoted to anatomical detail and the meticulous characterization of

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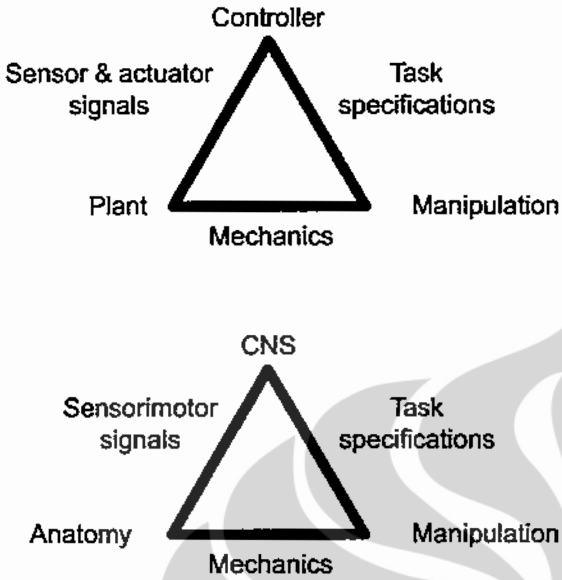

Fig. 1. Conceptual paradigm outlining fundamental neuro–musculo–skeletal components of the human hand and their interactions. For an electromechanical manipulator (Top), laws of mechanics define what grasping function a given manipulator (i.e., plant) can accomplish. Whether and how this function is realized depends on the ability of the controller to appropriately interpret task specifications and sensor signals, implement the appropriate control law, and send actuators signals to the plant. For a biomechanical system such as a human hand (Bottom), the anatomy (articulations, bones, sensory organs, muscles, etc) and central nervous system (CNS) are analogous to the plant and controller, respectively. Both machine and biological systems are part of the same continuum of solutions to the same mechanical challenge of manipulating objects. To date, our investigations have focused on how these fundamental neuro–musculo–skeletal elements of human fingers interact to produce static and dynamic fingertip forces for manipulation tasks such as precision pinch. We interpret "fingertip" loosely to mean the portion of the distal phalanx in contact with the object. (Adapted from Valero-Cuevas, 2000a.)

muscle activity. This paradigm has motivated me to pursue collaborative studies that combine principles of mechanics, anatomy and neurophysiology.

To understand the impairment and restoration of manipulation, I have begun by first comprehending the biomechanical requirements for static and dynamic precision pinch, and how the neuro–musculo–skeletal system meets those requirements. I refer to "static precision pinch" as the sensorimotor ability to regulate the magnitude and direction of the fingertip force/torque vectors in the absence of fingertip motion. "Dynamic precision pinch" also requires the regulation of finger motion (Murray et al., 1994; Valero-Cuevas et al., 1998; Valero-Cuevas et al., 2003b). For simplicity I use "finger" to mean any finger—including the thumb—unless otherwise specified, and "fingertip" as the portion of the tissue surrounding the distal phalanx in contact with the object manipulated. My focus on static and dynamic precision pinch is necessarily limited in that it does not yet address important issues such as neural and anatomical coupling among digits (Leijnse et al., 1993; Zatsiorsky et al., 1998; Latash et al., 2001; Li et al., 2001a; Keen and Fuglevand, 2003; Keen and Fuglevand, 2004a; Keen and Fuglevand, 2004b; Maas et al., 2004) or free finger motion (Cole and Abbs, 1986; Dennerlein et al., 1998b; Santello et al., 1998; Dennerlein et al., 1999; Sancho-Bru et al., 2001).

This overview of our work on the biomechanical function and neuromuscular control of the fingers is presented around three Research Themes: (I) Mechanics-based quantification of fingertip forces; (II) Anatomically realistic musculoskeletal finger models; and (III) Neural control of finger muscles.

2. Research Theme I: Mechanics-based quantification of fingertip forces

Using the scientific method requires that hypotheses be tested against experimental data. Therefore, a rigorous mechanics-based definition of finger function, and appropriate means to measure it, are prerequisites to progress in our clinical and scientific understanding of the biomechanical function and neuromuscular control of the fingers in manipulation. Roboticists, for example, have long been inspired and challenged by the functionality and versatility of the human hand—especially because its musculotendons are relatively sluggish actuators, nerve conduction velocities are much slower than electrical signals, and the musculature appears unnecessarily abundant. In their efforts to create comparably versatile robotic hands, they developed a mathematical framework to study the mechanical effectiveness of multifingered hands based on the function of their fundamental unit: the individual finger (Cutkosky, 1983; Murray et al., 1994). Effective precision pinch depends fundamentally on our ability to move and place the fingertips on an object, and to produce appropriate fingertip force and torque vectors (Cutkosky, 1983; Murray et al., 1994). In this Research Theme, we use a mechanical framework to find ways to define and measure the mechanical output of human fingertips as a necessary step to understanding multi-finger manipulation by the human hand.

From this mechanics perspective, human fingers are modeled as open serial kinematic chains of three rigid links with rotational degrees-of-freedom (DOFs) that allow control over the position and orientation DOFs of the distal phalanx (Fig. 2). The "Jacobian" matrix of this mechanism specifies the vector mapping from net torques at each DOF and fingertip forces/torques, and vice versa (Cutkosky, 1983; Murray et al., 1994). We have used these well-known relationships away from singularities to design experiments that unambiguously define the mechanical task specifications

