Designing safety into products
Making ergonomics evaluation a part of the design process

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Designing safety into products

Making ergonomics and safety part of your design process

This is a handbook for designers and producers of consumer products, written by The Product Safety and Testing Group at the University of Nottingham and funded by the Department of Trade and Industry (DTI).

The Product Safety and Testing Group was established in 1991 to carry out investigations into the safety and design of consumer products. The group is multi-disciplinary, being based jointly within the Institute for Occupational Ergonomics and the Department of Manufacturing Engineering and Operations Management at the University of Nottingham. The work of PSTG draws on ergonomics, psychology, materials and engineering expertise and includes evaluations of product safety for Government Departments and for industry, and fundamental research into ergonomics, product design and consumer safety issues.

The authors would like to thank Drs Alison Black, Samantha Porter and Christine Haslegrave for their advice and comments.
**Foreword**

Product safety in the UK is achieved through a number of different but complementary measures – regulations (National and European), voluntary standards, voluntary agreements/codes of practice and consumer safety awareness initiatives. There is however a more basic means of improving product safety, which is sometimes overlooked: the ergonomics evaluation of safety of the product throughout the design process. This requires the designer to take account of the characteristics, abilities and limitations of potential users throughout the process of designing, developing and marketing products.

In the past, the application of ergonomics to the product design process has been limited, sometimes due to a lack of specific, applicable data but always by a lack of practical methodological advice. The dearth of operational guidance does in part reflect the difficulty of providing such advice, in a form which is sufficiently general to be appropriate to a range of products and users, yet sufficiently specific to be directly applied by those involved in design and production. A vital part of any ergonomics contribution to product development is the testing of the product-user interaction, but assessing this can be extremely complex both in the methods used and also during development.

The University of Nottingham has combined with the Department of Trade and Industry and the Design Council to develop this guidance document to help improve the design process and ‘build in’ safety. Ergonomics evaluation within product design will have a number of benefits for both the producer and the user. Greater emphasis on safety at the design stage will lead to reduced frequency and severity of accidents for users and thus to fewer legal problems, either with dissatisfied customers or with the enforcement authorities. At the same time usability and product quality will be improved, developments which will boost UK business, as they increase business competitiveness, and also benefit the consumer.

Indeed early and continuing ergonomics evaluation, if applied at the right times and with the appropriate level of sophistication, can give significant gains in the efficiency of the development process, thus accelerating the development of a new and better products.
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About this book

What this handbook contains

This handbook will help you:
- understand the issues involved in ergonomics evaluation, and their importance in product safety
- gain competitive advantage from improving your evaluation
- develop a more formal and valuable evaluation process.

The advice we give is wide enough to be relevant to most sectors and types of products. Similarly it is adaptable enough to be used by small and large companies alike. We show how ergonomics evaluation can help when you are:
- developing a completely new product concept (for example mobile phones, car airbags)
- designing a new product within an existing concept (a new stair gate)
- redesigning an existing product to incorporate a new:
  - function (multi-function infant carrier)
  - feature (cordless power tools)
  - control/operating procedure (remote versus hands-on)
  - display (head-up car display)
  - mechanism (child resistant lighters)
  - structure (railings on the side of a cot)
  - styling (change of colour for controls).

Who should read it

This handbook is aimed primarily at product designers, but can also be read by design managers, directors and marketing managers – anyone who is concerned with product safety. If you have a basic understanding of ergonomics you will be familiar with some of the issues we discuss.
Designing safety into products

INTRODUCTION

This handbook is about improving the safety of your products. As we shall see this can also mean enhancing the effectiveness of your product as well as customer convenience and satisfaction. To understand how to do this we need to introduce the concepts of design safety, ergonomics and evaluation.

Safety of a product has two broad components. Construction safety depends on appropriate use of materials, components that do not wear out, quality of manufacturing – anything related to how the product is constructed, no matter what the design. All producers should have in-house total quality procedures, and access to test houses where necessary, to ensure the construction safety of their products.

Design safety is determined by whether the concept and presentation of a product provides anyone who might come into contact with it a level of safety that might reasonably be expected. This safety should extend to users, bystanders and even misusers – for instance, children who may ‘play’ with a product in a way not intended.

Because we are interested in design safety we are interested in interactions. The study of how people interact with products, tasks, environments and other people is called ergonomics. More importantly, ergonomics uses the knowledge from such study to improve effectiveness, efficiency, comfort, satisfaction, health and safety of people at work, in the home, on transport and at leisure.

Ergonomics evaluation is a process that incorporates ergonomics data, knowledge and testing within the whole design process. It helps you to:
- ensure your product is reasonably safe for its intended use and its intended users
- extend such safety to include foreseeable misuse, including use by unintended users such as children
- identify those at risk
- identify the likelihood of injury
- quantify the likely severity of any injury
- highlight possible design improvements.

This handbook encourages you to see ergonomics evaluation as something which takes place throughout the design process.
Designing safety into products [5]

INTRODUCTION

DESIGN SAFETY AND ERGONOMICS

Approaches to ergonomics evaluation

There are four main approaches to ergonomics evaluation:

• Checking against sources of ergonomics data and guidelines (see page 13) – ergonomics data describe the physical, motor and cognitive capabilities of humans, for instance average arm length, the force required to turn a handle, stride distance, reaction times and so on. Ergonomics guidelines will be general design rules derived to take account of the user – avoiding sharp edges, colour coding of controls, varying surface temperatures. Taking data and guidelines into account when designing will give you some basic parameters within which your product must fit in order to be usable, but are fairly limited in terms of safety. This is because most data and guidelines are generic and they do not enable you to take specific conditions or environmental factors into account, they don’t allow for people’s attitudes or preconceptions to a product or safety, and because they don’t enable you to consider misuse. They give standard information, but people rarely behave in standard ways.

• Modelling (see page 15) – modelling involves using some kind of representation of potential users to assess a design. The representation (or model) can be paper-based or computer-based and can represent the user to varying levels – two- and three-dimensional models through to dynamic computer models. Modelling is most useful for assessing the physical ‘fit’ between users and products, for instance, reach to controls, movement spaces around products, and the lines of vision around a product.

• Design appraisal (see page 16) – design appraisal involves asking people with some specialist knowledge (often other than the design team) to assess a design or product. This aims to provide an insight into the product, and particularly its safety, which would not be provided by the design team alone. The assessors can be people with a background in safety or in a particular group of products, specialists with knowledge about a specific groups of users (such as the elderly), or users themselves, such as those who have experience with a product or even who have never used it.

• User trials (see page 17) – this is the name we use to describe observing and measuring a sample of ‘users’ carrying out a task with a product and assessing how they do it. A user can be anyone who may potentially come into contact with the product (see page 10 for ways of identifying them). This is most useful for safety, as the tests can closely resemble real life. User trials are vital if you want to understand how a product will be used, to understand how an accident might happen, or to identify unknown hazards, and are generally necessary when there are no directly applicable data, guidelines or models.
INTRODUCTION

DESIGN SAFETY AND ERGONOMICS

How evaluation can help you: competitive advantage and commercial gain

Any of the four approaches to evaluation can lead to improved usability, better interfaces, presentation and styling as well as safety. These improvements will help to make your products competitive and increase customer satisfaction. Further commercial advantages can also be realised by making ergonomics evaluation an integral part of your design process.

You must consider the issue of compliance with standards and regulations.

Of course designers take these standards seriously, and companies make sure that their products comply with regulations. But in many companies this is where concern with safety starts and finishes: ‘As long as we comply with the regulations and don’t do anything wrong, then we’re doing our bit, aren’t we?’

