The University of Sydney
Faculties of Health Sciences and Architecture
The Home Modification:
Information Clearinghouse Project

Evidence Based Research

Selecting diameters for grabrails

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Abstract:

Objectives: To determine the suitability of grabrails with a 25mm outside diameter for supporting older people in their homes.

Design: Systematic review of electronic and other published literature.

Main outcome measures: Hand size and grasp type are critical measures in determining the grabrail diameter required to provide maximal contact surface area. Maximal contact surface area at the hand – rail interface increases friction. Increased friction decreases the grip strength required to prevent hand slip along the grabrail.

Safety interventions: Grabrail features that facilitate maximal grip strength can reduce fall risk and reduce the severity of injury in the event of a fall. Grip strength is influenced by contact surface area and friction at the hand – rail interface and the type of grasp used.

Results: No existing research was found relating grip strength of older people or people with a disability to grabrail diameters. Existing research does indicate that grip strength is a product of extrinsic finger muscle length i.e. it is influenced by wrist position and contact surface area. Hand size also influences the grip strength in relation to the contact surface area and type of grasp used. Consequently, hand size should be considered in prescribing the outside diameter of a grabrail.

In addition, greater surface contact area and greater friction at the hand - rail interface reduces the strength required to prevent hand slippage along the grabrail. This interaction may also influence the effectiveness of the grip in relation to other variables such as the finished surface of the grabrail and the location of the grabrail.

Conclusions: Australian Standard 1428.1 recommends a grabrail outside diameter 30 – 40mm. This dimension may not be appropriate for all people. Grabrail design should reflect the needs of the individual, intended activity and specific environmental context.

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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In producing this systematic review, the authors gratefully acknowledge the able assistance provided by the Health Sciences library and in particular John Paul Cenzato the librarian responsible for organising inter-library loans. Without their active assistance, production of this document would not have been possible.

As this particular review introduces strategies for addressing individual variants in relation to hand diameter, the issue of appropriate measurement was critical, therefore, international advice was sought. Many thanks to David Feather and team at the IDEA Center, School of Architecture and Planning, State University of Buffalo, New York.

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Table of Contents

Problem Statement

Does a 25mm grabrail diameter provide support for older people when installed in their homes?

Area of Concern

Use of an appropriate assistive device i.e. prescribing a grabrail outside diameter that provides an adequate support for older people.

Background

Falls are common in older people and often occur in the home. Bathrooms, specifically in relation to balance and transfers during toileting and bathing, have been identified as high-risk areas in the home (Mullick, 1993; Sanford, 2001). Older people also tend to have more accidents on stairs and easily sustain injuries (Templer, 1992) . Grabrail installation, as an aspect of environmental modification, plays a major role in reducing falls risk around the home, particularly at changes in level and during transfers (Clemson & Martin, 1996; Walker, 1990).

Grabrails are prescribed to promote safety and independence, and to improve and maintain function (Moy, 1987). Appropriate prescription of grabrails must consider the person, the intended activity and the specific context or environment where the activity occurs. Inappropriate prescription or design of grabrails has social and economic costs including non-use of the rail, secondary disability, injury to carers, premature admission to residential care, and decreased independence (Bridge, 1998; Clemson & Martin, 1996; Cooper, 1991; Hunter, 1992; O'Meara, 2004; Sanford, Arch & Megrew, 1995; Sanford, 2001). Hence, appropriate grabrail prescription is crucial for supporting people at home.

Outside diameter is one of many design features to consider in grabrail prescription (Bobjer, 1993; Buchholz, Frederick, & Armstrong, 1988; Dusenberry & Simpson, 1996; Fothergill, Grieve, & Pheasant, 1992; Maki, Perry & Mcliroy, 1998; O'Meara, 2004; Pauls, 1985; Roland, 1996b). Successful grasp during grabrail or handrail use is dependent on a number of factors including:

- design features such as cross-sectional profile, coefficient of friction of the finished surface, texture of the finished surface
- environmental factors such as location, rail orientation, installation and the individual's orientation to the rail
- individual attributes such as hand size, grip strength, grip endurance and the type of grasp employed

Alone or interacting together, each of the design features above may facilitate or inhibit successful use of a grabrail. For example, the grabrail's finished surface influences the grip strength required to avoid hand slip and improve fall avoidance. The finished surface affects surface friction at the hand – rail interface. As friction decreases, greater grip strength is required to prevent hand slip thereby affecting stability during transfers (Buchholz, 1988). In fact, Bobjer et al (1993) argue that increased friction may enable a person with weak hands to complete an activity that would not be possible otherwise. Therefore, there are many grabrail attributes to consider for an ultimately stable grasp.

Grabrail Attributes

An important attribute, friction, increases at the hand - rail interface with increased surface contact area (Fothergill, Grieve, & Pheasant, 1992; O'Meara, 2004). This means that greater contact surface area between the hand and grabrail should reduce the grip strength required to prevent hand slip, all other elements being equal. Surface contact area is also influenced by the cross-sectional profile of the grabrail. Profile refers to the shape and diameter of a grabrail or handrail (Feeney & Webber, 1994; Fothergill, Grieve, & Pheasant, 1992; O'Meara, 2004; Pauls, 1985). Circular profiles and some oval profiles maximise contact between the hand and rail (Achea, Collins, & Stahl, 1979; Feeney & Webber, 1994; Maki, 1985; Pauls, 1985; Steinfeld, Shea, & Levine, 1996; Templer, 1992). This suggests that circular or oval profiles reduce the grip strength required to maintain adequate grasp and prevent the hand slipping along the rail.

Individual Attributes

Grip strength is not only related to grabrail profile but to the type of grasp used and the size of hand, that is the grip diameter of the hand, relative to the outside diameter of the rail. To avoid a fall and in the event of a fall, maximum grip strength is desirable. Typically, power grasps enable greater grip strength than other types of grasp (Achea, Collins, & Stahl, 1979; Armstrong, 2001; Dusenberry & Simpson, 1996; Fothergill, Grieve, & Pheasant, 1992; Pauls, 1985). This means that using a power grasp should reduce the risk of falls or the severity of injury if a fall occurs. However, a power grasp can only be achieved with the appropriate grabrail diameter for the user.

A power grasp is formed when the hand encircles the grabrail with phalangeal and metatarsophalangeal joints in a flexed position so that all segments of the hand contact the grabrail (Maki 1985). The extrinsic finger flexors are the primary muscles responsible for grip strength in power grasps (Armstrong, 2001). There appears to be an optimal muscle length that enables maximum grip strength. Maximum muscle strength generally occurs when the associated joints are at mid range of motion (Armstrong, 2001; Flatt, 2000). For the wrist, this length occurs when the wrist and forearm are aligned as shown in Figure 1 and the wrist is extended 20 – 30 degrees i.e. the wrist is in a neutral position (Achea, Collins, & Stahl, 1979; O'Meara, 2004; Pauls, 1985; Templer, 1992). Deviations from a neutral wrist position potentially reduce the maximum grip strength.

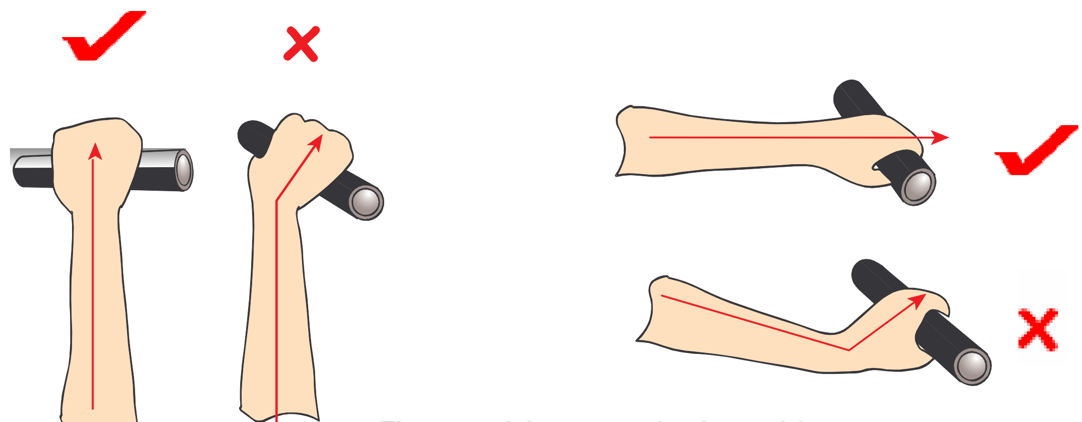

Figure 1: Alignment of wrist and forearm

This means that although an increased hand – rail interface and use of a power grasp facilitate increased grip strength; the forces generated during grabrail use are also sensitive to rail placement (individual's orientation to the grabrail) and the rail profile. Fothergill, Grieve & Pheasant (1992) state the interaction between profile and hand size may influence the grasp type used. Maximum grip strength requires a grabrail profile (diameter and shape) that enables the wrist to remain in a neutral position while a power grasp is used.