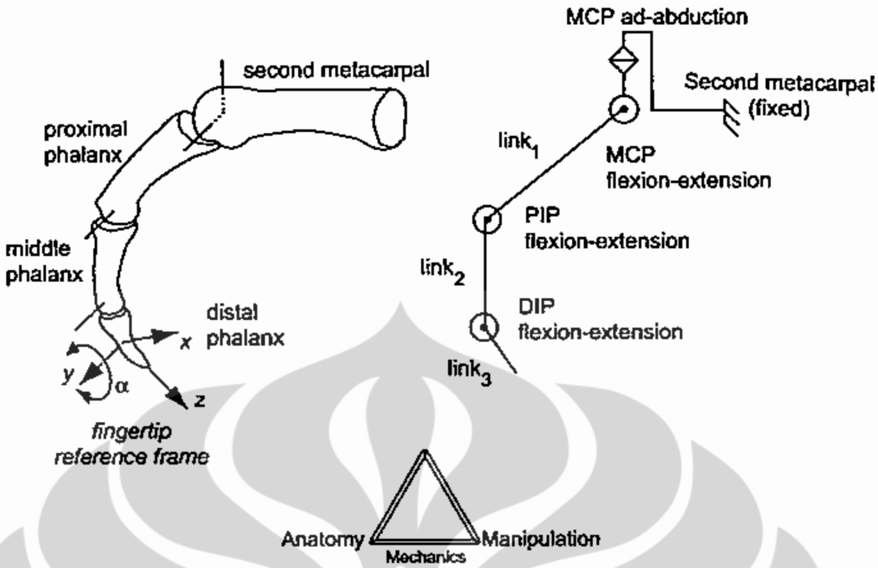

Fig. 2. Mechanics-based description and analysis of human fingers. Human fingers (Right) are assumed to be open serial kinematic chains of three rigid links with at least four rotational DOFs (Left—MCP: metacarpo-phalangeal, PIP: proximal inter-phalangeal; DIP: distal inter-phalangeal joints). Some "finger joints," like the MCP have more than one DOF, such as flexion-extension and ad-abduction (Research Theme II.1). Given that the three flexion-extension DOFs lie roughly in the same plane, the DOFs of the distal phalanx include its orientation (α) in that flexion-extension plane, plus its 3D location (x, y and z). This angular DOF at the distal phalanx grants it the ability to produce torque output in addition to the 3D fingertip force vector (Valero-Cuevas, 1997; Valero-Cuevas et al., 1998). For these idealized mechanisms, well-defined matrix functions like the "Jacobian" map joint angular velocity vectors into the vector of linear and angular velocities at the distal phalanx; as well as relate net torques at each DOF (the "net joint torque vector" in Fig. 7) to the vector of fingertip forces and torque. Such "wrenches" of combined linear/angular elements at the distal phalanx are part of screw theory upon which much of robotics analysis is based (Cutkosky, 1985; Murray et al., 1994).

(i.e., experimental question) to be studied. This mechanics-based approach has the important benefit of promoting mechanical equivalence between measured fingertip output and the predictive biomechanical models described in Research Theme II—which together inform our studies on the control of finger muscles described in Research Theme III.

2.1. Static fingertip forces

In the case of static precision pinch, we developed a thimble with metallic beads embedded on its outer surface, Fig. 3. When asked to produce static fingertip forces against the low-friction surface of a six-axis force sensor, participants had to direct fingertip force vectors within 16° of the surface normal or the thimble would slip, and produce no fingertip torque output (Fig. 2) or the thimble would rotate and change finger posture (Cutkosky, 1983; Murray et al., 1994; Valero-Cuevas et al., 1998; Valero-Cuevas et al., 2003a). In contrast, asking subjects to squeeze pinch meters with their bare fingertips (Mathiowetz et al., 1985) is a more ambiguous task. Higher surface friction allows fingertip force vectors to be directed inside a larger friction cone of about 30°, and finger posture can change by rolling on the finger pad (Cutkosky, 1983; Murray et al., 1994; Valero-Cuevas et al., 1998; Valero-Cuevas et al., 2003a).

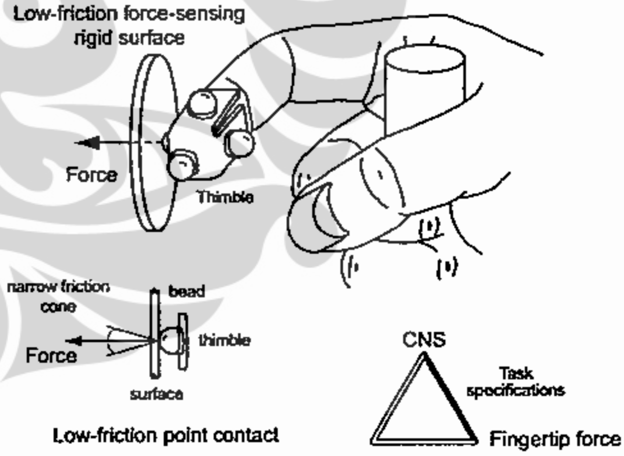

Fig. 3. Fingertip producing force against a rigid surface though a low-friction point contact. (Adapted from Valero-Cuevas, 1997; Valero-Cuevas et al., 1998.) To successfully maximize static force in each of five directions, subjects had to direct fingertip force vectors within 16° of the surface normal or the thimble would slip, and produce no fingertip torque output or the thimble would rotate and change finger posture.

2.2. Dynamic fingertip forces

The effectiveness of dynamic precision pinch (where finger motion is allowed) is determined by our sensorimotor ability to regulate the motion of the fingertips simultaneously with the magnitude and direction of the fingertip force/torque vectors (Valero-Cuevas, 2003; Valero-Cuevas et al., 2003b). This mechanics-based definition led me to develop the Strength–Dexterity (S–D) Test to quantify the simultaneous dynamic regulation of fingertip force vector magnitude (strength) and directional accuracy (dexterity) (Valero-Cuevas, 2003; Valero-Cuevas et al., 2003b). The S–D Test is based on the principle of buckling of compression springs (Fig. 4). The strength requirement is defined as the ability to produce sufficient fingertip force magnitudes to compress the spring. The dexterity requirement (quantified by the Dexterity Index; Valero-Cuevas et al., 2003b) is defined as the ability to prevent buckling by dynamically regulating fingertip movement and the magnitude and direction of fingertip force vectors. Because the S–D Test specifically quantifies one's ability to dynamically regulate finger motion and fingertip force vectors in 3D at submaximal force levels, it has the clinical potential to be informative of people's everyday manipulation ability. Testing maximal finger strength, in contrast, may not be as informative because submaximal forces suffice to accomplish activities of daily living in all but the weakest hands. To shorten the S–D Test for clinical use, we are developing a quick protocol (i.e., <5 min) to analyze the nonlinear dynamical behavior of how subjects delay or prevent spring buckling in physical or haptic virtual-reality systems, which provides valuable information about the sensorimotor capabilities of the fingers during dynamic precision pinch (Venkadesan et al., 2003a, b).