While standards and regulations ensure a basic level of consumer safety, a higher level of safety can only be achieved by thorough and systematic evaluation of products.

This guide encourages you to make safety an initial concern, from early prototypes onwards. Doing so saves costs and time. It is usually easier to adapt a product while it is still at an early design stage, rather than change it later. Safety ‘designed in’ costs less than safety ‘bolted on’. Although the up-front costs of ergonomics evaluations can seem high, they should be recouped through:

• increased sales
• reduced alteration costs in later stages of design and manufacturing
• improved company and product image
• reduced accidents and associated legal costs.

Ergonomics evaluation is particularly helpful in sectors or product ranges where:

• there are few standards. A well-run evaluation process can help you become a best-practice company, ahead of the competition and in a position where you are not so much complying with standards as setting them. In some markets you could then advertise safety advantages. Furthermore, over time your record could lead to a good relationship with consumer groups, strong showings in consumer tests (eg Which? magazine) and a word-of-mouth reputation for safety, with consequent strong commercial advantages.

• regulations are constantly changing. If you find yourself having to change products or even manufacturing processes to comply with new regulations, then the costs involved can harm your competitiveness. Your aim should be to get ahead of the game in terms of safety, rather than being reactive.

• regulations vary throughout the world. If you are selling your product in different geographical markets, you may find that safety levels acceptable in one are insufficient in another. The ideal approach is to achieve safety levels that exceed the standards of the most stringent market. This may mean you need to work harder at safety than previously. Ergonomics evaluation will help you achieve this.
Bringing safety into the product development process

There are a number of ways in which ergonomics can be used to bring safety into the product design process, and there are various stages at which this can happen.

The diagram below indicates where ergonomics design considerations and inputs fit into a typical product development process:

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1 CHILDATA: The handbook of child measurements and capabilities is a collection of data on over 180 measurements on children, aged from birth to 18 years from Europe and elsewhere, published by the DTI. The data include anthropometry, strength, psychological characteristics and product-related performance. The handbook is a designer’s resource aimed at increasing the use of ergonomics data in designing for children. Available from R. Rose, CACP1, 4, G. 9, 1 Victoria Street, London SW1H OET, tel 0171 215 0383.

A similar publication on adults – ADULTDATA – will be published at the end of 1997.
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DESIGN SAFETY AND ERGONOMICS

What should you evaluate?
The interaction between a product and its user is affected by four factors:

• the features of the product: structure, moving parts, power sources, cas-
ingings, packaging, controls, displays, information and instructions, fixings
and ancillary equipment

• the physical and psychological characteristics of the user (see diagram
below)

• what the user wants to do with the product

• environmental factors such as the visual, thermal and auditory environ-
ments of use and social conditions.

<table>
<thead>
<tr>
<th>User characteristics</th>
<th>examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal characteristics</td>
<td>age, gender, family, literacy, education</td>
</tr>
<tr>
<td>Anthropometric characteristics</td>
<td>stature, weight, limb lengths, head size, hand size, reach, movement</td>
</tr>
<tr>
<td>Strength</td>
<td>momentary or sustained forces that can be exerted, pushing strength, bite strength</td>
</tr>
<tr>
<td>Motor skills</td>
<td>hand-eye co-ordination, reaction times, movement, balance, climbing stairs</td>
</tr>
<tr>
<td>Psychological characteristics</td>
<td>visual perception and auditory perception, information processing related to labelling, attention, memory</td>
</tr>
<tr>
<td>Experience and exposure</td>
<td>years of driving, use of power tools</td>
</tr>
<tr>
<td>Personality</td>
<td>motivation, risk taking, perseverance, attitude</td>
</tr>
<tr>
<td>Physiological characteristics</td>
<td>fatigue, endurance, energy expenditure</td>
</tr>
<tr>
<td>Behaviour</td>
<td>skilled performance at tasks specific to a product</td>
</tr>
<tr>
<td>Sensory characteristics and tolerance</td>
<td>vision, hearing, taste, smell, touch, sensitivity to temperature, vibration</td>
</tr>
<tr>
<td>Socio-economic background</td>
<td>related to exposure and experience with products, tasks or environments</td>
</tr>
<tr>
<td>Cultural differences</td>
<td>housing, income</td>
</tr>
<tr>
<td>Disabilities</td>
<td>physical, social, language</td>
</tr>
</tbody>
</table>

You must consider all of the above factors when evaluating safety. You
should also look at every stage of your product’s lifecycle, embracing:

• manufacture
• transport
• packaging
• assembly
• installation
• use by all potential users
• misuse by all potential users
• storage
• maintenance
• cleaning
• dismantling
• disposal
• re-use (second-hand life)
• recycling.
Suggested evaluation process

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Design appraisal 16
User trials 17
Acting on the results 26
First steps in evaluation

Identify all possible users
Identify potential hazards
Set performance criteria
Choose a method of evaluation

The issues discussed in the following pages are not presented as step-by-step instructions. They cover a generic process, which you can pick and choose from and adapt into an approach of your own. You don’t need to do everything we suggest, nor do you need to do things in this order, though they are arranged logically.

In some areas we set out a best case scenario, and then outline the implications of concessionary steps away from it. ‘Perfect’ testing is not always possible in the real world, where time, cost, personnel resources and other factors need to be taken into account.

While this process is aimed primarily at improving safety, it will also contribute to other aspects of your design and manufacturing process, leading to improved product quality all round.

The first steps in the evaluation process are to identify all possible users of your product and then all potential hazards. You can then choose the best type of evaluation.

Identify all possible users
Think about everybody who might come into contact with your product. This means looking at:

- intended users – your target market
- potential users – other people who might use the product
- unintended users – people who are not expected to use the product but may come into contact with it anyway, such as children.

If this process identifies vulnerable users (for instance children, the elderly, or people with special needs), then you must focus on their use of the product.

If your product will be used internationally, or by different cultures or groups within the same country, then the users may have differing experiences or previous exposure to it. These will affect the way the product is perceived and used.

Outcome
A list of intended users, potential users and unintended users, plus their characteristics, abilities and perceptions as they relate to the product.

Example

**Designing a new product concept – a mobile phone**

- Intended users: adults from teenage upwards
- Other potential users: elderly, physically impaired
- Unintended users: small children
Identify potential hazards

Anticipate everything about your product that could go wrong or be dangerous – its hazards. It helps to look at them in a structured way and come up with a considered and thorough list.

How to identify potential hazards

There are a number of things you can do and sources of information you can use to draw up a list of potential hazards:

- review regulations and standards. If these exist for your product, then some potential hazards will already have been identified and minimum safety criteria set for them.
- analyse accident statistics to see what types of accidents are occurring, who is being injured, where, when and how.
- produce a user specification based on your list of potential users (see page 10)
- build up scenarios of how different people might use a product in different circumstances
- observe and analyse how similar products are used.
- carry out design appraisal (see page 16) with people other than the design team who may have an idea about the way the product will be used and its potential hazards.

Set performance criteria

Once you have a list of potential hazards, you must assess how likely they are. This is known as the element of risk. To do this you must set performance criteria for each hazard. These criteria are effectively design specifications which your product must meet so that hazards do not occur, and which will form the basis of your testing procedures. (The process of setting performance criteria is shown as an example within ‘User trials’, see page 20.)

In cases where a hazard cannot be completely ‘designed out’ and you cannot avoid some level of risk, then make the most of other means of accident prevention such as instructions, labelling and safety education.

