Designing inclusive products for everyday environments: The effects of everyday cold temperatures on older adults' dexterity

Elton E and Nicolle C

Loughborough Design School, Loughborough University, Loughborough, UK

Phone: +44 (0)1509 226921

Fax +44 (0)1509 226960

e.elton@lboro.ac.uk

http://www.lboro.ac.uk/departments/lds/

The authors would like to thank the EPSRC for funding this work which was part of the i~design 3 research project.

Abstract

This paper focuses on the effect an everyday cold temperature (5°C) can have on older adults (+65 years) dexterous capabilities and the implications for design. Fine finger capability, power and pinch grip were measured using objective performance measures. Ability to perform tasks using a mobile phone, stylus, touch screen and garden secateurs were also measured. All measures were performed in a climatic cold chamber regulated at 5°C and in a thermo-neutral environment regulated between 19°C-24°C. Participants were exposed to the cold for a maximum of 40 minutes. Results from the study showed that older adult's fine finger dexterity, ability to pick-up and place objects and ability to use a mobile phone was significantly (p<0.05) affected by an everyday cold temperature of 5°C when compared to performance in the thermo-neutral environment. However, power and pinch grip strength and ability to use the gardening secateurs was not significantly affected by the cold. Based these findings, the following guidance is offered to designers developing products that are likely to be used outside in an everyday cold environment: 1) Minimise the number of product interactions that require precise fine finger movements; 2) Try to avoid small controls that have to be pressed in a sequence; 3) Maximise the number of product interactions that can be operated through either exerting a gripping action (power or pinch grip) or by gross hand and arm movements.

Keywords: Inclusive design, dexterity, cold temperatures, older adults.

1. Introduction

Capability is one of the fundamental attributes a person needs in order to access and use everyday products. The underlying principle is that products have a combination of characteristics that place a demand on the user's capabilities. If the demand of using the product is greater than that of the user's capabilities (i.e. what they are functionally able to do), ultimately it will result in their becoming excluded from product use [1]. The need to consider users' capabilities when designing has dramatically increased over the past decade due to our ageing population. Generally, with increasing age, comes the loss of ability to interact with everyday products [2].

Inclusive design is the philosophy that aims to consider this reduced functional capability during the design process, with the aim of making products functionally accessible and usable to as many people as reasonably possible [3]. Two inclusive design tools have been developed over the past 10 years in order to help designers better understand and consider the reduced functional capabilities of the ageing and disabled population: HADRIAN (Human Anthropometric Data Requirements Investigation and Analysis) [4], and the Inclusive Design Toolkit [5]. Whilst such capability tools are a big step forward, they fail to consider capability in real-life environments [6]. In particular, the tools do not consider the impact of the physical environment (external surroundings/conditions) on users' capabilities. To date, a number of studies have reported significant reductions in functional capability due to factors associated with the physical environment. Elton and Nicolle [7] reported how older adults' visual acuity is affected by everyday lighting levels; Riley and Cochran [8] reported how younger adults' dexterous ability decreases through reduced ambient temperature; Baker and Mansfield [9] reported decrements in dexterity when exposed to vibration.

The question arising from this is whether such capability data is necessary to design inclusive everyday products. The short answer is yes. Today's baby boomer generation promises to be different from previous elder generations - they expect great things from design and technology. In particular, wireless information and communication technologies have become part of the fabric of their everyday life [10]. These advancements have allowed for the use of more everyday products when out of a controlled home environment. For example, there is no restriction as to where mobile phones, mp3 players, digital cameras, PDAs, satellite navigation systems, signature recording devices, etc. can be used. Also, as we move towards a 24 hour society, there are no limits to when products will be used. It is not just technological devices that are used whilst out of the home environment; products such as flasks, keys, drinks bottles, maps, door handles, bus timetables, gardening products, packaging, etc. are also used in a wide range of different environments. Failure to consider the capabilities of users in these everyday environmental conditions could result in products excluding or causing difficulties to those intended to be included. Thus, if a mismatch between context and a product occurs, it is unlikely that the (inclusive) benefits of a product will be realised [11].

Prior to conducting experimental investigations, there is firstly a need to establish what type of real-life capability data and contexts are of greatest significance to inclusive product design. In particular, there is a need to establish what capabilities are common to the majority of product interactions and which environmental conditions are most likely to affect such capabilities.

2 Capabilities and context

2.1 Product interaction capabilities

When interacting with a product, demand will typically be made on up to six user capabilities [5,12]. These capability categories have been identified as:

- Vision
- Hearing
- Cognitive
- Locomotion
- Reach and Stretch
- Dexterity

The demand placed on each capability is dependent upon the characteristics of the product being used and the task being accomplished. However, the vast majority of product interactions make demands on the visual and dexterous (arm, hand and finger) capabilities of the user [6]. Whilst other capabilities are also used, it is these that are most common. Previous research investigated the effect of everyday lighting levels on visual capabilities [7]. This paper will specifically focus on the impact of the physical environment on dexterity.