3. Research theme II: anatomically realistic musculoskeletal finger models

The legendary neuro–musculo–skeletal complexity of the human hand makes it challenging for even the most experienced clinicians to understand and predict how specific orthopedic and neurological pathologies and treatments affect finger function and multifinger manipulation. Our scientific community routinely predicts the complex neuro–musculo–skeletal interactions within and among fingers using biomechanical models based on principles of anatomy, biomechanics and neurophysiology (e.g., Chao et al., 1976; Cooney and Chao, 1977; Chao and An, 1978a; An et al., 1979, 1985; Spoor, 1983; Giurintano et al., 1995; Leijnse, 1997a; Santello and Soechting, 1997; Dennerlein et al., 1998a; Valero-Cuevas et al., 1998; Li et al., 2001b; Sancho-Bru et al., 2001; Kamper et al., 2002; Valero-Cuevas et al., 2003a). In spite of these efforts and advances in computer graphics, computational methods and CAD-like packages for biomechanical systems, we still lack validated predictive models of the neuro–musculo–skeletal interactions that produce finger force and/or motion. Our modeling efforts are directed toward overcoming what I consider today's two main computational challenges to creating clinically useful finger models: kinematically complex representations of finger joints with multiple DOFs and viscoelastic tendinous networks.

The unifying theme behind these challenges is the need to explicitly distinguish between model topology (i.e., the assumed biomechanical structure) and parameters values (i.e., the particulars of that structure). Today's biomechanical models consist of manually assembled topologies whose parameter values are adjusted to explain and/or reproduce some experimental data. Importantly, the inevitable discrepancies between predicted and measured data can be attributed to unsatisfactory parameter values, inadequate model topology or both. The challenge is to determine if additional or alternative explorations of the parameter space would improve results sufficiently, or if using an alternative model topology would be more fruitful. Improving current models necessitates that we explicitly investigate how the assumed model topology fundamentally determines and limits model behavior (Valero-Cuevas et al., 2003a). Therefore, we should begin to speak of a model space defined by the type, connectivity, properties and interactions of available "building blocks" such as links, tendons, muscles, etc. From this perspective, a specific model topology is, by construction, an instantiation in model space subject to the advantages and limitations of that model space (Lipson and Pollack, 2000). Our engineering training naturally encourages us to create tractable model topologies by using building blocks that are mathematically convenient, such as rigid links for phalanges, hinges for joints, inextensible strings for tendons, etc. There is certainly wisdom in Occam's Razor "Pluralitas non est ponenda sine neccesitate" (plurality should not be posited without necessity): One should not increase, beyond what is necessary, the complexity of model topology required to explain data. I shall nevertheless argue for extending the model space because available finger models do not explain basic motion and/or forces sufficiently well (Valero-Cuevas et al., 2003a). That is, additional or alternative searches of the parameter space may not suffice in cases when the model topology is inadequate. Specifically, I believe we need to add building blocks for (i) kinematically complex representations of finger joints with multiple DOFs (Valero-Cuevas et al., 2003a), and (ii) viscoelastic tendinous networks (Valero-Cuevas et al., 1998). In addition, the simultaneous exploration of model and parameter spaces is likely to be more a powerful means to create truly parsimonious realistic models, the goal of Occam's Razor.