<table>
<thead>
<tr>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>A list of potential hazards, consequent risks and corresponding performance criteria.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Child safety gate</strong></td>
</tr>
<tr>
<td>In the example of a child safety gate, a potential hazard might be the inadvertent operation of the catch by a child. The performance criterion for this hazard would be that the catch cannot be opened by any child under five years old.</td>
</tr>
<tr>
<td>If a hazard cannot be completely ‘designed out’, performance criteria may have to be set for an acceptable level of risk. For instance, a catch on a safety gate that can be opened by 10% of two-year-old children would be an unacceptable risk, but a mechanism with .001% risk of a bruised finger might be acceptable.</td>
</tr>
</tbody>
</table>

Choose a method of evaluation

You now need to work out which type of evaluation best suits the hazards and users you have identified. The chart on page 12 gives some example suggestions. We explain these evaluation methods in the next sections. Sources of more detailed information on most of the methods described here are given in the bibliography (see page 29).
## Suggested Evaluation Process

### First Steps in Evaluation

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Hazard Scenario</th>
<th>How to Evaluate the Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical Hazards</strong>&lt;br&gt;• access to hazard&lt;br&gt; (by whole body or body part)&lt;br&gt;&lt;br&gt;• entrapment/jamming/&lt;br&gt; pinching/shearing&lt;br&gt; • between moving parts&lt;br&gt; • in an aperture&lt;br&gt; • between structures&lt;br&gt;&lt;br&gt;• impact&lt;br&gt; • user into product&lt;br&gt; • product into user&lt;br&gt; • powered&lt;br&gt; • sharp edges&lt;br&gt;&lt;br&gt;• fall&lt;br&gt; • between levels&lt;br&gt; • on same level&lt;br&gt; • unstable product</td>
<td>reach through guarding, child climbing over a stair gate, finger in electrical socket&lt;br&gt;• fingers trapped in doors&lt;br&gt;• head in cot sides&lt;br&gt;• open stairs&lt;br&gt;• trip into furniture&lt;br&gt;• insecure fittings&lt;br&gt;• slipping with a power tool&lt;br&gt;• dropping/falling onto a knife&lt;br&gt;• fall down stairs&lt;br&gt;• slippery floor surface&lt;br&gt;• fall from stepladder</td>
<td>check against anthropometric data, user trials possibly with simulated users&lt;br&gt;check against anthropometric data, computer simulation, user trials possibly with either simulated hazards or users&lt;br&gt;user trials, possibly with simulated users or product, or by protecting user during test</td>
</tr>
<tr>
<td><strong>Ingestion Hazards</strong>&lt;br&gt;• toxic substances&lt;br&gt;• choking</td>
<td>- cleaning products&lt;br&gt;- small parts swallowed by children</td>
<td>user trials, with simulated users</td>
</tr>
<tr>
<td><strong>Explosive Hazards</strong>&lt;br&gt;batteries, pressurised containers or mobile phones in contact with fire</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fire Hazards</strong>&lt;br&gt;children’s use of lighters, clothes in contact with naked flames</td>
<td></td>
<td>ergonomics guidelines, user trials, technical evaluation</td>
</tr>
<tr>
<td><strong>Electrical Hazards</strong>&lt;br&gt;not unplugging product before maintenance, handgrip too close to live component</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thermal Hazards</strong>&lt;br&gt;(extremes of ambient and surface temperatures)&lt;br&gt;contact with cooker surfaces, metal surfaces in extremes of heat or cold, fires and room heaters, radiators, freezer parts</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vibration Hazards</strong>&lt;br&gt;sustained use of power tools</td>
<td></td>
<td>ergonomics guidelines, user trials with simulated users, checking against data on human exposure rates, technical evaluation</td>
</tr>
<tr>
<td><strong>Noise Hazards</strong>&lt;br&gt;prolonged exposure to alarms</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chemical Hazards</strong>&lt;br&gt;carbon monoxide poisoning, cosmetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Radiation Hazards</strong>&lt;br&gt;checking against data on exposure rates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Checking against ergonomics data and guidelines

How and where data can help
Checking your product against standard ergonomics data is a useful starting point for evaluating safety. Some examples are:

<table>
<thead>
<tr>
<th>user interacts with</th>
<th>examples</th>
<th>how data could help</th>
<th>examples of what data to check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>safety pictograms</td>
<td>recognition and comprehension by all users</td>
<td>understanding of colour codes, symbols, perception of hazards</td>
</tr>
<tr>
<td></td>
<td>warning alarms</td>
<td>recognition and comprehension by specific occupational users</td>
<td>auditory perception</td>
</tr>
<tr>
<td>Social environment</td>
<td>supervision</td>
<td>recognition of child hazards by adults, design of warning systems</td>
<td>adult knowledge/perception of child capabilities</td>
</tr>
<tr>
<td>Physical environment</td>
<td>window and door handles</td>
<td>make usable by adults, elderly and disabled but inoperable by children</td>
<td>overhead reach height, opening strength, specific behaviour related to window handles</td>
</tr>
<tr>
<td></td>
<td>public movement areas</td>
<td>optimal movement space for general use and in emergencies</td>
<td>general ergonomics guidelines and national building regulations for movement spaces</td>
</tr>
<tr>
<td>Personal space</td>
<td>machine guarding</td>
<td>prevent access to hazard through or around guard</td>
<td>maximum and minimum adult finger size, hand size, pushing and pulling strength</td>
</tr>
<tr>
<td></td>
<td>stairs</td>
<td>prevent tripping and falls</td>
<td>step height, balance, foot length</td>
</tr>
<tr>
<td></td>
<td>fireguard</td>
<td>prevent access and operation of catch by children</td>
<td>child finger size, hand strength, pushing and pulling strength, specific behaviour related to mechanism</td>
</tr>
<tr>
<td>Product</td>
<td>medicines and packaging</td>
<td>make child resistant (inoperable and unattractive) whilst accessible to adults, elderly and the disabled</td>
<td>opening strength, psychomotor skills, cognitive/problem solving abilities of all potential users</td>
</tr>
<tr>
<td></td>
<td>infant soother or pacifier</td>
<td>prevent swallowing by child</td>
<td>mouth and throat size</td>
</tr>
<tr>
<td></td>
<td>bicycle</td>
<td>reach to pedals and handlebars, size of handlebars</td>
<td>arm length, leg length, sitting height, hand size</td>
</tr>
</tbody>
</table>
SUGGESTED EVALUATION PROCESS
CHECKING AGAINST ERGONOMICS DATA AND GUIDELINES

Limitations of using ergonomics data and guidelines

There are a number of issues to bear in mind before using published data and guidelines:

• anthropometric or strength data may have been measured on a different population to that for which you are designing. Early anthropometric data were measured on military personnel – fairly inappropriate for the wider population. There are less, or less accessible, data on children and the elderly because they were not needed for occupational or military design. Check who the data were collected for.

• anthropometric data can also be out of date as some human characteristics change over time: for instance people are bigger now than they were fifty years ago. Check when the data were collected.

• the conditions in which ‘performance’ data are collected should be similar to those in which they will be applied: task conditions (e.g., size and position of controls), environmental conditions (lighting, temperature) and social conditions (time of day) will affect how people will perform. For instance, opening strength measured on a 5cm diameter horizontal door handle cannot be applied with confidence to assessing the strength required to open a 2cm screw-top on a drugs container.

• ergonomics guidelines can sometimes be too general to apply with confidence, or else too specific to the application for which they were originally derived.

• guidelines often do not take account of users’ psychological characteristics – their previous experience with a product, expectations, perception of risk, attitude – which will all affect how a product is used.