Grip spans that are too large or small, relative to the hand size (grip diameter of the hand), may reduce grip strength (Hedge, 1999; O'Meara, 2004). Larger diameters, relative to hand size, result in undergrip; the hand does not encircle the grabrail and form a power grasp. Under grip therefore reduces grip strength. Smaller diameter grabrails, relative to hand size, result in over grip; the hand encircles the grabrail and the fingers and thumb overlap. Over grip requires greater intrinsic hand muscle activity. This type of muscle activity requires greater energy expenditure to produce the same grip strength; there is a greater risk of failure to maintain an adequate grasp. Figure 2 illustrates over grip, optimal grip (power grasp) and under grip.

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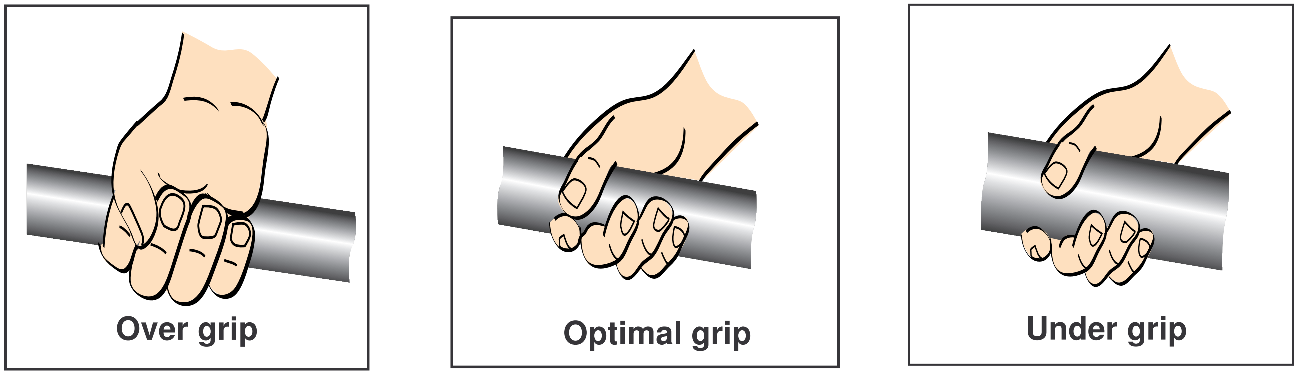

Figure 2: Alignment of wrist and forearm

It appears the ideal diameter of a grabrail relates to hand size and the possible degree of hand closure (power grasp) (Templer, 1992). Dusenberry (1996) argues that smaller hands generate greater grip strength on smaller diameter handrails. This is consistent with Maki (1985) who suggests that the optimum handrail diameter for children was smaller than that of adults. Applying this argument to other cohorts with small hand size such as older women, smaller diameter grabrails should facilitate greater grip strength.

Appropriate design and prescription of grabrails becomes increasingly important with age. Peebles (2000) noted that maximum strength peaks in adulthood, decreasing with age from 50 years. Furthermore, Diffrient (1981) states that strength decreases with age in a non-uniform manner. Hands and arms decrease to 15% and 50% respectively by age 60 years with women 30 – 35% weaker than men (Diffrient, Tilley, & Harman, 1981). This means older people may have more difficulty maintaining adequate grip strength when using a grabrail making other elements that optimise grip strength on grabrails increasingly important.

Anthropometrics of Grasp Diameter

Hand size appears to vary with age and gender. Diffrient (1981) indicates a difference of approximately 50mm between women in the 2.5 percentile and men in the 97.5 percentile men and a difference of 15mm between 50th percentile men and women. Similarly, Smith (2000) shows, for age groups 65 years to 85+years, hand size varied by approximately 15mm between men and women of the same age group and approximately 20mm between women 85+years and men 65+years. Despite these variations of up to 50mm, the dimensional requirements for outside diameter grabrails in Australian Standard (AS) 1428.1 are 30 – 40mm, a range of 10mm.

The scope for AS1428.1includes men and women aged 18 to 60 years. It seems implausible that a range of 10mm could adequately accommodate hand size variations of 15 – 50mm. However, AS1428.1 is mandatory in public buildings; it is not mandatory in class 1 buildings. Public spaces must accommodate a broader range of people with differing functional abilities and hand sizes. This is not true in home environments (typically class 1 buildings) where an individual's requirements can be determined.

Grabrail design recommendations based on AS1428.1 for people outside the scope of AS1428.1 may not allow maximal grip strength thereby decreasing the effectiveness of the grabrail in fall avoidance or injury minimisation. If good design of grabrails provides maximal contact area at the hand - rail interface and a diameter that enables the use of a power grasp, the diameter and shape of the grabrail are critical design elements. Application of AS1428.1 requirements rather than assessing and applying the individual's attributes to prescribe a grabrail may not be valid and may breach duty of care.

Since hand grip diameter is critical in determining the most appropriate outside grabrail diameter, as the fingers and thumb must be able to wrap around the grabrail (Maki, 1985), valid and reliable measurements and tools for relating

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
www.homemods.info

hand size to grabrail diameter are required. Previous studies have published British and USA anthropometric data for the general population (Diffrient, Tilley, & Harman, 1981; Pheasant, 2002); see Table and Table . In addition, a recent British study by Smith (2000) provided anthropometric data of older people; see Table . The Pheasant and Diffrient data below does not include people over 65 years. Table 3 includes data for people over 65 years. No comprehensive study of the anthropometrics of people with a disability was found.

Body parameter	Men (mm)			Women (mm)		
	5th %tile	50th %tile	95th %tile	5th %tile	50th %tile	95th %tile
Hand length	175	190	205	160	175	190
Palm length	98	107	116	89	97	105
3rd finger length	76	83	90	69	77	84
2nd finger length	64	72	79	60	67	74
Maximum grip diameter (thumb and 3rd finger touch)	45	52	59	43	48	53

Table 1 Anthropometric Estimates for British Adults from Pheasant (2002)

Body parameter	Men (mm)			Women (mm)		
	5th %tile	50th %tile	95th %tile	5th %tile	50th %tile	95th %tile
Hand length	183	198	211	165	180	193
Palm length	104	112	117	97	102	107
3rd finger length	79	86	94	71	79	86
2nd finger length	69	76	81	61	69	79
Maximum grip diameter (thumb and 3rd finger touch)	43	51	53	N/A	N/A	N/A

Table 2 Anthropometric Estimates for USA adults (Diffrient, Tilley, & Harman, 1981)

Body parameter	Men (mm)			Women (mm)		
	5th %tile	50th %tile	95th %tile	5th %tile	50th %tile	95th %tile
Hand length	169.61	185.87	202.14	156.37	171.89	187.41
Palm length	98.06	107.39	116.73	88.61	97.50	106.40
3rd finger length	72.89	82.05	91.20	67.87	76.11	84.34
2nd finger length	65.73	73.84	81.95	60.50	67.59	74.69
Maximum grip diameter[1] (thumb and 2nd finger touch)	35	41	47	31	38	42

Table 3 Anthropometric Estimates for Older British Adults aged 65+ years from Smith (2000)

These studies provide a range of information that is relevant to measuring grip including hand length, palm length, length of fingers and insider grip diameter (tables 1, 2, and 3). No clear and consistent relationship that could predict grip diameter can be seen between the different body parameters within each percentile group within any of the tables. Measurement methods are consistent across all data collection with the exception of grip diameter. In all cases, grip diameter is measured grasping a cone at the largest circumference that allows the thumb and finger to meet. Measurements of grip diameter vary in the formation of the grasp i.e. whether the 2nd or 3rd finger touches the thumb; however the crucial factor is hand closure.