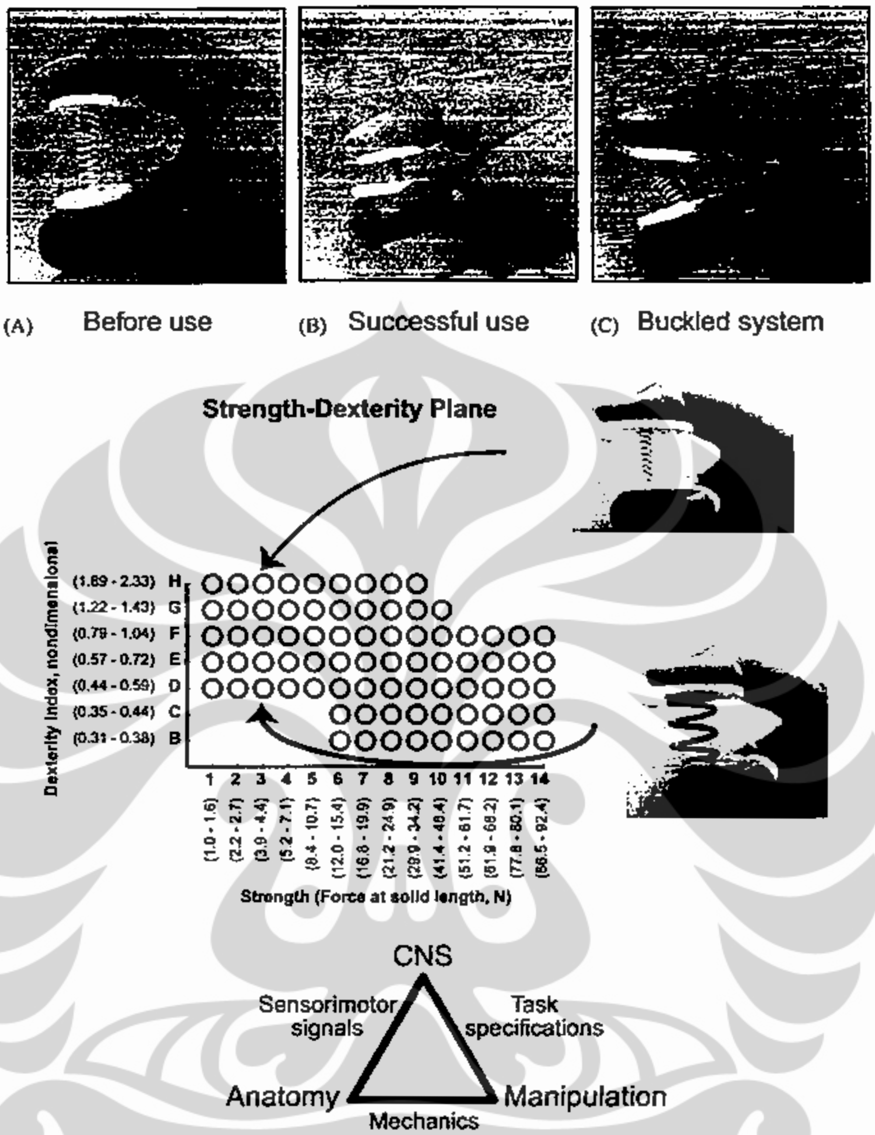

Fig. 4. The Strength–Dexterity Test (Valero-Cuevas, 2003; Valero-Cuevas et al., 2003b). Top: Using the fingertips to compress a helical spring prone to buckling. Fully compressing a helical spring with fingertip forces requires (i) that the magnitude of opposing forces overcome the spring resistance, and (ii) that fingertip movement and the directional accuracy of the forces be dynamically controlled to prevent buckling. (A) Initial configuration; (B) successful compression; (C) buckling of spring due to inappropriate control of fingertip forces, or directional accuracy. Middle: Every combination of strength and dexterity requirements can be represented as a point in the strength–dexterity plane. We have developed a discretized version of the strength–dexterity plane using 87 springs to form a grid, to be administered in random order. The subject is shown using dynamic key pinch with two springs with the same strength requirement (they are in the same strength column), but the top spring requires higher dexterity because it is more prone to buckling (see Valero-Cuevas et al., 2003b) for a detailed description).

3.1. Kinematically complex representations of finger joints with multiple DOFs

My work to date has focused on creating anatomically plausible, 3D biomechanical models to realistically reproduce a basic finger function: static fingertip force production in 3D. We have had encouraging success in creating a 4-DOF, 7-muscle index finger model capable of realistic predictions of static fingertip forces in multiple directions in the plane of finger flexion and the muscle coordination that achieve them (Valero-Cuevas, 1997; Valero-Cuevas et al., 1998). An exception to this finding was the inability of our model to predict the co-contraction of the interossei muscles seen during production of fingertip forces to the sides of the flexed index finger (Valero-Cuevas et al., 1998); which we interpret as a neural strategy to protect the collateral ligaments of the metacarpo-phalangeal (MCP) joint from longitudinal torsional damage, and which our model is inherently unable to predict because the model topology assumed the MCP to be a universal joint impervious to longitudinal torsion (Valero-Cuevas et al., 1998) (see Research Theme III.1).

In addition, we still lack such a model for the thumb. We are investigating whether the limitations of previous thumb models (Cooney and Chao, 1977; Chao and An, 1978a; Giurintano et al., 1995) arise from an incomplete search of the parameter space (i.e., uncertainty about parameter values and their variability) or inadequate model topology. We began by constructing a 3D, 5-DOF, 8-muscle thumb model with carpo-metacarpal (CMC) and MCP joints defined by two orthogonal and intersecting hinges (i.e., a universal joint; Valero-Cuevas et al., 2003a). We used Monte Carlo simulations to find the type and range of possible behavior for this model topology (Fishman, 1996; Hughes and An, 1997; Chang et al., 2000), where each of the 50 musculoskeletal parameters is described by a statistical distribution instead of a specific value. We explored the parameter space for this model topology by running to convergence iterative simulations with different random combinations of parameter values sampled from those distributions. We found this kinematic model topology could not map net joint torques into realistic thumbtip forces, regardless of parameter adjustments. Moreover, our recent cadaveric work suggests load-dependent motion of the trapezium (Pearlman et al., 2004) such that the thumb may act as a "floating digit" whose kinematics are affected by tendon loading, as suggested previously for the trapezium (Brand and Hollister, 1999) and carpus in general (Valero-Cuevas and Small, 1997). These results not only justify but also demand that we enlarge the model space to include alternative model topologies for thumb joints with multiple DOFs. We are currently exploring the model and parameter spaces with more kinematically complex representations of thumb CMC and MCP joints that (i) consider non-orthogonal and non-intersecting axes of rotations (the virtual 5-link thumb model; Giurintano and Hollister, 1992; Giurintano et al., 1995); or (ii) abandon mathematically convenient hinges in favor of model topologies where joint kinematics emerge from the interactions among joint forces, contact surfaces and ligamentous structures (Piazza and Delp, 2001).