Data can also often be difficult to find and access (see bibliography page 29).

Outcome

Identify data relevant to your product and its users. Turn these data into basic design parameters. If no appropriate data are available, consider how such data could be measured or estimated.

Example

Redesigning an existing product to incorporate a new mechanism – a child-resistant lighter.

The designer might look at data for:

• child finger and hand size
• children and adult grip strength
• child cognitive capabilities with prevention devices
• motivation to explore and play with the product.

When you have found useful data, check when they were collected and who they were measured on, and make sure you used the most up-to-date, applicable and reliable source.
Modelling involves user representation, usually to assess the physical ‘fit’ of the product to the user. Methods include two- and three-dimensional computer modelling to evaluate, for instance, reach to controls, movement spaces around products, and lines of vision around a product. Modelling methods can be quick, cheap and simple to use and can provide early answers to questions of fit and avoid the need for user trials.

Two- and three-dimensional techniques include static and moveable mannequins and dummies. The limitations of these techniques are:
- they usually only represent a selection of the population you are designing for
- the usefulness of dummies and mannequins depends on how relevant the anthropometric data on which they are based are to your design – check the data they are based on
- they cannot account for human behavioural or psychological characteristics and the effect they have on safety, for instance the effect that motivation and stretching can have on maximum reach.

Commercially-available computer software enables designers to model some aspects of the product/user interaction. Most programs contain a model of the user which can be manipulated to some degree. These vary from stick drawings to Virtual Reality. Programs can model dimensional fit between the human, product and environment, force exertions and the effects of manual handling on the body.

Computer modelling is most useful when you are assessing ‘fit’ – the size of the products, reach, movement and visual fields. Advantages are:
- the ability to visualise things clearly
- the ability to calculate safety tolerances (for instance the minimum distance allowed between the user and a moving part of a product)
- models can be re-used and adapted indefinitely
- evaluations are quick once models are established
- the ability to integrate with other computer techniques such as CAD, and presentation software
- low running costs after initial purchase.

Disadvantages are:
- models may have unrealistic or limited movement
- accuracy depends on the data on which the program is based
- getting the modelling started can be time-consuming.

User trials themselves (see page 17) can involve an element of modelling in that sometimes it may be necessary to use a representation of the user, because of ethical or practical restrictions (weighting a bike during crash-testing instead of using a rider for instance). This is referred to as simulation in user trials and is discussed in that section.
Design appraisal

Design appraisal uses the knowledge and insight of groups of people, usually other than the design team, to give an alternative view of the design and its safety. This can be especially useful in identifying hazards or usability problems that the design team will not have predicted. Design appraisal will rarely provide any ‘measurements’ of safety or quantifiable results, for instance that all elderly people will be able to operate a fire extinguisher.

Appraisals work best when they bring together a panel drawn from as many as possible of:

- ergonomists
- safety professionals
- engineers
- other designers
- experts in the product (manufacturers, suppliers, installers, repairers, servicers)
- experts in the environment (school teachers, gardeners, residential care suppliers)
- experts in the task (parents, DIY enthusiasts)
- experts in the user groups (nursery staff, carers)
- existing users
- new/potential consumers
- people who have some experience with the product, the task, the environment or in design appraisals
- people who have experienced injuries or difficulties with similar products.

Design appraisal techniques include:

**Interviews**

Show the appraisal panel your design, or ask them to use it, and then interview them for their impressions and views. Interviews can be structured or semi-structured, but need to focus on safety issues.

**Focus groups**

Lead an open and/or focused discussion of the product, stimulating ideas and thoughts. Focus groups usually work best with real or potential users of the product, who may be unused to other assessment techniques or to safety issues.

**Checklists**

Ask the appraisal panel to provide lists of factors relating to safety. These can be:

- checked against for a particular product
- used to stimulate ideas if people are new to the appraisal process
- returned to later in the evaluation process.

**Walk-throughs**

The appraisal panel ‘walks-through’ imaginary tasks or scenarios to highlight potential problems.

**Participative methods**

These focus ‘user’ appraisers’ attention on design issues and call on their intuitive knowledge of the product or task. Typical exercises include:

- word map – participants volunteer words associated with the product in order to suggest potential problems
- round robin – an open-ended questionnaire is passed around in which each person has to find a new answer to each design problem
- users are asked to draw their own version of how the product is used
- ergonomics issues are discussed, then users draw their own ideal solutions to the design problem which are again presented and discussed
- solutions are sought by working in pairs, first drawing the design, then working through to modelling layouts and building mock-ups.

The results of these exercises can then be used in user trials, if appropriate.
Choose your users 17
Prepare the test 18
Collect the results 22
Working out statistical significance 24
Applying test results 25

User testing can be defined as any evaluation process where the user is represented in the test. This most commonly takes the form of user trials, where a sample of subjects, representative of the intended users, is observed using the product or carrying out an example of a task. The observation can be of ‘natural use’ or can be controlled so that measurements can be taken. Sometimes it may be necessary to simulate some or all of the features of the user, product, task or environmental conditions because of practical or ethical restrictions.

Choose your users
Ensuring a representative sample of users
It is clearly helpful to have a sample as representative as possible of all potential users.
However, to make this feasible, it helps to think about what characteristics are important. Think about what ‘representative’ actually means in relation to the tasks you intend to test. For example, a person’s physical characteristics will have little bearing on how they interpret safety labelling, but their literacy and educational levels, socio-economic background, first language, prior experience and preconceptions of the product will almost certainly be critical.

Recruiting users
Recruiting users can be difficult. You need to cast your net wide enough to gather a sufficient range, yet small enough to recruit quickly and efficiently.
Users can come from an existing group such as members of clubs or residents of a specific area. Advertising can be used to attract subjects. However this involves self-selection (people’s knowledge of their own characteristics is often unreliable, due to forgetfulness or tendencies to exaggerate or underestimate) and produces a certain type of subject – motivated, but not necessarily for the right reasons. You can always discount the results from inappropriate people after the test, but this is not an efficient approach.
You could keep a permanent ‘bank’ of users. You will gain from having experienced, available people, but lose because they may become over-familiar with general ergonomics and safety issues or with the testing process and, as a result, may cease to be representative of the eventual users (findings may have little validity).

How many to choose
You’ll need enough users to ensure reliable and valid results. If your sample is too small then the results may not be a very good prediction of what would happen in real life. There may not be enough variation (size, strength, attitudes), and there could be disproportionate influence from someone whose performance is very different to the ‘norm’.
The ‘right number’ depends on what is being tested. While generally the more the better, it is not worth increasing subject numbers past the point where no new information is being gathered or where reliability is not being improved.
Research suggests that if you are collecting ‘opinions’, then as few as five users will do for any specific group (eg if your sample is all-female, the results can only predict female performance).
Such results best indicate ideas or trends, and are most useful when you are looking to generate design improvements, identify potential problems, or for initial stages of evaluation.
If you are after more specific or critical data, then a minimum of 10 people is recommended for ‘informal’ testing (where statistical significance will not be assessed), and 15–20 for ‘formal’ testing (where statistical significance is important).
On page 24 we discuss statistical significance, and extrapolating the findings of a sample into population-wide judgements.

Motivating your sample of users
People’s attitudes to safety, and their reasons and motivations for taking part in your test may affect their performance. They may make things seem more of a risk than they are, or ignore problems in order to appear co-operative. You will need to be on your guard for these things, and account for them in the way you plan your test.
Evaluating for safety often means you want people to show extremes of abilities or behaviour, for example their maximum pushing strength or fastest reaction times. Your results will depend on whether people are motivated to produce their maximum effort. This can be particularly difficult for children, who may not understand instructions, or for the elderly, who may fear injury or over-exertion.
You can actively encourage people, give them feedback to let them know how well they are doing or offer rewards/incentives, so long as this is the same for all users and does not put them at risk of injury.