Anthropometric data (tables 1, 2 and 3) is based on static measurements; grasp is a dynamic activity. In forming and executing a power grasp, muscles in the hand contract to enable flexion of the fingers. The muscle shape changes during flexion so that predicting a grip measurement such as diameter or circumference from an extended hand measurement is not reliable. In the absence of valid and reliable measurements that relates hand size to grabrail diameter, information regarding grip size measurement for tennis racquets may be useful. The grip required on a tennis racquet is a modified power grasp so dimensional requirements are similar. However, the forces acting at the hand - racquet interface during play differ from the forces acting on a grabrail both during a transfer and during a fall.

Typically, grip size for tennis racquets is measured on an open hand with fingers adducted and extended as shown in Figure 3. The correct grip circumference is equivalent to the distance from the proximal palmar crease to the top of the 3rd finger (About, 2004; Tennis Company, 2004; Tennis Warehouse, 2004). The required grip diameter can then be calculated using the following formula: Diameter = Circumference / Pi. For example a circumference of 100mm divided by 3.14 (pi rounded) equals 30mm. Therefore, if applied to grabrail prescription, a diameter of 30mm may be recommended. However, further research may be valuable in determining the usefulness of this grip size measurement.

[1] Publication included grip diameter data for Japan and Netherlands only. It did not include UK data. Netherlands data is included in this table.

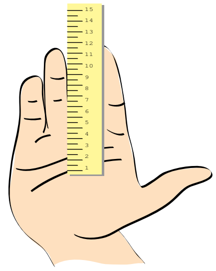

Figure 3 Measuring grip size

It is important to note that other factors may influence the formation of an adequate grip. For example, reduced range of motion in the hand and fingers caused by spasticity or arthritis must be considered when prescribing grabrail diameter.

Terminology & definitions

Australian Standard 4226 Guidelines for safe housing design (Standards Australia, 1994) defines a handrail as "a rail fixed to the top of balusters or posts or to a wall at hand height. It acts as a safety rail on stairs, balconies and the like to stabilise a walking person" (cl 1.5.8 p. 7). The same standard defines grabrails as "a handrail placed for support in positions where a slip or a fall is considered possible" (cl 1.5.7 p. 7).

Confusion exists between the terms handrail and grabrail as they are often interchanged. At a broad level, handrails and grabrails may appear to meet similar needs; providing support to increase safety and avoid falls. However, in reality handrails and grabrails are installed for different and specific activities. Definitions differentiate between grabrails and handrails in terms of the activity undertaken; grabrails are used for balance and support or to assist in transfers (Mullick, 1993) whereas handrail function is often described in relation to guidance and stability while negotiating changes in level e.g. stairs (Achea, Collins, & Stahl, 1979; Templer, 1992). Despite the functional differences of grabrails and handrails, this paper draws on research relating to handrail use, particularly handrail use in falls. This is due to the paucity of research considering optimal grabrail design for older people and people with a disability.

Evidence Based Practice Search Methodology

Question refinement strategy

Consistent with the Home Modification and Maintenance Information (HMMInfo) Clearinghouse (Phibbs & Bridge, 2003) project's systematic review protocol, the research question was refined into an operational format that could be researched systematically by application of appropriate search criteria. See Table 4 below. Table 5 contains the synonyms and search terms used.

Problem	Intervention	Outcome	Comparison	Target population
▸ grabrail diameter	▸ 25mm diameter	▸ Maximised support at home ▸ Decrease falls risk ▸ Decrease severity of injury in the event of a fall ▸ Increased confidence ▸ Decrease secondary disability ▸ Increased quality of life	▸ Hand size ▸ Diameter	▸ Older people

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
www.homemods.info

Table 4 Grabrail diameter inquiry researchable question components

Problem	Intervention		Target Population
grabrail	diameter	size	Aged
grab rail	thickness	wideness	Ageing/Aging
grab bar	width	wide	Geriatric
support rail	design	measure	Elderly
support bar	specification	grip	Old
handrail	dimension	grasp	Older
hand rail	breadth	support	Senior
rail			
horizontal bar			

Table 5 Search terms

Inclusion criteria

Material consistent with the systematic review protocol (Phibbs & Bridge, 2003) including: (a) No limit on publication year, or document type and (b) Defined key search terms. Synonyms and variant forms of the search terms were used in designing the search strategy. Search terms included British and American terminology and spelling. The citations selected were based on information in the text of the material identified in the search result.

Connectors

AND, NOT, OR, ADJ (adjacent)

Truncation symbols:

*, $, ?, # (dependant upon database searched)

Search strategies for identification of publications

As the stated problem is technical and specific, a range of electronic databases were considered to determine their relevance to the stated problem. A series of search strategies were implemented in accordance with the HMMInfo Clearinghouse systematic review protocol (Phibbs & Bridge, 2003). In addition to the standard protocol, the following sources were included:

- British, American and Australian disability discrimination legislation and the relevant building codes were reviewed including International Organization for Standardization documents.
- International advice was sought from the IDEA Center, State University of Buffalo, New York in relation to appropriate measurement to address individual variants.
- Search of specific websites that focus on design and construction or building legislation in relation to accessible environments. This included:
    - Centre for Accessible Environments (UK)
    - Joseph Rowntree Foundation (UK)
    - Center for an Accessible Society (USA)
    - Center for Universal Design (USA)
    - Trace Research and Development Center (USA)
    - Center for Inclusive Design & Environmental Access (USA)
    - Only material available on the website and at no cost was retrieved.

- Manufacturers' specifications: The databases of Independent Living Centres (ILC) in New South Wales, Queensland and South Australia were searched to obtain grabrail manufacturers' and suppliers' details. Other state ILCs were not searched due to the duplication of search results.
- Periodical publications produced by organisations that promote disability issues relating to design / construction or building legislation. These publications, available through paid subscription, are not listed on the standard electronic databases. The articles are typically not peer reviewed. This review included:
  - Independent Living: Independent Living Centre, (AUS)
  - Access by Design: Centre for Accessible Environments, (UK)
- Personal correspondence with a selection of grabrail manufacturers regarding rationale underpinning grabrail diameter design decision

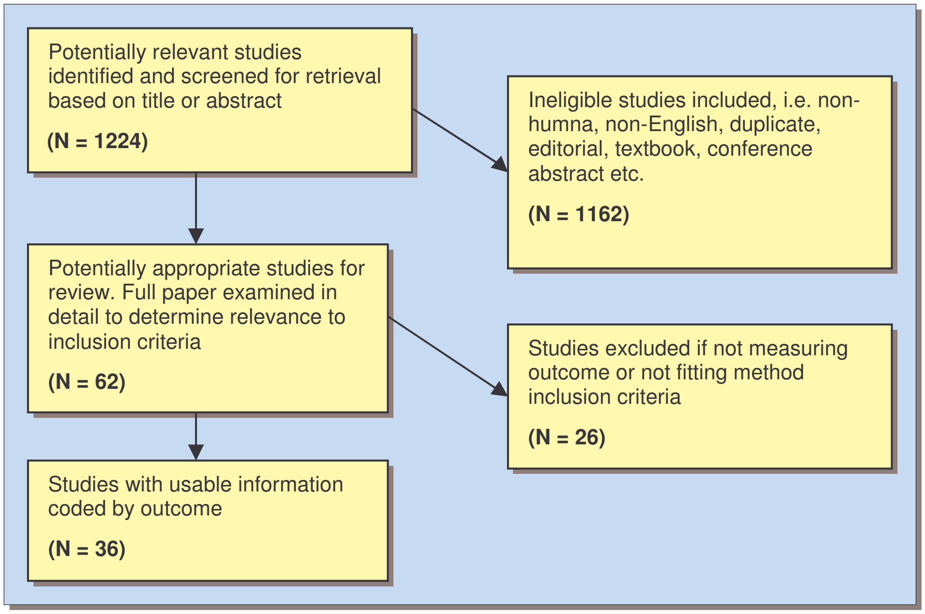

Figure 4: Review process flow

Exclusion criteria

The review did not include finished surfaces, maintenance, position or orientation relative to user. Reference to these rail attributes is limited to the materials included in the selected citations. Publications available only through purchase were not included and potentially weaken the study through omission of relevant studies. Conference papers were excluded. Materials that were not in English were excluded. Figure above illustrates the stages at which review criteria were applied.