3.2. *Viscoelastic tendinous networks*

The network of viscoelastic tendinous interconnections among intrinsic and the extrinsic extensor muscles is called the "extensor mechanism" or "dorsal aponeurosis" of the fingers (Bunnell, 1944; Zancolli, 1979; Tubiana, 1981; Garcia-Elias et al., 1991a, b; Zancolli and Cozzi, 1992; Netter, 1997). Sadly, Bunnell's words remain as true today as in 1944, especially with regards to biomechanical modeling of the extensor mechanism: "In the literature regarding the function of the intrinsic muscles controlling the fingers, one finds such a wide divergence of opinion that it is evident that the subject is still in the controversial stage. Textbooks of anatomy largely agree but are incomplete as they fail to consider synergic action between the muscles, stabilization and coordination, and the conception that lumbricales and interossei have a different action when the proximal finger joints are in their first half (45°) of flexion, than when in their second half, and a different function, depending on whether or not the extensor tendon stabilizes the proximal finger joints in extension.... The thin sliding dorsal aponeurosis of a finger [the extensor mechanism] is a complicated mechanism which makes for ingenious coordination in the action of the long extensors and flexors, and the lumbricales and interossei." (Bunnell, 1944, pp. 350, 351) (see also Bunnell, 1944; Tubiana, 1981; Ikebuchi et al., 1988; Garcia-Elias et al., 1991a, b; Netter, 1997; Brand and Hollister, 1999). There is clinical urgency to understanding the function of the extensor mechanism in the presence of anatomical variability (Ikebuchi et al., 1988) because muscle damage and imbalance often produce finger impairment and deformities such as clawing (Littler, 1973; Srinivasan, 1976; Mentari, 1978; Malaviya, 1991; Leijnse et al., 1992, 1993; Malaviya and Husain, 1993; Leijnse, 1997b; Brand and Hollister, 1999).

Biomechanical modelers understandably use simplified representations of the extensor mechanism for the sake of computational feasibility. Our work has shown that only when we represent the extensor mechanism as a 3D "floating net" (as a truss network in equilibrium) can models reproduce measured maximal isometric forces and the coordination patterns that produce them (Valero-Cuevas, 1997; Valero-Cuevas et al., 1998). Subsequent studies have successfully used this floating net approach to study finger movement (Sancho-Bru et al., 2001). However, there is still lack of an anatomically realistic comprehensive model of the extensor mechanism that can account for finger force, motion, and their pathologies. Achieving these research goals requires that we broaden the model space to include building blocks that allow representing the extensor mechanisms as topologies with 3D wrapping, non-symmetric deformable networks of viscoelastic bands. To this end we have created a modeling environment that can simulate load transmission in complex viscoelastic tendinous networks such as the extensor mechanism (Fig. 5) (Valero-Cuevas and Lipson, 2004; Lipson, in review; Valero-Cuevas and Lipson, in review).

3.3. *Model validation*

To validate our finger models we need to use experimental measurements beyond those presented in Research Theme I. One of our approaches is to use

Fig. 5. Extensor mechanism of the fingers. Graphical user interface of a modeling environment capable of simulating viscoelastic tendinous networks to represent the extensor mechanism (Lipson, in review; Valero-Cuevas and Lipson, in review). This modeling environment is a computational implementation of a 3D model space to assemble arbitrary finger topologies from building blocks that include rigid bones, joint contact mechanics, and wrapping deformable networks of viscoelastic tendons to simulate the extensor mechanism. We are using this modeling environment to create realistic finger models by simultaneously exploring both the model and parameter spaces.

direct actuation of the tendons of cadaveric fingers with simultaneous measurement of fingertip force/torque output (Valero-Cuevas et al., 2000; Valero-Cuevas and Hentz, 2002; Pearlman et al., 2004). These methods have helped validate modeling predictions in the tetraplegic hand, such as that bowstringing of the flexor profundus tendon at the PIP joint can greatly increase index finger strength (Valero-Cuevas and Hentz, 2002), and compare the force production capabilities of alternative tendon transfers for the thumb (Pearlman et al., 2004). The computer-controlled tendon actuation of cadaveric fingers (Pearlman et al., 2004) now allows us to combine parameter estimation techniques with on-demand data collection to quickly explore model and parameter spaces. At convergence, these finger models would reproduce experimental finger motion and force data in a maximal likelihood sense.

4. Research theme III: neural control of finger muscles

The fingers and their musculature are the interface between the central nervous system (CNS) and the objects being manipulated. Understanding the neuromuscular control of the fingers is, therefore, helpful to improving our understanding of how the nervous system interacts with the physical world. The problem of how the nervous system selects and regulates the coordination of "redundant" (or "abundant") musculature is central to the field of motor control. The production of submaximal static and dynamic fingertip forces is an under-constrained problem because multiple coordination patterns can achieve a mechanical task equivalently (Close and Kidd, 1969; Chao and An, 1978a, b; Darling and Cole, 1990; Valero-Cuevas et al., 1998; Valero-Cuevas, 2000b) (even though each coordination pattern has particular consequences in other functional dimensions such as musculoskeletal loading, metabolic cost, signal-dependent noise, etc.). Our insistence on mechanically well-defined experimental protocols (Research Theme I) stems from our attempt to leave as few aspects of the task as possible open to interpretation to mitigate the confounding effects of anatomical, neuromuscular and cognitive variability inherent to psychophysical studies of voluntary function. This approach also enhances the mechanical equivalence between the task specifications presented to human subjects and biomechanical models. The unifying theme of our studies described in Research Theme III is to drive the system to some limit of performance (i.e., constraining the task sufficiently; Raasch et al., 1995; Loeb, 2000) as an effective means to elucidate principles of biomechanical function and neuromuscular control.

4.1. Muscle coordination patterns necessary to reach limits of biomechanical performance

Our experimental approach has been to ask motivated subjects to maximize fingertip force magnitude to estimate the limit of biomechanically feasible fingertip forces, where muscle redundancy is predicted to disappear (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000b). Not surprisingly, investigators have reported subject-dependent coordination patterns for submaximal finger forces (Close and Kidd, 1969; Maier and Hepp-Reymond, 1995). By designing experimental paradigms with well-defined mechanical task specifications, and refining fine-wire electromyogram (EMG) techniques (Burgar et al., 1997), we have shown that different people use similar muscle coordination patterns to produce maximal voluntary fingertip forces in the index finger (Valero-Cuevas et al., 1998) and thumb (Johanson et al., 2001; Valero-Cuevas et al., 2003a). Moreover, such coordination patterns depend on the accuracy with which fingertip force vectors need to be directed and regulated (Johanson et al., 2001). These results are important because they motivate and justify seeking out task-specific and general principles for motor control of the hand.