2.2 Identification of relevant physical environmental characteristics

The physical environment refers to the external surroundings or conditions. This is comprised of ambient illumination levels, atmospheric conditions, temperature, auditory conditions, vibration and the built environment [13].

In relation to dexterity, both vibration and cold temperatures have been identified as having an effect [5, 8, 9]. Whilst both of these factors are experienced when interacting with products, it is cold temperatures which are experienced for long durations (annually for up to 3-4 months). Again, with a large number of products being used both inside and outside the home, it becomes an environmental factor relevant to a large number of product interactions. This paper will focus on the effect everyday cold temperatures have on dexterity and the implications for design.

3 Dexterity

Dexterity refers to the ability to use one's hands [14] or the ability to manipulate objects with the hands [15]. Heus *et al* [16] defines dexterity as: *"a motor skill that is determined by the range of motion of arm, hand and fingers and the possibility to manipulate with hand and fingers."*

Dexterity comprises both gross and fine finger dexterity [17]. Fine finger dexterity refers to the ability to manipulate objects with the distal (fingertip) part of the hand. This involves precise movement of the fingers, e.g. when using a keypad/ pressing buttons/switches, picking up a coin, using a touch screen, inputting a code, etc. Gross dexterity involves less refined and less precise movements of the arm, hand and fingers [17].

The object is usually larger and manipulation requires more gross movements, e.g. digging, opening a door, placing a saucepan on the hob, etc.

There is also the hand function grip strength which is common in most gross and fine finger tasks. Most products require stabilisation with a grasp or a pinch before it can be moved or used [18]. The human hands therefore provide us with the ability to make a wide range of movements, from very fine precise actions to forceful gripping actions over a range of distances.

The human hands are controlled through the articulation at joints performed by muscles originating in the hand (intrinsic muscles) and by muscles originating in the forearm (extrinsic muscles) [19]. Extrinsic muscles control most hand movements [20]. Functioning of the hands is determined by several physiological factors that are described in table 1. Both ageing and cold temperatures have been shown to affect these physiological factors.

Table 1 Factors that influence dexterity [16]

Component of dexterity	Description
Reaction time	The time between a stimulus being presented and the start of motor response
Sensibility	The response of receptors in the skin to tactile, pressure, thermal and pain stimuli
Nerve conduction	The speed at which nerves conduct signals
Grip strength	The force that can be developed by the muscles of the upper and lower arm
Time to exhaustion	The time to when a decrease in force exerted by the muscles occurs
Mobility	The range of motion of the hands and fingers

3.1 Effects of ageing and increased pathology on dexterity

The relationship between ageing and dexterity has been widely investigated. It has conclusively been shown that dexterity seems to stay unchanged until the age of 65 years, after which it declines gradually [21-24]. Losses occur due to the natural ageing process and increased pathology [21, 24]. Morphological changes occur in the hand as a result of ageing. These are best described in table 2.

Table 2 Morphological changes due to ageing and how they affect hand function

Morphological change due to Ageing	Change in dexterity
The atrophy and loss in motor neurons and mechanoreceptors, seen in older adults, results in slower nerve conduction [21]	**Increased:** reaction time, **Reduced:** sensibility, nerve conduction, grip strength
The degenerative loss in skeletal muscle mass (sarcopenia) and reductions in muscle fibre length [21, 25, 26].	**Increased:** reaction time **Reduced:** grip strength, mobility, time to exhaustion
Wear and weakening of bones and joints [25] where increased pathology of joints (osteoarthritis) is more significant [21].	**Increased**: reaction time **Reduced**: mobility
Reduced sweat production from palm sweat glands in old age results in a drier skin surface. Sweat is required to create adhesion and prevent slip on gripping surfaces [21, 27].	**Reduced:** grip strength

In the UK, 40% of those 'not in good health' are people over the age of 65 [28]. It is apparent that with old age comes the increased prevalence of pathology. Pathological conditions common in older adults that affect dexterity are Osteoarthritis, Rheumatoid arthritis and Parkinson's disease [21, 28]. Arthritis is the most common long term condition which affects around nine million people in the UK [29]. The consequence of such a condition includes pain, restricted range of motion of the wrist and fingers, and difficulty in performing manual activities that require grip and pinch actions [30]. Thus, as a result of these morphological changes and increased pathology with age, older adults (+65 years) are at a greater disadvantage than younger adults when it comes to performing dexterous actions.