Outcomes of Search

The stated research problem required information and knowledge across a number of disciplines including building & construction, biomechanics and human movement. The electronic databases that produced relevant material included:

Ageline, API: Architectural Publications Index, BUILD: Australian Building Construction Engineering Database, Compendex Plus, Current Contents, Expanded Academic Index ASAP, OSH-ROM, Science Direct, USYD, Web of Science.

Only two of the specific websites searched, Joseph Rowntree Foundation and Center for Inclusive Design and Environmental Assessment, offered relevant publications at no cost. Both Independent Living and Access by Design included relevant articles. Two articles from the IDEA Centre, State University of Buffalo were screened and included.

In total, 36 papers were reviewed, see appendix 2.

The studies reviewed covered a time span of 33 years. The earliest study was published in 1971 and the most recent 2004. The following analysis examines the results in terms of nationality, person, activity and environmental variables, and methodologies employed.

Nationality

All the literature reviewed from the electronic databases search originated in English speaking countries. Figure 5, below illustrates the breakdown of the material reviewed by the authors' country of origin. The Australian, USA and UK national building codes were the building codes most commonly cited in the papers reviewed. The implications of the limited number of building codes cited are discussed in the section 'quality of evidence for attributing outcomes' below.

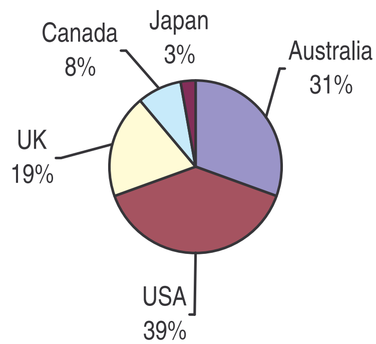

Figure 5: Nationality of literature reviewed

Analysis outcomes of content variables under review

The variables within each study reviewed were coded as activity, person or environment. The variables identified as 'Activity' orientated included grasp, transfer, change in level or both change in level and transfer (combination). 'Grasp' included studies that focused on gripping as a task or outcome in itself as opposed to the different grasps employed (person variable). The three remaining categories in 'activity' related to support and balance. The studies reviewed appear to consider support and balance in terms of transfers or change in level (stair negotiation) or did not distinguish between transfer and change in level.

'Person' orientated variables were categorised as type of grasp, biomechanical forces and all users. Type of grasp included studies that specifically considered attributes of various grasps. Studies explicitly related to forces resulting from muscle actions on the skeletal system were included in 'Biomechanics'. The term 'all users' describes studies of non-specific population groups.

The variables coded as 'Environment' included diameter, profile and interface. Environment orientated variables relate to conditions external to the person where these conditions are not readily changeable for the completion of the given activity or task. 'Diameter' includes studies that specifically address the issue of rail diameters. 'Profile' refers to the cross-sectional shape of the rail. Studies that considered the interaction at the hand and rail contact surface were coded as 'Interface'.

Of the total variables within the activity, person, environment framework used for analysis, the most frequently cited variable was 'all users', as shown in Figure 6. 'All users' typically occurred in studies where the attributes of specific population groups were not the primary interest. None of the studies reviewed directly addressed the stated problem: Is 25mm an appropriate grabrail diameter for older people?

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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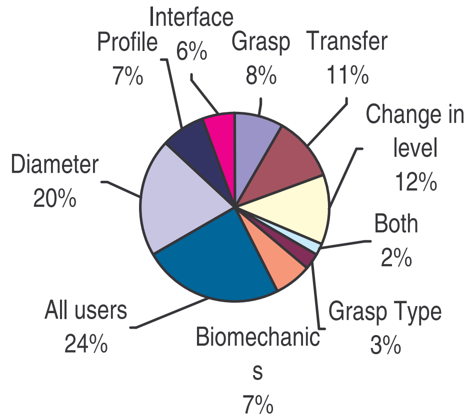

Figure 6 All variables

Relative to other activity-orientated variables, transfers (33%) and change in level (36%) were the most common variables discussed as shown in Figure 7. Two papers examined both change in level and transfers, both in relation to relevant building codes. Of the papers that considered transfers, only two did not include rail diameter as a variable.

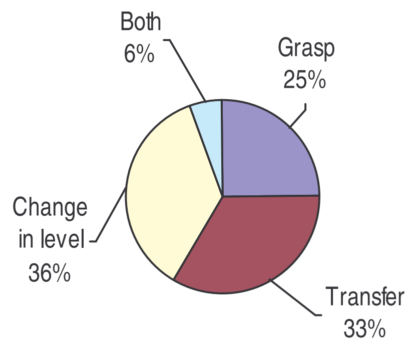

Figure 7 Activity related variables

Few studies considered specific population groups. Primarily the studies were concerned with the underlying biomechanics or physiology of grasp or consideration and comment on standards and building codes. In relation to person orientated variables biomechanics was considered in 20% of the studies reviewed. Grasp was specifically considered in only 8% of the studies. See Figure 8 below.

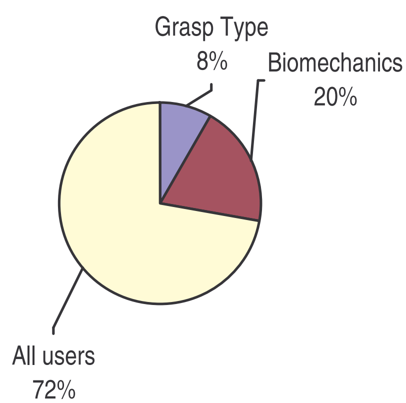

Figure 8 Person related variables

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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Rail diameters were considered in more than half of the studies (61%) as shown in Figure 9. Only one study, Ayoub (1971), considered diameter in relation to grasp. This study however focused on participants vertically pulling on handles of varying diameters.

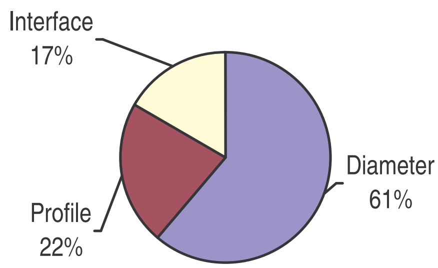

Figure 9 Environment related variables

Quality of evidence for attributing outcomes

In reviewing the methodologies of the included studies, the most systematic of the methodologies could be considered classically experimental in design; for instance, quasi-experimental methods accounted for ten of the studies (28% of those reviewed). However, no previous systematic reviews, random control studies, case studies or anecdotal papers were found in the included studies, see figure 10 below. No previous research was located that considered appropriate grabrail diameters for older people or people with a disability in terms of grip strength although a number of studies have considered grabrail diameters in relation to non-disabled populations. Consequently, evidence relating to prescription of grabrail diameters for older people is primarily limited to expert opinion.

A number of the expert opinion papers quoted or referenced building code requirements. Australian, USA and UK building codes were most commonly cited. We attempted but were unable to obtain the original research underpinning these building codes' requirements that related to grabrail diameter. Other expert opinion papers cited a limited number of quasi-experimental research projects.

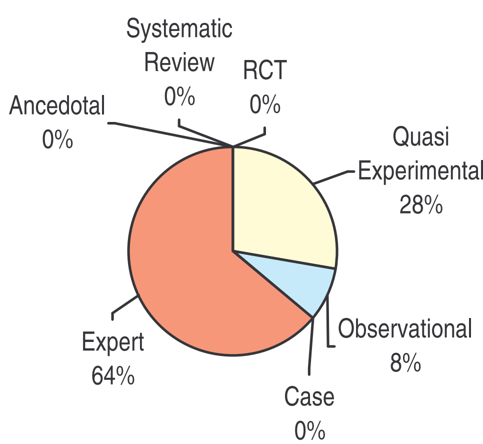

Figure 10: Methodology

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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Legislations/Regulations Relevant to Grabrail Diameter

A search for both Australian and international documents was conducted to include legislation regarding grabrail diameter. The following table summarises the requirements for grabrail diameters.