One such line of research is to test the hypothesis that the neural control of finger musculature can be

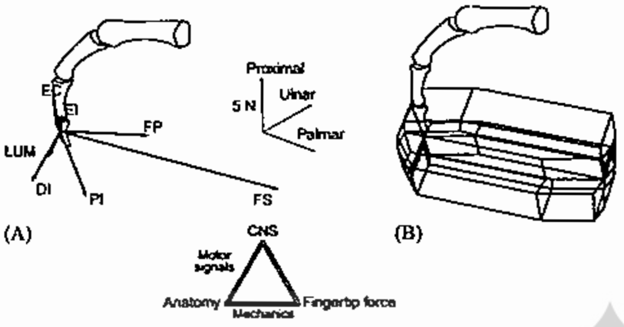

Fig. 6. The feasible force set of the index finger. The maximal biomechanically feasible fingertip forces, and the unique coordination patterns that achieve them, can be found by calculating the finger's "feasible force set": the 3D vector space representing maximal force production in all directions in "force space" (Lee and Rim, 1990). Each muscle produces a force vector at the fingertip (Valero-Cuevas et al., 2000; Pearlman et al., 2004) (Fig. 6A). The "convex hull" of all positive linear combinations of these vectors is the finger's FFS (Fig. 6B) (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000b; Valero-Cuevas and Hentz, 2002; Yokogawa and Hara, 2002). Nonlinearities in the transformation from tendon tension to fingertip force may distort the feasible force set (Pearlman et al., 2004), but it serves, at the very least, as a linearized approximation of the force production capabilities of a fingertip.

preferentially driven by the mechanical specifications of the task, as opposed to, for example, driven by possible sensorimotor interactions among motor unit pools within and across fingers (Schieber and Hibbard, 1993; Keen and Fuglevand, 2004b). In support of this hypothesis, we found the subject-independent coordination patterns measured during maximal voluntary static fingertip forces to compare favorably with the unique coordination patterns predicted to achieve those forces (Valero-Cuevas et al., 1998; Valero-Cuevas, 2000b). See Fig. 6 for a description of these predictions. This evidence encourages and justifies developing mechanics-based models to investigate the clinical impairment and restoration of hand function (Valero-Cuevas et al., 2000; Valero-Cuevas and Hentz, 2002), but only for those tasks where such mechanics-based control has been established. Importantly, distinguishing between what is or is not "task-driven" control depends on what we consider the task to be. For example, the co-contraction of the interosseous muscles seen for lateral forces with the flexed finger (Research Theme II.1) can be interpreted as a ligament-protecting neural strategy, or alternatively as an artifact of our incomplete definition of the task specifications of the nervous system that we are trying to meet. The next section discusses other aspects of co-contraction.

4.2. Using the "feasible set" analysis to understand co-contraction and important anatomical features

A fingertip needs to be able to produce force in every direction to be versatile (Spoor, 1983; Leijnse, 1996; Valero-Cuevas et al., 1998; Brand and Hollister, 1999; Valero-Cuevas, 2000b; Valero-Cuevas and Hentz, 2002). Said mathematically, the "feasible force set" of the fingertip (the description of the maximal fingertip force vector achievable in every direction of "force space;" Fig. 6B shows a 3D example; Lee and Rim, 1990) must span portions of all Cartesian quadrants. This functional requirement has important consequences to the routing of tendons and muscle co-contraction. Consider the 2-joint, 5-muscle planar finger in Fig. 7A, simplified to have only two DOFs to helps visualize coordination patterns. At a nonsingular finger posture, the Jacobian matrix relates fingertip forces and net joint torques to each other (Research Theme I). Thus for the fingertip to be versatile, the "feasible torque set" of the finger (the description of the maximal net joint torque vector achievable in every direction of "torque space") must also span portions of all Cartesian quadrants. See Fig. 7C for a 2D example for this planar finger. That is, finger musculature must be able to produce any combination of net joint torques. Fig. 7 shows how the multiarticular muscles m1 and m5 are particularly helpful to span quadrants I and III, respectively), which would otherwise require two uni-articular muscles (Leijnse, 1996; Valero-Cuevas et al., 1998; Brand and Hollister, 1999). Note that no finger muscle can produce torque exclusively at the distal joints (the vertical axis in Figs. 7B–D) because all tendons cross the most proximal joint. I now use the "feasible set" analysis to highlight three ideas. First, every muscle or tendon transfer, no matter how weak, contributes uniquely to the size and shape of the feasible force set of the fingertip. Thus, impairment or rehabilitation of any muscle will degrade or enhance the feasible force set, respectively (Valero-Cuevas and Hentz, 2002; Kuxhaus et al., in review). This perspective challenges current notions of "muscle redundancy" by making it difficult to decide which finger muscle we would rather do without; and suggests means to quantify the impairment and rehabilitation of subsets of muscles (Kuxhaus et al., in review). Second, spanning of quadrant IV of torque space benefits greatly from a multiarticular muscle (i.e., m4) that flexes the proximal joint and extends the distal joint (Figs. 7D). Interestingly, this tendon cross-over from flexor to extensor is a defining anatomical feature of the extensor mechanism (Research Theme II.2). Enlarging coverage of quadrant IV can only enlarge the feasible force set of the fingertip in some directions. Fig. 6 shows that the muscles acting on the extensor mechanism of the index finger (lumbrical and palmar interosseous) contribute to fingertip force vectors in directions useful to opposing the thumb during grasp and manipulation. While the opposite cross-over tendon route is also possible, those fingertip force vector directions would be in directions roughly opposite to those needed to oppose the thumb, which I speculate did not have as strong an evolutionary advantage. This view of the extensor mechanism