How much to tell them
Give everyone consistent instructions and information, so that you can compare performance on equal terms. Plan the information you’re going to give, and keep a written record in case more than one person is running tests.

Ethically, you should tell people exactly what the test will involve, and obtain their written consent. However, there are times when providing full information may compromise the usefulness of the test. For instance, you may be looking at an unsafe behaviour such as whether people unplug electrical equipment before maintenance, or how far they are willing to over-reach when using stepladders. Here the conditions of the experiment need to be as natural as possible: you may need the subjects to be unaware they are being observed, or you may have to disguise the real experiment.

This lack of openness about the reasons for the test is a useful tactic but can only be justified if:
- the results cannot be collected any other way
- users will not be induced to do something they would not otherwise agree to
- the importance of the results justifies lack of openness.

Prepare the test
How realistic can you be? – using simulation
The closer to real-life conditions your test is, the more useful your results are likely to be. But sometimes a ‘real’ interaction is impossible, because of practical or ethical restrictions. In such cases you need to simulate aspects of the test.

Reasons for simulation include:
- you cannot make a full working model of the product
- you cannot find a representative sample of users
- there are ethical restrictions as to what you can ask people to do (particularly children, the elderly and disabled)
- there are practical restrictions on what you can ask people to do, such as children who cannot understand instructions
- there are time limitations where, for instance, something needs to be used for longer periods or more frequently than is feasible to ask people
- a hazard cannot be tested on people, such as head entrapment or the ability of the body to withstand an impact.

The aim of any simulation is to ensure a safe, ethical and efficient test while maintaining enough realism, reliability and validity and thus applicability of results (these issues are discussed on page 25). The major requirement of any simulation is that you must account for all features which could affect the human-product interaction. For instance, finger probes used to test gaps in a fire guard should not only cover the range of finger sizes and shapes, but should also account for the force with which a finger would be pushed and the resistance of the materials in the probe and guard.

Simulation is often thought of as just making a mock-up of the product. But you can also simulate:

User characteristics
- anthropometric variables (whole body, body part)
- strength
- impacts on the body
- movement (whole body, body part)
- weight (impact, weight distribution, dynamic loading)

Tasks
- operation of controls
- hazardous contents or materials
- emergency conditions
- distance of movement

Mock-ups are cheap and easy ways to test products, particularly during early design stages when a full product cannot be manufactured. You only need to mock-up the aspects you are testing. For instance, if you are testing portability the mock-up doesn’t need operational controls but would need to be the correct weight. If your test will look at all stages of use, including maintenance, assembly and disassembly, then the mock-up should be internally and mechanically fully functional. Factors that can be mocked up include:
- product dimensions, including weight
- product stability
- dynamics between user and product
- power source
- moving parts
- surface and texture
- position and orientation of product in relation to the environment
- position and orientation of product in relation to the user
- dimensions of controls
- resistance of controls
- design and realism of displays, information and labelling styling.

Regardless of how safe the actual experiment may be, you should not expose children to a potentially hazardous product or feature until they are old enough to understand its dangers. Otherwise any exposure is likely to raise their interest in a potentially hazardous product. Tests in such a case could therefore be disguised so that children cannot connect what they see and use to real life.
Product characteristics
- packaging
- controls
- displays
- size
- weight
- dynamic characteristics
- physical contact points
- power source

Environmental conditions
- temperature
- noise
- vibration
- interactions with other products.

Where to test
As with the considerations above, the location of your test will affect the usefulness of your results. Environmental factors and conditions can have a serious effect on safety. For instance:
- environmental conditions
  - temperature: extreme temperatures can affect motor skills such as dexterity
  - visual conditions: glare, or general ambient lighting can affect visual performance
  - noise: background noise can affect reaction times to auditory warnings
  - vibration: vibration of machinery can affect motor skills
- conditions of use
  - indoors/outdoors: weather conditions, terrain, lighting
  - home/work: use will be different due to responsibility to others, ownership of products
  - supervision and training: will the product be used without formal training or supervision
  - supporting literature: will instructions/labeling usually accompany the product
  - power supply: a real power supply will affect the way a product is used
- social conditions
  - private/public/observed: use will be different according to who else is present
  - group use: group effects can include quicker use, competitiveness, distraction.

Ideally tests should be held in realistic conditions, often called field work – the home, workplace, street or school. However this is often impractical, and you may need to carry out your tests in a 'laboratory' environment, either in your company's facilities or at a site provided by a third party. Both real-life situations and laboratory replications have advantages and disadvantages (see diagram on page 21).

Ergonomics and safety consultants and other bodies may be able to provide facilities for testing, such as suites with video-recording and one-way mirror services (see page 28).

Prepare your questions and tasks
Although by now you have identified what hazards exist, what level of risk is acceptable and what performance criteria to set, it helps to formalise the questions you will be asking and the tasks you will be setting in your user trials.

This will help:
- eliminate wasted time during the test
- make sure everyone completes the same tasks
- concentrate the test on ergonomics and safety factors and avoid redundant side issues.

If you do not do this, you may end up with a room full of people all looking at different aspects of your product, unsure what exactly they're supposed to be testing and getting sidetracked into aesthetic value judgements about whether they 'like' the product.

You should already have set your performance criteria which define whether your product will be safe (see pages 11 and 22). Using these, start generating general questions about the way the product will be used, and try to turn these into specific questions. The tasks you set people to do in the user trials should answer these specific questions.

This process is shown on the next page using the example of designing a stair gate (more information on how to select measurements is given in 'Working out statistical significance' on page 24).

<table>
<thead>
<tr>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>A full set of questions and measurements.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designing a new product within an existing concept – new stair gate. The designer might draw up the chart on the next page.</td>
</tr>
</tbody>
</table>
### Generating performance criteria and test questions for evaluation of a stair safety gate