Table 6 Australian and international grabrail requirements

Country	Document	Date Published	Application	Requirements
Australia	Disability Discrimination Act (DDA)	1993	Access to premises	Makes it unlawful to discriminate against a person on the grounds of disability. Until the new Access to Premises standard is finalised, the BCA should be referenced for grabrail and handrail requirements.
	Building Code of Australia (BCA)	2005	Public and residential buildings	Cites AS 1428.1 for technical specifications – not mandatory for residential buildings. Part D3 includes specifications for handrails and grabrails.
	AS 1428.1 (Standards Australia, 2001)	2001	New public building work	Specifies an outside diameter of 30 – 40mm for grabrails and 30 – 50mm for handrails. Not a regulatory document for building classes 1, 2 or 4.
	AS 1428.2 (Standards Australia, 1992)	1992	Additional public building requirements	References AS 1428.1 for definitions and dimensional requirements for grabrails and handrails.
	AS 1428.3 (Standards Australia, 1992b)	1992	Children and public buildings	References AS 1428.2 for definitions and dimensional requirements relating to grabrails and handrails for children 3-18 years.
	AS 4299 (Standards Australia, 1995)	1995	Adaptable housing	Applies to residential buildings based on AS 1428 parts 1 and 2. No dimensional requirements are set out for handrails and grabrails.
	AS 4226 (Standards Australia, 1994)	1994	Safe housing design	Section 7, Bathroom Design, makes general reference to grabrail provision. Section 8, Toilet Design, states grabrails should be in accordance with AS1428.1. Clause 11.9.1of AS 4226 recommends handrail diameters of 32 – 50mm.
	AS 2610.1 (Standards Australia, 1993)	1993	Public spas	Handrails on ladders are required to have a diameter of 30 – 50mm. No specification given for handrail diameters on steps (Standards Australia, 1993b).
	AS 2610.2 (Standards Australia, 1993)	1993	Private spas	Part 2 requires handrails on ladders to have a diameter of 30 – 50mm. No specification given for handrail diameters on steps (Standards Australia, 1993a).

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
www.homemods.info

	AS 3979 (Standards Australia, 1993)	1993	Hydrotherapy Pools	Projecting handrails shall be nominally 38mm in diameter (Standards Australia, 1993a).
	AS 1735.12 (Standards Australia, 1999)	1999	Lifts and escalators	A handrail with a diameter of 30 – 50mm is required in accessible lifts.
	AS 1924.2 (Standards Australia, 1981)	1981	Playground equipment for parks, schools and domestic use	Diameters for handrails are set at 19 – 38mm. It is assumed that the smaller diameter reflects the smaller hand size of children.
United States of America	Americans with Disabilities Act Access Guidelines (ADAAG)	1990	Provision of access to public buildings	Handrails and grabrails must have a diameter of 32 – 38mm (Architectural and Transportation Barriers Compliance Board, 2000).
United Kingdom	Building Regulations 2000: The Approved Documents (BR 2000)	2000	Access to employment and services	BR 2000 Clause 1.37 requires handrails diameters of 40 – 45mm for circular rails or 50mm width for oval rails. BR 2000 does not specify a diameter for grabrail or grab bars.

Table 7 below displays the range of diameter variables recommended by different countries, as cited from the database (see appendix 2) and legislation searches.

Table 7 Diameter Variables Recommended

Country	Grabrail Diameter
Australia	30 mm - 51 mm
Canada	32 mm – 51 mm
Japan	33 mm – 35 mm
UK	30 mm – 50 mm
USA	32 mm – 57 mm[2]

Customary Behaviour/Published Guidelines

A review of supplier & manufacturer documentation, catalogues, and brochures for grabrails available in Australia indicated the most readily available grabrail diameter is 32mm. Manufacturers produce these documents to inform the consumer of the products available and to assist the consumer to make more informed product decisions. The documents also serve to reduce liability of the manufacturer by listing the conditions for safest application of their product.

[2] Note: the cross-section of the grabrail may be non-circular (Dusenberry & Simpson, 1996; J.G. Braun Company, 2002).

Information is quite limited in many of the brochures. Typically, diagrams demonstrating off-the-rack configurations are included with length dimensions but little accompanying text is provided. Some diagrams showed grabrails that did not comply with AS 1428.1 in relation to diameter or uninterrupted passage of hand. On review, 25mm and 32mm diameter grabrails were the most common noted grabrail diameters. However, most manufacturers also offer a 'customer made' option. In relation to manufacturer design decisions, the only information noted was compliance to relevant disability codes.

Other information was more technical in nature and may be difficult for people unfamiliar with technical drawing or professional terminology to interpret. The meaning of some terms and abbreviations such as I.P.S. (Iron Pipe Size) is not self-evident. I.P.S. relates to the internal diameter. However, outside diameter is more useful to designers and consumers as the building code specifications refer to outside diameter.

Anecdotal evidence:

Ten grabrail suppliers and manufacturers, located via the databases from the Independent Living Centres in New South Wales, South Australia, Victoria and Queensland, were emailed asking for clarification of design decisions relating to grabrail diameters. Six responses were received. Suppliers typically referred the query to manufacturers or stated they were unable to assist. Manufacturers noted costing and availability of materials, and compliance with Australian Standards as the most significant factors regarding grabrail diameter. An additional email from Barrie Fitchett noted, "There is no 30mm tubular material available commercially. That is why 32mm is used. We mainly use 28.6mm. Anecdotal data has shown this to be better for older persons" (Personal communication, 8 January 2004).

The suppliers' or manufacturers' websites were also reviewed for evidence of the rationale underpinning design decisions. No information relating to design rationale was provided on the websites.

General findings of studies reviewed

The contact area and wrist orientation are the key factors for determining the optimal diameter, generally between 30 – 50mm (Pheasant & O'Neill, 1975). Maki (1985) and Templer (1992) recommend a circular handrail with 38mm diameter as the optimum for greatest stabilising force and consequent accident prevention and injury reduction.
Goldsmith (2000a) provides dimensions for handrails only. He states circular handrails with a diameter of 30-50mm are most comfortable to use. Goldsmith provides no evidence for the recommendations he makes.
Humanscale 5a (Diffrient, Tilley, & Harman, 1981) provides recommended maximum and minimal dimensional data for a variety of controls. This includes handrails: 19mm – 67mm; grabrails: 19-32mm; cylinder handles: 25-38mm and hand levers: 25-44mm. The authors advise that the dimensions should be altered to accommodate the specific activity and user group.
Diffrient et al (1981) advise that design should consider comfort, avoidance of disability and maximal productivity. They continue that good design begins with anthropometric data, including hand size, of the intended user.
Currently, there appears to be a paucity of strong evidence available relating to the selection of grabrail diameters; more research is urgently required.

Summary

Appropriate prescription and design of a grabrail affects successful outcomes. Successful use of a grabrail is achieved when the individual has completed the given activity in a safe and dignified manner. This includes minimising the risk of secondary disability due to falls or overuse injuries. In addressing the research question, it appears that one grabrail diameter cannot be universally recommended.

Customary behaviour in Australia for the prescription and design of grabrails in private residences is frequently based on AS 1428.1. This standard is useful as a default when individual's anthropometric measurements are unknown. It is important that one size never becomes mandatory for private residential buildings, as optimal design needs to accommodate individual variation.

To optimise outcomes in grabrail design, variation from the standards may be indicated particularly where the individual falls outside the scope of the relevant standard. Grabrail prescription and design is a complex activity. A number of elements interact to support or constrain the likelihood of successful outcomes. In relation to diameter, these elements have been considered in relation to person, activity and environment.

Person

An individual's physical capability is a key component to the potential grip strength. For example, impaired sensation, restricted range of motion, coordination and muscle strength will constrain or support the individual's ability to grasp, the type of grasp and grip strength possible.

A power grasp is most appropriate for use with grabrails in transfers and avoiding falls. The wrist should remain in a neutral position to optimise the length of extrinsic finger muscles and the consequent strength generated.

Hand size of the individual must be considered in grabrail design. As friction is increased by increased surface contact area, the required grip strength can be moderated by increasing the surface contact area of the hand and grabrail. This is true within the constraints that the individual can form an adequate grasp. Too small a diameter decreases surface contact area and increases the grip strength required, and too large a diameter may reduce ability to form a power grasp.

Therefore, the hand size of an individual is critical in determining the optimum grabrail diameter.