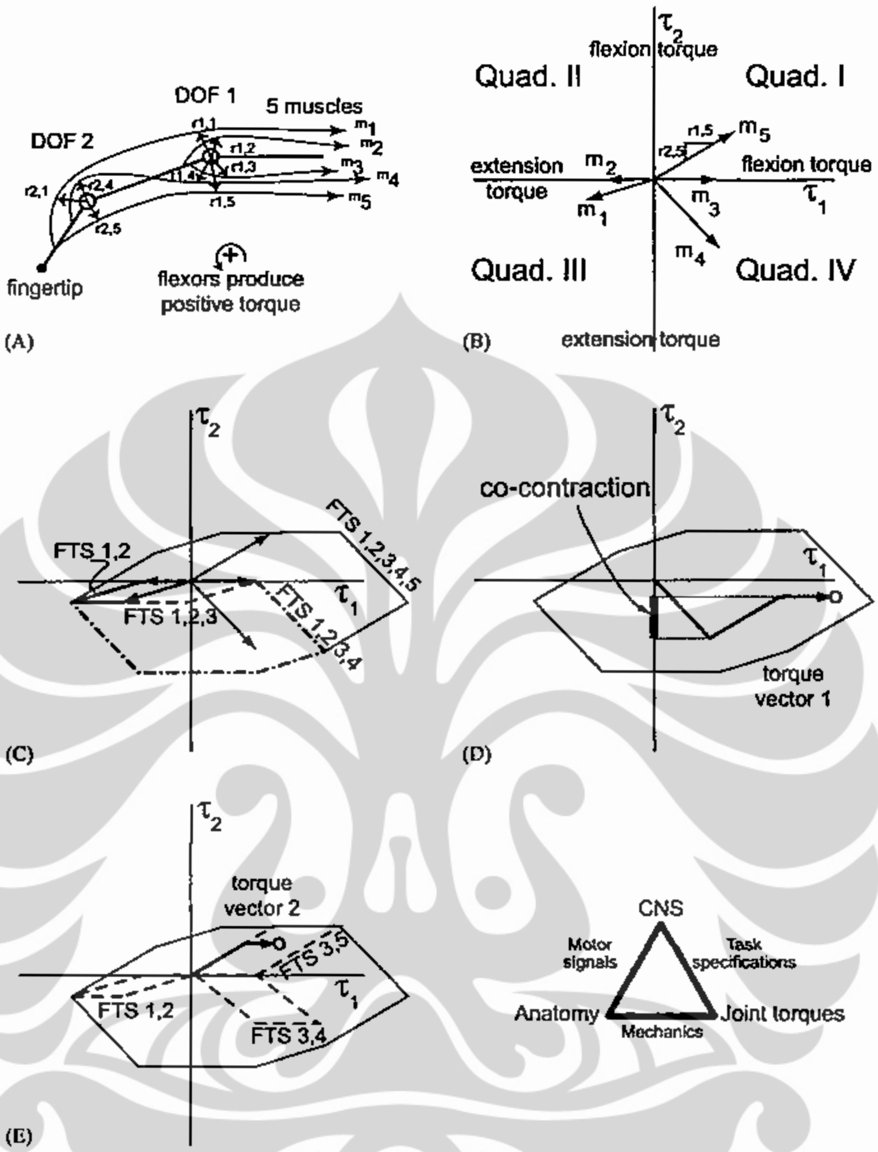

Fig. 7. Graphical interpretation of muscle coordination patterns for static force production in force and torque spaces. (A) Consider the 2-joint, 5-muscle planar finger, simplified to have only two flexion DOFs to helps visualize coordination patterns. To be versatile, the finger should be able to produce fingertip force vectors in all directions of force space (i.e., the plane of the finger in this case, or 3D space in Fig. 6). The anatomical routing of tendons results in a moment arm $r_{i,j}$ at DOF i for muscle j. (B) These moment arms determine the contribution of each muscle force to the net joint torque at each joint, which can be shown graphically as a vector in "torque space" (An et al., 1983; Leijnse, 1996; Valero-Cuevas et al., 1998; Brand and Hollister, 1999). Any net joint torque combination is simply a point described by a vector in torque space. To be versatile, the finger should be able to produce net joint torques in all quadrants of torque space. (C) The feasible torque space (FTS) defines all possible net joint torque vectors a group of muscles can produce. The FTS is calculated by finding all positive linear combinations of muscle actions in torque space (muscles can only actively pull). All possible torque vectors that m1 and m2 can produce are described by FTS1,2, and so on. Thus FTS1,2,3,4,5 specifies all biomechanically possible net joint torque vectors the musculature can produce. Note that (i), every muscle or tendon transfer, no matter how weak, contributes uniquely to the size and shape of the feasible torque set (and thus to the feasible force set). And (ii) spanning of quadrant IV of torque space benefits greatly from a multiarticular muscle (i.e., m4) that flexes the proximal joint and extends the distal joint—which is a defining anatomical feature of the extensor mechanism. (D) The simultaneous activation of agonists and antagonists at a DOF (i.e., co-contraction) is necessary to reach most regions of FTS 1,2,3,4,5 (Valero-Cuevas et al., 1998). Co-contraction is described graphically by a reversal along a torque DOF during production of a net torque vector. For example, producing net joint "torque vector 1" unavoidably requires reversing direction in at least one torque DOFs, as shown by the wide bar on the vertical axis for a solution combining the actions of muscles m3, m4 and m5. E: Only in the subset regions FTS 1,2, FTS 3,4 and FTS 3,5 is it possible to achieve a net joint torque vector without reversing direction, as in the case of "torque vector 2". Note that producing net joint torque vectors inside feasible FTS 1,2,3,4,5 is a redundant task because it can be accomplished by multiple strategies (Valero-Cuevas, 2000b). Thus, while reaching points in regions FTS 1,2, FTS 3,4 and FTS 3,5 can be done without co-contraction at any joint, there exist numerous other coordination strategies where co-contraction can be used (i.e., using a more circuitous vector addition). In contrast, co-contraction along at least one DOF is unavoidable anywhere else in FTS 1,2,3,4,5 (the total FTS for this finger).