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Examples of general questions</th>
<th>Performance criteria</th>
<th>Examples of specific questions</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child gets past the stair gate</td>
<td><strong>Child opens lock</strong></td>
<td>Is lock operable by children?</td>
<td>No child in a specified age group should be able to open catch</td>
<td>Define ‘operable’</td>
</tr>
<tr>
<td></td>
<td><strong>Child climbs over gate</strong></td>
<td>Can children climb over gate?</td>
<td>No child should be able to climb over gate or get injured trying to</td>
<td>What is a successful climb and how likely is a fall?</td>
</tr>
<tr>
<td></td>
<td><strong>Child pushes or pulls gate open</strong></td>
<td>Can children push or pull gate open?</td>
<td>No child should be able to push or pull gate open</td>
<td>Define ‘open’</td>
</tr>
<tr>
<td>Child gets stuck in the stairgate</td>
<td><strong>Child forces head/arm/hand/foot through gap(s)</strong></td>
<td>Can a child’s head/arm/hand/foot pass through any gap and get stuck?</td>
<td>Ideally no child should be able to pass their head/arm/hand/foot through any gap if they can without risk of injury</td>
<td>What is maximum size of gaps that prevents head/body part of smallest child entering? What level of entrapment may cause injury?</td>
</tr>
<tr>
<td></td>
<td><strong>Child pinches arm/hand/finger/leg/toe in gate or lock</strong></td>
<td>Are there any moving parts where child’s arm/hand/finger/leg/toe could get caught?</td>
<td>No child should be able to insert their finger/leg/toe into any moving parts</td>
<td>Can the smallest/largest child reach moving parts? Can the smallest child insert a finger/leg/toe? What cognitive elements are involved?</td>
</tr>
<tr>
<td>Child’s limb is pinched by the stair gate</td>
<td><strong>Adult gets stuck in the stair gate</strong></td>
<td>Can an adult’s arm/leg pass through any gap?</td>
<td>No adult should be able to insert an arm or leg in any gap</td>
<td>What level of entrapment is likely to cause injury? What is the maximum gap that still prevents the arm/hand of the smallest adult entering?</td>
</tr>
<tr>
<td></td>
<td><strong>Adult forces arm/leg through gap(s)</strong></td>
<td>Can an adult’s arm/leg pass through any gap?</td>
<td>No adult should be able to insert an arm or leg in any gap</td>
<td>What level of entrapment is likely to cause injury? What is the maximum gap that still prevents the arm/hand of the smallest adult entering?</td>
</tr>
<tr>
<td></td>
<td><strong>Adult falls over the stair gate</strong></td>
<td>How easily can an adult climb over the gate?</td>
<td>Ideally all adults should be able to climb over the gate with acceptable ease</td>
<td>What is considered a successful climb? Can those users likely to fall be identified?</td>
</tr>
<tr>
<td>Adult falls themselves assembling the stair gate</td>
<td><strong>Ease of assembly</strong></td>
<td>How could injuries occur during assembly?</td>
<td>All adults should be able to assemble the gate with no risk of injury</td>
<td>Identify assembly tasks and rate of occurrence. If safe assembly is achievable by some users, identify which may have difficulty (eg elderly)</td>
</tr>
</tbody>
</table>

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*CEN committee TC252 are drafting a European safety standard on stair gates which addresses these issues*  
*see page 7*
### Types of testing: real life versus laboratory

<table>
<thead>
<tr>
<th></th>
<th>real life situation</th>
<th>laboratory simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Realism</strong></td>
<td>a high level of realism is offered as all the variables that affect the use of the product (other people, equipment and environment) are represented as they would be in real life</td>
<td>the important variables must be recreated in the laboratory but some realism will always be lost</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>there is a lack of control over external factors</td>
<td>important variables can be controlled but it is difficult to control everything</td>
</tr>
<tr>
<td><strong>Generality</strong></td>
<td>it is easier to generalise to real life</td>
<td>an artificial situation reduces the ability to generalise and therefore validity</td>
</tr>
<tr>
<td><strong>Bias</strong></td>
<td>there is least bias as there is less control over other variables</td>
<td>controlling variables can lead to bias</td>
</tr>
<tr>
<td><strong>Repeatability</strong></td>
<td>as each situation only happens once, repeating makes the situation artificial</td>
<td>the evaluation is repeatable as the equipment and subjects are available, allowing more analysis or tests to be done if necessary</td>
</tr>
<tr>
<td><strong>Comparing designs</strong></td>
<td>it’s difficult to compare alternative designs in a real life situation because subjects get used to the product and realism is lost if they repeat the task</td>
<td>experimental is repeatable as the make comparisons between alternative designs</td>
</tr>
<tr>
<td><strong>Practicalities</strong></td>
<td>it can be difficult to set up and run</td>
<td>it’s much easier to set up and run evaluations in real-life situations</td>
</tr>
<tr>
<td><strong>Time and resources</strong></td>
<td>it can be time consuming to run evaluations in real life due to the availability of situations to observe</td>
<td>recreating conditions in the laboratory can be expensive especially if special equipment and rigs have to be built</td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
<td>experimental and recording equipment needs to portable, and technical support may have to be taken to the site</td>
<td>experimental ‘space’ can be designed to suit the evaluation and technical support is on hand</td>
</tr>
<tr>
<td><strong>Users</strong></td>
<td>users may be found more easily ‘in-situ’ if they are specific to the environment eg children and carers in a playground, but if they’re not in-situ, you need to consider how practical it is for people to get there</td>
<td>you can establish a ‘bank’ of users who are used to going to one laboratory, so long as familiarity is not an issue</td>
</tr>
<tr>
<td><strong>Confidentiality</strong></td>
<td>confidentiality and security can be a problem as the product needs to be taken out to the public</td>
<td>the product can be kept in private and secure conditions</td>
</tr>
</tbody>
</table>
SUGGESTED EVALUATION PROCESS

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Selecting variables

By identifying hazards or hazard scenarios (see page 11), you can specify the behaviours that might be found in normal safe use of the product that have some level of risk associated with it – either acceptable or unacceptable – and in the misuse of the product. Examples of each of these types of behaviour are:

• reaching out to the side when on a stepladder
• not unplugging an electrical appliance before cleaning it
• undesirable opening of a container by a child.

For some products there is only one behaviour or interaction of interest for safety – for example, can children under five years reach a window catch? For other products there may be several critical behaviours or interactions; with a stepladder we might want to know how far people are prepared to reach sideways, how high they go willingly, and whether they lock the stepladder correctly. Identifying these behaviours helps us decide what will be our measures of safe performance – in experimental design these are called dependent variables. Our examples could be:

• the distance subjects are freely prepared to reach sideways
• the proportion of times a sample of users do not unplug the appliance
• the average time taken by children to open the container, and the success rate at opening the container.

It is not enough only to test and measure the dependent variables. We need to consider all of the hazards and risks associated with a product in use and measure them. Examples of these might be: the stepladder does not tip up when anybody reaches out as far as they are prepared to; the appliance is only left plugged in on 5% of occasions; 99% of children aged 2–3 years cannot open the container in ten minutes.

While our measurements (dependent variables) tell us how safe the design is we have to decide which factors influence behaviour and interactions; how safe the design is. In experimental design these are called independent variables. They can be any aspect of the product design, person, environment or circumstances of use. Our examples could be:

• the width of stepladder treads
• the size of warning on the appliance
• the diameter of the container closure.

In user trials we systematically manipulate the key independent variables and record how the combinations of these affect the critical behaviours – our measurements or dependent variables.

Collect the results

The way you collect results should intrude as little possible into the test, while getting all the information you need. The following three methods are in increasing order of intrusion:

Directly recording users’ actions

This involves an observer noting and interpreting the users’ actions or else making a record to be interpreted later.

Work out beforehand what to record, and what not to record. This will help you avoid the problems of having too much to analyse, or not being able to keep pace with the speed or amount of events.

Recording methods include:

• Hidden or unobtrusive observation – observe users from another location through either one-way mirrors or cameras. This encourages natural behaviour (if the camera is hidden), but be aware of the ethics of not telling someone they are being observed. If you do tell them then the point of being hidden may be diluted.

• Paper-based recording – use prepared recording sheets, with as many tick boxes, codes, marking diagrams and other short-cuts as possible. Train the people who will be recording, and assess them against a standard and each other to make sure they are consistent.

• Video recording – allows repeated analysis, and is good for things that happen quickly or when several things happen at once. Useful for precise measurements of parameters such as reach, time, height and distance. Video recording can be public or hidden. Do not just video everything and assume you’ll get round to analysing it later – analysing a video can take up to ten times as long as the event itself.

• Automated data collection – there are computer and mechanical methods for collecting human performance data (heart rate, oxygen uptake) and product performance data (stress in a structure). These may have to be developed specifically for each application, though some commercial versions exist such as equipment to record eye-movement.