Activity

Grabrails are used to provide stability or support while an individual completes a specific task. This may include vertical and horizontal movement of the individual, such as in transfers. Grabrails also serve to avoid or minimise injuries in the event of a fall.

Position or orientation of the grabrail influences the potential grip strength generated. As previously noted, grip strength is reduced when the wrist is not aligned with the forearm. Where the activity involves a change in position, the position of the individual relative to the rail will also alter. Consequently, the wrist position will alter changing the strength required to maintain adequate grasp.

Grabrail designers and prescribers should consider grip strength, particularly concerning position, angle and task. Modifications to orientation and position that minimise the required grip strength may be required.

Environment

The frictional properties of the grabrail surface impact directly on the grip strength required to maintain stability.

The greater the contact surface area at the hand and grabrail interface the greater the friction thereby decreasing the strength required to prevent the hand slipping on the grabrail. The lower the coefficient of friction the greater the grip strength required.

Grabrail profile, including diameter, is a critical factor in maximising the contact surface area.

Other factors to consider

Diameter is only one factor influencing a successful use of grabrails. Design and prescription should also consider:

Finished surface of rail

The coefficient of friction of the finished surface will influence the grip strength required to maintain a stable grasp. Textured surfaces are more likely to retain contaminants than smooth surfaces. However, some textured surfaces may increase the coefficient of friction when wet.

Contaminants

Exposure to contaminant should be minimised. The location of the grabrail, e.g. shower recess or adjacent to the toilet, should be considered in relation to maintenance and grabrail finished surface. Thorough and regular maintenance and cleaning should reduce the risk of contaminant build up.

Profile or shape of grabrail

Circular or some oval profiles provide the greatest surface contact area, thereby reducing the grip strength required.

Orientation or location of grabrail – reach distance, vertical or horizontal

The orientation of the person to the grabrail influences the wrist position and hence the grip strength required to maintain adequate grasp.

Conclusion

Grabrails frequently are prescribed to reduce the risk of falls. In part, fall avoidance is related to the quality of grasp and grip strength. Grabrail design decisions should consider the person's physical attributes, the activity (task) and environmental components.

Hand size is a critical component in the grabrail design decisions relating to diameter because it influences the quality of the grasp and grip strength. Due to the variation in hand sizes across the population, it is not possible to specify one grabrail diameter for all applications. Consequently, it is not possible to make a definitive statement regarding the suitability of 25mm diameter grabrails installed for older people in their homes. However, as people's size appears to diminish with age, the use of code dimensions based on the general population maybe invalid. Each grabrail diameter for home installation should be prescribed based on the individual's hand size.

While hand size is critical in prescribing the appropriate grabrail outside diameter, a number of other design features may also affect grip strength. These features include:

- Maximising surface contact area is critical in safe use of grabrails during transfers or in fall avoidance.
- Grabrails with a circular or oval profile maximise surface contact area.
- Power grasps provide the maximum surface contact area.
- Orientation to the grabrail such that the wrist is in a neutral position optimises grip strength when a power grasp is used.
- Contaminant exposure and collection should be minimised through choice of finished grabrail surface, location and maintenance program.

Information Strategies

- Develop a fact sheet on grabrail design and prescription for use by home modification and maintenance service providers, occupational therapists, and designers.
- Develop a plain English fact sheet on advantages and limitation of grabrail attributes for consumers to encourage informed choice.

Research Strategies

- Hand size is a critical factor in designing and prescribing grabrail diameter. However, evidence is required to support design decisions relating to grabrail diameter. Research is recommended to evaluate the hypothesised relationship between inside hand grasp diameter and grabrail diameter.
- Handrail diameters required by Australian Standards should be reconsidered to reflect the different biomechanical demands, relative to normal mobility, in event of a fall. Current code requirements for handrail diameters exceed that of grabrail diameters. These requirements appear to assume use for guidance or balance only, not how the rail is used in the event of a fall i.e. the need for a diameter that enables maximum power grasp. They do not explicitly discuss the biomechanical variations resulting from the difference in use of handrails and grabrails. It may then be judicious to minimise the likelihood of a fall and severity of injury by reassessing building code requirements for handrail diameters. A handrail that enables use of a power grasp and generation of adequate grip strength at the time of fall is prudent. However, further consideration needs to be given to the strength required or the ability of people with a disability and older people to maintain grasp on a handrail with a smaller diameter over an extended period e.g. when negotiating stairs. Research evaluating current and optimal handrail diameters is recommended.

- AS 1428.3 refers to the requirements of AS 1428.2 for grabrails and handrails. As hand size and contact surface area are critical factors in the optimal design of grabrails, diameters for adults, as provided in AS 1428.2, maybe inappropriate for children. Research to evaluate appropriate diameter of grabrails and handrails for children is recommended.
- Current building codes provide limited information on appropriate finished surface of grabrails and handrails. Contaminants may limit the effective use of a grabrail or handrail. Research to assess the performance of various finished surfaces for grabrails in relation to grasp stability is recommended.

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Appendix 1: Search Strategy

Databases	Strategy	Results	Inclusion
Ageline	((support bar*) or (support rail*) or (hand rail*) or (grab rail*) or grabrail* or (grab bar*) or handrail*) or (horizontal bar*) AND (diameter or wide* or width or thick* or grasp or grip* or dimension* or design* or specification* or breadth or size or measure)	60	3
Ageline	(rail or rails) NOT (yard or light or train* or track) AND (diameter or wide or width or thick* or grasp or grip* or dimension* or design* or specification*)	10	0
API: Architectural Publications Index	grab bar	0	0
API: Architectural Publications Index	grab rail	0	0
API: Architectural Publications Index	grabrail	0	0
API: Architectural Publications Index	support rail	0	0
API: Architectural Publications Index	support bar	0	0
API: Architectural Publications Index	handrail	4	2
API: Architectural	rails	40	0

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
www.homemods.info

Databases	Strategy	Results	Inclusion
Publications Index			
Arch: Australian Architecture Database	((support bar*) or (support rail*) or (hand rail*) or handrail* or (grab rail*) or grabrail* or (grab bar*) or (horizontal bar*) AND (diameter or wide* or width or thick* or grasp or grip* or dimension* or design* or specification* or breadth or size or measure) AND (age* or geriatric* or elder* or old* or senior)	12	0
Arch: Australian Architecture Database	(rail or rails) NOT (yard or light or train* or track*) AND (diameter or wide* or width or thick* or grasp or grip* or dimension* or design* or specification* or breadth or size or measure)	66	0
AVE: Avery Index to Architectural Periodicals	(grab rail?) or handrail? or (grab bar?) or (support rail?) or (support bar?) or (horizontal bar?)	0	0
AVE: Avery Index to Architectural Periodicals	railing or railings	86	0
BUILD: Australian Building Construction and Engineering Database	(diameter or width or wide* or design or specification* or dimension* or grip or grasp or thick* or breadth or size or measure) ADJ7 (rail or rails) NOT (track or train or yard or clapper or light)	0	0
BUILD: Australian Building Construction and Engineering Database	(diameter or width or wide* or design or specification* or dimension* or grip or grasp or thick* or breadth or size or measure) AND railing*	4	0
BUILD: Australian Building Construction and Engineering Database	((support bar*) or (support rail*) or (hand rail*) or (grab rail*) or grabrail* or (grab bar*) or handrail* or (horizontal bar*)) AND (diameter or wide* or width or thick* or grasp or grip* or dimension* or design* or specification* or breadth or size or measure)	18	4