provides a framework to investigate the degeneration of force and motion capabilities of the fingers when the tendinous or muscular balance of the extensor mechanism is disrupted (Bunnell, 1944; Srinivasan, 1976; Mentari, 1978; Malaviya, 1991). And third, co-contraction at some DOFs (i.e., simultaneous activation of agonists and antagonists of the same DOF) is in many instances not an option, but an unavoidable consequence of having multiarticular muscles (e.g., m3, m4 and m5 in Fig. 7D) (Valero-Cuevas et al., 1998). See Fig. 7D for examples of how producing vectors in most regions of torque space (and thus force space) necessitates co-contraction. The above three ideas naturally: (i) demand that we consider carefully the implications of the biomechanical structure of fingers before drawing conclusions about the neural selection of coordination patterns, or their optimality with respect to a given cost function. And (ii) suggest that drawing conclusions about the unique roles of "bi-articular" muscles may be premature without first considering the "tri-" and "tetra-" articular muscles of the fingers. See Prilutsky (2000) for a review of the current state of these issues.

4.3. *Scaling and regulation of muscle coordination patterns for static precision pinch*

Researchers have long proposed task-specific neural strategies to tolerate inaccuracies in the motor command and simplify the control of multiple muscles (Bernstein, 1967). By quantifying the similarity among coordination patterns—estimated via fine-wire EMG—during modulation of static fingertip force magnitude, I found evidence that the nervous system can control multiple muscles by simply scaling their relative activations (Valero-Cuevas, 2000b). This was important experimental evidence that simplifying strategies might exist at the level of the neural command. Prior evidence of simplifying strategies came from kinematic and kinetic data, which can often be produced by different neural commands (Latash et al., 2004). Recently, we (Valero-Cuevas and Todorov, 2003) have begun to investigate whether the control of multiple muscles of the fingers obey a "minimal intervention" principle (Todorov and Jordan, 2002). This ongoing work seeks to establish if the nervous system improves task-relevant performance by actively accumulating the inevitable variability and inaccuracy in the motor command in task-irrelevant output dimensions (the "uncontrolled manifold;" Scholz and Schoner, 1999; Latash et al., 2004). Our preliminary results suggest that variability in EMG (indicative of noise in the motor command) is actively combined in ways that attenuate noise in the desired fingertip force vector magnitude and direction (Valero-Cuevas and Todorov, 2003).

4.4. *Limit of sensorimotor integration for dynamic precision pinch*

The S–D test is different from maximal force production tasks in that it brings the fingers to a limit of sensorimotor integration at low force magnitudes comparable to those used in everyday tasks (Valero-Cuevas et al., 2003b).We have found the S–D test for key and tip pinch to be repeatable and able to distinguish between unimpaired hands and those with thumb osteoarthritis (Valero-Cuevas et al., 2003b). More recent results suggest that this limit of sensorimotor integration is independent of the person's pinch strength (Venkadesan et al., 2003a, b). In collaboration with neurophysiologists and radiologists, we are combining the S–D test with fMRI to characterize cortical activity correlated with sensorimotor processes necessary for successful manipulation (Talati et al., 2003). Extending this work has the potential to help us understand the association between specific brain disorders and loss of specific features of manipulation function (e.g., strength vs. dexterity).

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TABEL VI
NILAI-NILAI CHI KUADRAT

dk	Taraf signifikansi					
	50%	30%	20%	10%	5%	1%
1	0,455	1,074	1,642	2,706	3,481	6,635
2	0,139	2,408	3,219	3,605	5,591	9,210
3	2,366	3,665	4,642	6,251	7,815	11,341
4	3,357	4,878	5,989	7,779	9,488	13,277
5	4,351	6,064	7,289	9,236	11,070	15,086
6	5,348	7,231	8,558	10,645	12,592	16,812
7	6,346	8,383	9,803	12,017	14,017	18,475
8	7,344	9,524	11,030	13,362	15,507	20,090
9	8,343	10,656	12,242	14,684	16,919	21,666
10	9,342	11,781	13,442	15,987	18,307	23,209
11	10,341	12,899	14,631	17,275	19,675	24,725
12	11,340	14,011	15,812	18,549	21,026	26,217
13	12,340	15,19	16,985	19,812	22,368	27,688
14	13,332	16,222	18,151	21,064	23,685	29,141
15	14,339	17,322	19,311	22,307	24,996	30,578
16	15,338	18,418	20,465	23,542	26,296	32,000
17	16,337	19,511	21,615	24,785	27,587	33,409
18	17,338	20,601	22,760	26,028	28,869	34,805
19	18,338	21,689	23,900	27,271	30,144	36,191
20	19,337	22,775	25,038	28,514	31,410	37,566
21	20,337	23,858	26,171	29,615	32,671	38,932
22	21,337	24,939	27,301	30,813	33,924	40,289
23	22,337	26,018	28,429	32,007	35,172	41,638
24	23,337	27,096	29,553	33,194	35,415	42,980
25	24,337	28,172	30,675	34,382	37,652	44,314
26	25,336	29,246	31,795	35,563	38,885	45,642
27	26,336	30,319	32,912	36,741	40,113	46,963
28	27,336	31,391	34,027	37,916	41,337	48,278
29	28,336	32,461	35,139	39,087	42,557	49,588
30	29,336	33,530	36,250	40,256	43,775	50,892