• Automatic event recording – these techniques record specified events such as the activation of
**SUGGESTED EVALUATION PROCESS**

**USER TRIALS**

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### Questionnaires

A questionnaire should motivate people and elicit accurate and full responses. Pilot your questionnaire, first on colleagues to highlight basic problems and then on a sample of users. Use these basic guidelines:

- **arrange questions in an order that is logical from the point of view of the person filling it in**
- **use filter questions (‘if ‘no’ go to question seven’ etc) to guide respondents past inapplicable questions**
- **questions should be: short, clear, unambiguous, specific, precise, non-leading, avoid bias based on real information (avoiding hypothetical questions)**
- **questions can be: factual (yes/no), mutually exclusive (what type of product was used), multiple (what was the product used for), of responses (who the product is used by, how often and why)**
- **open ended (allows unrestricted response, but means more effort later in interpreting and collate results), and closed (people can only choose one specific answer)** You must cover all possible answers, including ‘other’ and ‘don’t know’ categories. This may bias or force an answer, but it does allow easier analysis, and generates more meaningful responses.

(See bibliography for more guidance on questionnaire design.)

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### a movement sensor, the force imparted between product and user, reach beyond certain distances and so on. Again these usually have to be developed specifically for each application.

### Users recording their own actions

These methods rely on users either recording or interpreting their own actions. They are useful for field work, assessing use over longer time periods and in gaining ‘honest’ assessments of a product.

- **Commentary** – ask the user to comment on what they are doing and thinking during a task, the information they are using and the decisions they are making (known as protocol analysis). They should give concurrent, unprompted and natural descriptions. This is different to interviews, which are interviewer-led and which can be focused more on strategies than processes. Bear in mind it can be time-consuming and difficult to interpret commentaries.
- **Private video booths** – encourage users to discuss their use of a product in a more open and honest manner than if interviewed. The user is left alone with a camera to explain their behaviour and preferences without any outside interference.
- **Diaries** – users can self-record their behaviour in a diary over longer periods than is possible in an observed test. Alternatively tags can be placed on the product for them to fill in regularly. Less information can be recorded in this way, and tags can be difficult to use, but it does enable naturalistic use of the product in a real environment without any intrusive observation. Diary methods are particularly useful for recording information such as frequency, time, circumstances of activity and use in combination with other products.

### Recording users’ opinions

These methods ask users for their verdicts in a structured format. Use them when:

- there are no direct measures of safety available
- you want to back up direct performance measures with subjective data
- you want to find out attitudes towards using a product – for example asking people whether they follow instruction labels.

You will find these methods described in detail in a number of standard texts (see bibliography page 29). Some of the methods include:

- **Ranking** – ask users to rank lists of design options (different types of controls, handle sizes, methods of assembly) in order of preference against several criteria (ease of use, comfort, safety). Do not ask them to rank more than nine options at a time. Often only the rankings at either end of the scale can be considered of most value.
- **Rating** – ask users to rate on a scale (usually 1–5 or 1–7) how they feel about something. An example is Likert scales, where people are asked to respond to statements such as ‘the catch is easy to open’ using a scale of possible answers. A 5-point Likert scale may be: ‘Strongly agree – agree – uncertain – disagree – strongly disagree’. Rating scales with an even number of points (ie no neutral point) can be used to force a decision. Rating is less sensitive to differences between options than is ranking, but allows you to calculate the absolute positions on a scale related to each criterion.
- **Paired comparisons** – a powerful method where every possible combination of pairs of design options is presented to the users in turn. The users must say which option of each pair best meets the particular criterion. For instance, if we wanted users to evaluate the comfort of four bicycle seats (A, B, C, D), we would ask each user to say which is more comfortable out of the possible pairs (A/B, C/D, A/D, B/C and so on). Once all comparisons have been made, the preferences can be converted into a rating scale with each item given a score. Because the possible number of pairs can get large the method works best with four to six and no more than eight items, especially if more than one criterion is used. Iterations of the process may be needed if the results highlight contradictions in people’s judgements.
- **Questionnaires** – are a flexible and widely used method of collecting data. They can be administered face-to-face, by mail or on the telephone. While questionnaires can allow fast access to the views and opinions of many people in a consistent fashion (they are the only feasible way of gathering data from thousands of people) there are drawbacks. They can require considerable resources to administer, analyse and interpret properly. Also, because they must usually be relatively short, they work best if the investigators and respondents share a common culture, language and at least some understanding of the issues.
- **Interviews** – these allow data to be collected in more detail than from questionnaires and are more controllable and responsive. Disadvan-
Working out statistical significance

In some cases you can be very confident about the results produced by user trials. For example, it may be possible to prove that no child, however small their limbs or however hard they try, will become stuck between the bars of a new stair gate. In other cases, probably the majority, your findings will only indicate degrees of probability. Furthermore your sample, even if it is large, cannot contain the entire user population. In such cases you may need to work out exactly how confident you are in your results. This means working out statistical significance, which can be daunting at first. In the section below we run through the basic calculations for generating statistically significant results.

Extrapolating your results to the whole population

Because you cannot test the whole population and can only test a sample of users, you need to know how well your results predict the performance of the whole user population (which may be all potential users, or just those at risk, for instance children under five or the elderly). For this we need to know the sampling error.

Provided that your sample of users has been randomly selected, you can work out the sampling error, or how representative your sample is of the general population, by calculating the Standard Error (SE) of the results. The SE is the way in which we quantify the representativeness of our samples and we can use this to work out how many users we need to test in a user trial.

Sampling

Being able to calculate the sampling error depends on whether the measure we are interested in is normally distributed and whether the sample we use is selected randomly.

Random selection means that every person in the target user population has an equal chance of being selected for the experimental sample. Techniques for randomly selecting (known as probability sampling) include things like random number tables – it must be possible to assign chance (or a number) to the whole population.

Some common methods of selecting subjects do not actually produce a random sample, for instance accidental or availability sampling (people on the street or telephone numbers from a directory). If the sample is not random the sampling error cannot be calculated in the way shown above.

If you can’t select your users randomly, you can estimate sampling error by comparing your results to statistical information on the target population, such as the mean and standard deviation of a critical characteristic (for example opening force).

However, such information is often not available, either because:

• no one has ever collected data relevant to the characteristic you are testing, or
• data exist for the characteristic, but do not fit with your target population.

In these situations you may have to estimate the relationship between your subjects and the target population by comparing a similar, related characteristic. For instance, if you are evaluating opening strength on a particular size and shape handle but no data exist on that exact operation, then standardised grip strength (data on which are widely available) could be compared between your sample and the target population. Take care when selecting characteristics for comparison to ensure that they:

• are related
• involve the same part of the body
• involve the same physiological function.

If you can neither extrapolate your results nor make comparisons, then make your sample as representative as possible of the target population, for example by increasing the number of users.

Comparing designs

In some cases you may want to compare alternative designs and you will need to know whether the differences in performance you may find are true differences, due to the changes you have made to your design, and not due just to chance. That is, that the differences are statistically significant. You will need to consider formal statistical analysis of your results, and think about this before you start any evaluation. Guidance on experimental design and statistical testing is beyond the remit of this.
SUGGESTED EVALUATION PROCESS

USER TRIALS

document, but there are plenty of texts to help you (see bibliography).

How confidently can you use your results?
The reliability and validity of your results will determine how confidently you can use them to improve safety.

Reliability is the extent to which the same results will be obtained if the test is repeated with different users or at a different time. You can increase your reliability by:

• increasing the number of users
• ensuring that everyone has the same instructions and is exposed to the same conditions such as light, temperature and time of day.