Databases	Strategy	Results	Inclusion
CAB abstracts	((support rail$) or (support bar$) or handrail$ or (hand rail$) or grabrail$ or (grab rail$) or (grab bar$) or (horizontal bar$)) AND (diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thick$ or breadth or size or measure) AND (age$ or geriatric$ or elder$ or old$ or senior)	6	0
CAB abstracts	((support rail$) or (support bar$) or handrail$ or (hand rail$) or grabrail$ or (grab rail$) or (grab bar$) or (horizontal bar$)) AND (diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thick$ or breadth or size or measure)	10	0
CAB abstracts	(support NEAR rail$) or (support NEAR bar$) or handrail$ or (hand NEAR rail$) or grabrail$ or (grab NEAR bar$)	10	0
CAB abstracts	(diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thick$ or breadth or size or measure) ADJ7 (rail or rails)) NOT (track or train or yard or clapper or light)	56	0
Cinahl	((support rail$) or (support bar$) or handrail$ or (hand rail$) or grabrail$ or (grab rail$) or (grab bar$) or (horizontal bar$)) and (diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thick$ or breadth or size or measure) AND (age$ or geriatric$ or elder$ or old$ or senior)	52	1
Cinahl	support NEAR rail$ or support NEAR bar$ or handrail$ or hand NEAR rail$ or grabrail$ or grab NEAR bar$	25	0
Compendex Plus	((grab bar*) OR (grab rail*) OR grabrail*) NOT (crane or train or clamping or waste)	145	4
Compendex Plus	(handrail* or (hand rail*)) AND (clasp* or design) NOT (machinery or railroad or construction or motor or bridge or train or clapper or railway)	90	4
Compendex Plus	(handrail* or (hand rail*)) AND (thick* or grasp* or dimension*)	77	3
Compendex Plus	(handrail* or (hand rail*)) AND (grip*or specification*)	16	2

Databases	Strategy	Results	Inclusion
Compendex Plus	railings AND (grasp* or grip* or clasp) AND (diameter or wide or width or design*)	26	4
Compendex Plus	(handrail* or (hand rail*)) AND (diameter or wide or width) NOT (wheel or tunnel or bridge or railway or railroad or track)	19	0
Current Contents	((support rail$) or (support bar$) or handrail$ or (hand rail$) or grabrail$ or (grab rail$) or (grab bar$) or (horizontal bar$)) and (diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thick$ or breadth or size or measure) AND (age$ or geriatric$ or elder$ or old$ or senior)	17	0
Current Contents	(grab bar*) or grabrail* or (grab rail*)	12	9
Current Contents	handrail* or (hand rail*)	55	1
Current Contents	(support bar*) or (support rail*)	27	0
Expanded Academic Index ASAP	((support rail*) or (support bar*) or handrail* or (hand rail*) or grabrail* or (grab rail*) or (grab bar*) or (horizontal bar*)) AND (diameter or width or wide* or design or specification* or dimension* or grip or grasp or thickness or breadth or size or measure)	17	3
Expanded Academic Index ASAP	hand railing*	16	3
Medline	((support rail$) or (support bar$) or handrail$ or (hand rail$) or grabrail$ or (grab rail$) or (grab bar$) or (horizontal bar$)) AND (diameter or width or wide$ or design or specification$ or dimension$ or grip or grasp or thickness or breadth or size or measure)	91	0
Medline	(diameter or width or wide or design or specification$ or dimension$ or grip or grasp or thick$) ADJ7 (rail or rails) NOT (track or train or yard or clapper or light)	15	0

Databases	Strategy	Results	Inclusion
Medline	(support NEAR rail$) or (support NEAR bar$) or handrail$ or (hand NEAR rail$) or grabrail$ or (grab NEAR bar$) AND (diameter or width or wide or design or specification$ or dimension$ or grip or grasp or thick$)	27	0
OSH-ROM	((support rail*) or (support bar*) or handrail* or (hand rail*) or grabrail* or (grab rail*) or (grab bar*) or (horizontal bar*)) AND (diameter or width or wide* or design or specification* or dimension* or grip or grasp or thickness or breadth or size or measure)	22	0
OSH-ROM	(diameter or wide or width or thick* or grasp or grip* or dimension* or design* or specification*) NEAR (rail or rails) not (yard or light or train* or track*)	19	0
OSH-ROM	((support rail) or (support bar) or handrail or (hand rail) or (grabrail) or (grab bar)) NEAR (diameter or width or wide or design* or specification* or dimension* or grip* or grasp or thick*)	24	3
Science Direct	railing* AND (diameter or width or wide or design* or specification* or dimension* or grip* or grasp* or thick*)	6	0
Science Direct	((support rail*) or (support bar*) or handrail* or (hand rail*) or grabrail* or (grab bar*)) AND (diameter or width or wide or design* or specification* or dimension* or grip* or grasp* or thick*)	9	3
USYD	grabrail* or (grab rail*) or (grab bars) or handrail* or (hand rail*)	9	6
Web of Science	railing* AND (diameter or width or wide or design* or specification* or dimension* or grip* or grasp* or thick*)	10	0
Web of Science	(diameter or wide or width or thick* or grasp* or grip* or dimension* or design* or specification*) AND ((support bar*) or (support rail*) or (hand rail*) or (grab rail*) or grabrail* or (grab bar*) or handrail*)	10	1
Results		1218	56

Appendix 2: Grabrail diameter analysis matrix

Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Goldsmith, 2000b)	UK	Circular handrails with a diameter of 30 - 50mm are the most comfortable to use. Drawings for alternative profiles and diameter up to 60mm are provided.	There is no evidence provided to support the recommenda tions. Diameter dimensions are provided for handrails only not grab rails.			1				1	1								1	
(Diffrient, Tilley & Harman, 1981)	USA	For people with a disability, handrails should be smooth and round with 38-51mm diameter. Humanscale 5a gives max & min dimensions for a variety of controls including handrails: 19mm – 67mm; grab rails: 19-32mm; & hand levers: 25-44mm.	Information on large, average and small, men, women, children and people with a disability. The authors advise that the dimensions should be altered to accommodat e the specific activity and user group.		1					1	1					1				

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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Steinfeld, Shea & Levine, 1996)	USA	Handrails and grab bars should have a diameter of 32 - 38mm.	Aim is to educate building professionals and consumers in issues and details of accessible modifications. Recommendations provided comply with CABO/ANSI A117.1 and ADAAG.				1			1	1								1	
(Mullick, 1993)	USA	Most common bathing difficulties were maintaining balance and transfers. Other issues identified included poor grasp, restricted reach and impaired sensation (thermal sensitivity). Most common unsafe practice was standing in the absence of a grab bar. Grab bars should meet the unique needs of individuals.	Grab bars used for balance and support and to assist in transfers. Qualitative methodology used - Interviews and focus groups. No evidence provided to support statement of findings and recommendations		1					1			1				1			

Reference	Nationality	Main findings	Process & issues	Activity: Grasp	Activity: Transfer (support)	Activity: Change in level	Activity: Combination	Person: Type of grasp	Person: Biomechanics	Person: All users	Environment: Diameter	Environment: Cross sectional profile	Environment: Grip span or hand / rail interface	Method: Systematic review	Method: RCT	Method: Quasi experimental	Method: Observational	Method: Case study	Method: Expert	Method: Anecdotal
(Sloane, 2000)	Australia	Generally handrails should have a diameter of 30 - 50mm.	Article notes that variation from the standards may be required for some individuals			1				1	1								1	
(Lacey, 2000)	UK	Diameter of handrails should be 45 - 50mm.	No statement is made regarding the handrail profile. It is implicit that these recommendations are based on British building regulations			1				1	1								1	
(Lacey, 1999)	UK	Diameter of handrails should be 45 - 50mm.	No statement is made regarding the handrail profile. It is implicit that these recommendations are based on British building regulations			1				1	1								1	

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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Fothergill, Grieve & Pheasant, 1992)	UK	Handles with the largest degree of hand / handle interface and those which allowed a power grasp produced the greatest pulling strength. Forces generated were also sensitive to handle placement. Except where poor hand / handle interface occurred.	4 types of handles were used, 1 elongated (lever style) and 3 knobs. The average age of the 30 subjects was 30 years. Type of grasp was chosen by subjects. However, only dominant hand was used, only feet contacted the floor and leading foot was not placed in front of the handle.	1					1				1			1				
(Ayoub & Lo-Presti, 1971)	USA	Lowest forearm muscle activity occurred for diameters between 25mm and 64mm. However, optimum diameter must consider weight also. Ratio of forearm muscle and activity and grip strength indicated optimal diameter of 38mm. Subjects hand size had minimal effect.	Power grasps only were tested. Task involved subject pulling handle vertically downwards while seated. Subjects included 6 x 21 - 25 year males only. Smallest hand length was 178mm, longest was 204mm.	1					1		1					1				

Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Stevenson, 2002)	Australia	Generally 30 - 50mm diameter is recommended	No evidence is provided to support the assertions. Introduction refers to all rails used on stairs & for transfers as grab rails. Remainder of the article only makes reference to transfers. It is unclear whether the recommenda tion refers to all rails, regardless of function, or rails used for transfers only				1			1	1								1	
(Bails, 1983)	Australia	Test A16 used 33 female subjects (9 visually impaired, 20 ambulant and 4 wheelchair users). 38mm was the most preferred size followed by 32mmm and 51mm.	Primarily a statement of results. Insufficient detail on methodology provided. Terminology 'issues' is not defined.			1				1	1					1				

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				Activity				Person			Environment			Method						
Reference	Nationality	Main findings	Process & issues	Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Hedge, 1999)	USA	Power (cylindrical) grasp generates maximum gripping strength. Deviation from 'normal' posture reduces maximum grip strength. Grasps spans that are too large or small reduce grip strength. Optimal grip span is 2" (50mm).	Evidence is not provided for these assertions	1				1					1						1	
(Buchholz, Frederick & Armstrong, 1998).	USA	Tendency for slip increases with lower friction surfaces requiring greater grip strength than higher friction surfaces	Sample size was too small to generalize results. Participants were aged 23-41 years. Study considered pinch grasp only.	1				1					1			1				
(Achea, Collins & Stahl, 1979)	USA	Handrails should enable a typical user to grasp rail so that thumb and index finger formed a 'C.' The ideal diameter relates to hand size and degree of closure/grip strength of user. Recommends 45-50mm based on results of other studies.	The recommendations are based on results of other studies. These studies were not all available to this review. Considers the needs of people with a disability and older people.			1				1			1				1			

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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Templer, 1992)	USA	Handrails should be circular with a diameter of 38mm.	A design checklist for stairs is provided. Recommendations are based on inference from review of literature and research.			1			1				1						1	
(Roland, 1996a)	Australia	Anterior-posterior and lateral forces indicated participants 'pulled' on the grabrail towards self. The forces increased sharply at beginning of movement, peaking at maximum hip flexion. Some participants used grabrail as a stabiliser i.e. during extension component of movement.			1				1			1				1				
(Steinfeld, Shea & Levine, 1998)	USA	Grabrails to be 1.25" - 1.50 " in diameter.	No evidence is provided to support the recommendations is provided		1				1		1								1	

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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Peebles & Norris, 2000)	United Kingdom	Maximum strength peaks in adulthood, decreasing with age from 50 years. Males in general were stronger than females.	Maximum static pushing and pulling force with both one and two hands. Diameter of cylindrical bar utilised was 20mm. No rationale provided for diameter selected.	1					1			1				1				
(Pauls, 1991)	Canada	Circular cross section with an outside diameter between 32 - 51mm or any other shape with a circumference of 100 - 159mm and no cross sectional dimension exceeding 57mm.	Introductory statements made in 'Appropriate shape, size and surface' are subjective only. They do not offer evidence. Limited studies reviewed to support the conclusions offered.	1						1		1							1	
(Medical Engineering Working Party, 1975)	Australia	Grab rail diameter should be 38 - 51mm.	An informal discussion relating to toilet arrangements of fixtures and fittings. No evidence provided to support statements		1					1	1								1	

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Maki, Perry & McIlroy, 1998)	Canada	During fall, axial handrail force component was directed along handrail using a pulling not pushing action as expected.	Participants included 4 adult males aged 23 - 27. First in a series of studies to consider handrail use in dynamic conditions. The handrail height, cross sectional profile and diameter (51mm) was consistent for all tests.			1			1			1				1				
(Mace, 1991)	USA	32 - 51mm diameter for grab bars	Reference to ANSI and UFAS only, no comments relating to original research or evidence is provided		1					1	1								1	

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Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(J.G. Braun Company, 2002)	USA	Proposed changes to ANSI and ADAAG 2003 relating to handrail dimensions include circular cross section with an outside diameter of 32 - 51mm. For non-circular cross section, the perimeter dimensions to be 100 - 160mm and cross sectional dimension to be 57mm maximum.	Reference to regulatory documents only, no comments relating to original research or evidence is provided			1				1		1							1	
(Independent Living Centre S.A., 2002)	Australia	Restates requirements of AS1428.1 -- 1993, 30 - 40mm outside diameter for grab rails	Reference to regulatory standards only, no comments relating to original research or evidence		1					1	1								1	
(Independent Living Centre N.S.W., 1994)	Australia	Restates requirements of AS1428.1 -- 1993, 30 - 40mm outside diameter for grab rails	Reference to regulatory standards only, no comments relating to original research or evidence		1					1	1								1	

Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Goldsmith, 1984)	United Kingdom	45 - 50mm diameter recommended for handrails and 30 - 45mm diameter recommended for grabrails.	No evidence is provided to support the recommenda tions is provided		1					1	1								1	
(Gibson, 1996)	Australia	Restates requirements of AS1428.1 -- 1993, 30 - 40mm outside diameter for grab rails	Reference to regulatory standards only, no comments relating to original research or evidence		1					1	1								1	
(Fernie, 1997)	Canada	Circular handrails with 38mm diameter are recommended	Summary statement of finding from earlier study by Maki, Bartlett & Fernie (1984). There is no information relating to rigour of research			1				1		1							1	

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www.homemods.info

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				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Feeney & Webber, 1994)	United Kingdom	Circular handrail with a diameter 32 - 38mm or oval handrails 18 x 32mm and 37 x 50mm are acceptable	Study critically reviews literature on design guidelines and studies for handrails. No information is provided on search strategies or inclusion & exclusion criteria	1						1		1							1	
(Dusenberry & Simpson, 1996)	USA	Milled handrails with cross sectional width of 38 - 57mm provide equal graspability as a circular handrail with 51mm diameter.	Limited information provided on sampling methods. Basic assumptions relating to the grasp type and force generation appear to be flawed. However, there is an indication that smaller hands generate greater grip strength on smaller diameter handrails.			1		1				1				1				

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(CSIRO Building Construction and Engineering Building Information Resource Centre, 2001b)	Australia	General reference to compliance with AS1428.1 for grabrails (30 – 40mm)	Building Technology File providing an overview of requirements for grabrails in unisex accessible toilets, cubicles for people with an ambulant disability, urinals and showers. There is no methodology or rationale for these statements provided.		1					1	1								1	
(CSIRO Building Construction and Engineering Building Information Resource Centre, 2001a)	Australia	General reference to compliance with AS1428.1 for grabrails (30 – 40mm)	Building Technology File gives an overview of building design and modifications in public spaces that provide access to people with a disability. There is no methodology or rationale for these statements provided.		1					1	1								1	

Diameter: Evidence based research: Selecting diameters for grabrails: January 2006 ✦ ISBN: 1 86487 761 8
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				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(CSIRO Building Construction and Engineering Building Information Resource Centre, 2001c)	Australia	States AS1428.1 requirements for cross sectional diameter of handrails. Additional statement that 38 – 50mm is 'more acceptable'.	Building Tech File provides guidelines & principles for handrail design in public spaces. Refers to AS1428.1 but offers preferred design that is still within regulatory requirements. There is no methodology or rationale for these statements provided.			1				1	1								1	
(City of Seattle Dept. of Design, 2002)	USA	Cross sectional diameter of handrails to be 32 – 51mm	Client Assistance Memo prepared by the Depart of Design, Construction & Land Use. Provides rationale for building code requirements in Seattle & Washington State relating to handrail installation. Mainly relates to public spaces but some consideration is given to private residential			1				1	1								1	

Reference	Nationality	Main findings	Process & issues	Activity				Person			Environment			Method						
				Grasp	Transfer (support)	Change in level	Combination	Type of grasp	Biomechanics	All users	Diameter	Cross sectional profile	Grip span or hand / rail interface	Systematic review	RCT	Quasi experimental	Observational	Case study	Expert	Anecdotal
(Ishihara et al., 2002)	Japan	Optimal handrails in Japan 33mm-35mm in diameter	Participants included 41 subjects 63-68 years, who suggested the optimal thickness and height of handrails and length of horizontal extensions. Is subjective and limited to population.	1						1	1						1			
(Edgren, Radwin, & Irwin, 2004)	USA	3.81cm optimal diameter fro maximum grip strength for most participants (73%)	61 subjects recruited from a manufacturin g facility grasped cylinders of 2.54cm, 3.81cm, 5.08cm, 6.35cm & 7.62cm diameter using a power grasp.	1						1	1					1				

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