Validity is the extent to which results truly represent what they are supposed to be measuring. Internal validity is the extent to which your company can use the results to draw conclusions. External validity is the extent to which results can predict performance under different but similar circumstances, and for the rest of the population beyond your sample.

You can increase validity by:

• choosing users carefully to represent the whole range of possible users
• selecting sensitive measures
• making experiments as realistic and as representative as possible.

Applying test results
How you use the results of user trials (and the outcomes of modelling and design appraisal) will depend on what is being evaluated. Most often the trials will be:

(1) assessing the expected safety of people using (or misusing) the product, or
(2) comparing safety across different circumstances (independent variables) of:

• the person (age, wearing gloves)
• the social/environmental conditions (time pressure, lighting)
• the product itself (two versions of a control, several types of warning label).

In the first case the purpose will be usually to ‘prove’ the safety of the final design before going to production and market – sometimes such trials will be carried out on a very early prototype to see if further development can be justified. In the second case the trials will normally be a part of the development process, to help decision making about design features, the targeted user population or product suitability for different circumstances.

Whichever the case, well thought-out user trials within ergonomics evaluation, as an integral part of the total development process, will improve the product quality, the satisfaction and safety of consumers and the market position of the producer.
Once you have carried out your tests, you need to turn the results into a safety assessment or design solutions. Remember tests are part of the evaluation process, not an end in themselves. For instance, you may need to retest your altered design to check that a hazard has been eliminated.

Ergonomics and design safety evaluation should not be, as has already been emphasised, a 'bolt-on' towards the end of product development. Properly and efficiently implemented, such evaluation will inform and improve product design and presentation at all stages of development (this is formative evaluation) as well as provide benchmarking and final assessment against performance criteria for the eventual production prototype (summative evaluation).

The outcomes of any ergonomics evaluations – whether the evaluation be data/guidelines, modelling, design appraisals, simulations or user trials – will be a mixture of ideas, approvals, measurements and statistically supported quantitative results. These outcomes must then be amalgamated and interpreted in terms of degrees of design safety (as well as product usability), and also will be used to generate ideas for improved designs.

The information and ideas in this guide should have given a first explanation of the ergonomics and design safety evaluation process. This guide should also have given a clear understanding of the business gains as well as improved consumer safety to be obtained from such a process.

Remember, all products are subject to a general safety requirement by law, and for many products there are European or international safety standards which clarify safety requirements.
Further information

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Sources of help and advice

**Points of contact**

Consumer Affairs and Competition Policy Directorate  
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fax 0171 215 0357

Product Safety and Testing Group  
Department of Manufacturing Engineering and Operations Management  
University of Nottingham  
Nottingham NG7 2RD  
tel 0115 9514039  
fax 0115 9514000

Design Council  
Haymarket House  
1 Oxendon Street  
London SW1Y 4EE  
tel 0171 208 2121  
0171 839 6033

Ergonomics Information Analysis Centre  
The University of Birmingham  
School of Manufacturing and Mechanical Engineering  
Edgbaston  
Birmingham B15 2TT  
tel 0121 414 4239  
fax 0121 414 3476

The Ergonomics Society  
Devonshire House  
Devonshire Square  
Loughborough  
Leicestershire LE11 3DW  
tel/fax 01509 234904

ICE Ergonomics  
Hollywell Building  
Hollywell Way  
Loughborough  
Leicestershire LE11 3UZ  
tel 01509 283300  
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Royal Society for the Prevention of Accidents (RoSPA)  
Edgbaston Park  
353 Bristol Road  
Birmingham B5 7ST  
tel 0121 248 2000  
fax 0121 248 2001

Child Accident Prevention Trust (CAPT)  
Clerks Court  
18–20 Farringdon Lane  
London EC1R 3AU  
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British Standards Institute  
389 Chiswick High Road  
London W4 4AL  
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fax 0181 996 7400

**Ergonomics and safety consultancies**

These offer advice, training and assessment on general ergonomics and product safety, and for example:

- provide advice on the issues to be considered in a particular application – types of hazards, the types of users at risk, whether or not data exist for a particular problem
- provide anthropometric and design data and guidelines
- highlight gaps and inadequacies in your existing methods, and guidelines on how to evaluate more effectively
- carry out ‘expert’ evaluation of a product, either in full or in part.

Consultancies have the facilities, equipment and expertise to carry out tests, including access to test-ers, video-recording suites and one-way mirror services. The cost of hiring these facilities or asking a consultancy to do part of a test for you may be less than trying to do it yourself. Research bodies aligned to university or academic institutions may sometimes be interested in becoming involved in a product development or evaluation project.

A list of ergonomics consultancies is available from the Ergonomics Society.
Anthropometric data and ergonomics guidelines

General

Usability and general evaluation techniques

Recording users’ opinions


Experimental design

Design appraisal

Accident analysis

Task analysis
Glossary

confidence (interval)
The likelihood (usually 95% or 99%) that a measurement of the population will lie within a range that has been measured on a sample of users.

construction safety
Product safety through appropriate materials, manufacturing, assembly or inspection.

design process/development process
The creative and problem-solving process by which a concept becomes a product ready for manufacture.

design safety
Product safety through an appropriate concept, presentation and associated information.

ergonomics
The study of people’s interactions with products, environments and other people and use of the knowledge gained to develop safer, healthier, more satisfying, effective and efficient interactions.

ergonomics evaluation (of products)
The process of assessing ergonomics aspects of product use against safety and usability criteria. Excludes any assessment of quality of materials or manufacturing.

hazard
A situation, event or object that, in particular circumstances, could lead to harm.

hazard scenarios
Sets of circumstances by which a hazard does lead to harm through interactions of personal, task, product and environmental factors.

population
The complete group of potential users/misusers.

product
Any item or artifact that is used or interacted with by people. Can include architectural and construction features, or packaging and instructions.

product design
The form, function, methods of use, features, structure, materials and styling of a product.

product safety
The extent to which a product, whether used in expected or unexpected ways, does not cause harm to people.

reliability
Consistency of measurement; the extent to which a testing process would produce the same results if repeated again with different subjects or at a different time.

risk
Probability that a particular adverse event will occur as a result of a hazard, per unit of time, usage or population.

risk perception
Individuals’ assessments of degree of risk associated with a hazard.

safety criteria
The level of a measurement (of dependent variable) deemed to constitute reasonable safety.

test
Assessment of how well a product performs in comparison to safety criteria.

user
In context of product safety, anyone who comes in contact with a product, whether intentionally or inadvertently, using, misusing or abusing it.

user sample
Group of people representing the population of product users, taking part in an ergonomics and design safety evaluation – usually in user trials.

user trials
Controlled process by which a sample of users test aspects of product performance and product use with the results assessed against safety criteria (characteristics of product, task, environment or even people may be simulated in such trials).

validity
Relevance of measurement; the extent to which what was intended to be measured was actually measured.
The pressures on designers and producers to deliver safer, more usable and more effective consumer products are growing all the time. The advantages of improving the ergonomics and design safety of products can be found in a longer product life cycle and a greater market share, as well as in increased consumer satisfaction and safety. This guide gives practical advice on how to evaluate product design using a comprehensive approach. Examples of particular types of product, hazard and evaluation are given throughout.

The authors, Beverley Norris and John R. Wilson, have between them over thirty years experience in the application of ergonomics, in particular to the design and safety of products. They manage the Product Safety and Testing Group and the Institute for Occupational Ergonomics at the University of Nottingham, and many examples in this guide are drawn from the work of this group. Production of the guide has been funded by the Department of Trade and Industry with the specific intention of encouraging and supporting ergonomics and safety evaluation by product designers and manufacturers.