3.2 Dexterity in the cold

Dexterity is not just affected by ageing and increased pathology, but also by cold temperatures. There are a few published studies which report the effects of reduced ambient temperature on dexterity. For example, Riley and Cochran [8] found that after less than an hour's exposure to an ambient temperature of 1.7°C, younger adults' (mean age = 24.5 years) fine finger dexterity decreased by an average of 15.7% when compared with performance at 23.9°C. Schieffer *et al* [31] found that the fine finger dexterous capability of South African factory workers decreased by an average of 20% when exposed to 6°C for 7 hours compared with performance at 24°C. Daanen [32] also found that the fine finger dexterous capability of young healthy adults (mean age = 27 years) decreased by 12% after 25 minutes exposure to -20°C; however, for this study participants wore military winter clothing and gloves which were only removed to perform the task. These reductions in dexterous capability can be attributed to the physiological effects of cold temperatures on the human body.

When people are in cold environments the temperature of their body's extremities (i.e. their hands) reduces initially, caused by cold air coming into contact with the skin. As the skin cools, the blood flow to that area decreases, which results in less heat being dispersed to that part of the body [33]. This then lowers the temperature of the skin on the hands and fingers further. Finger and hand skin temperature have been found to strongly reduce dexterity; reductions in dexterity have been reported at finger skin temperatures of 20°C [16]. Cold also decreases the nerve conduction velocity (i.e. the speed the nerve sends a message from the brain to the muscles that control the hand). Furthermore, it causes the synovial fluid which lubricates the joints to become more viscous, so that movements are slower and require greater muscle power. In summary, dexterity (both gross and fine finger) is significantly reduced due to physiological effects of the cold on the human body [16].

Older adults tolerate the cold differently to younger adults due to the morphological changes caused through the ageing process [34]. In particular, older adults are less able to maintain core body temperature as a result of reduced cutaneous thermal sensitivity and a slower vasoconstrictor response (i.e. thickening of blood vessels which restricts blood flow to the body's extremities in order to maintain core body temperature) [34]. Heus *et al* [16] conducted a review of studies that investigated the effects of reduced core temperature on dexterity; it was concluded that *"core temperature is of minor importance in maintaining manual dexterity."* However, will reductions in older adults' strength (caused through a decrease in muscle mass and muscle fibre length) mean the physiological effects of the cold (viscous synovial fluid) have a more pronounced effect?

4 Research questions and aim

Previous research findings into the effects of cold on dexterity have appeared to focus on young healthy adults, with a particular focus on either the productivity of workers [8, 31] or the ability of military personnel [32]. Data in these studies have been gathered mainly from young healthy adults. Dexterity data on older adults do exist [17, 35]. However, there are no previous studies that detail the effects of everyday cold temperatures on older adults' dexterous capability, and what this means in terms of their ability to interact with everyday products. A number of research questions (RQ) arise as a result of findings from the literature reviewed in this paper. These are:

RQ1 Which forms of dexterity will be affected by everyday cold temperatures and to what extent?

RQ2 What will be the effect on product interaction?

RQ3 Which dexterity tests are good predictors of product interaction capability?

The overall aim of answering these questions is to produce design guidance that can be used by designers to produce products that are inclusive in everyday environments.

5 Measuring capability

Capability data can be gathered using a number of different methods, which include self-report, proxy report and performance measures. Johnson *et al* [36] reviewed these different methods with a view to determining how capability can best be measured to facilitate inclusive design. In summary, it was concluded that:

1. Self-report can potentially provide access to physiological, environmental, cultural and attitudinal components of capability. However, it can be significantly affected by a number of factors

such as a person’s affective state, and their educational, cultural, language and social differences.

2. Proxy report methods are beneficial when individuals have insufficient capability to complete a survey. This method has been shown not to be as accurate as self-report among older people.
3. Performance methods have been found to be good at assessing functional ability, or capacity to perform a particular task. They have been argued to be more reliable, more sensitive to change and more able to accurately measure ability at higher levels. Performance measures are also more likely to reflect physiological aspects of capability.

Based on the review, performance methods appear to be most suited to answering the research questions posed as they have the advantage of providing direct measures of human response [37]. In particular, such methods have been found to be accurate, reliable and have the ability to reflect physiological changes in capability. To this end, performance measures will therefore allow the effects of cold to be quantified reliably, thus allowing RQ1 to be answered.

5.1 Dexterity performance measures

The overall aim of this research is to generate dexterity data that can provide guidance to designers on how to produce products that are accessible and usable in everyday environments. Thus, a primary concern of this study is to identify which dexterity tests (performance measures) closely mimic the dexterous capabilities used during the majority of product interactions. Through analysing the types of dexterous demands made by the products detailed in the introduction to this paper (i.e. wireless technological devices and everyday objects), it is possible to identify which dexterity tests will provide the most relevant data.

Nearly all wireless technological devices today require a grasp or pinch action to stabilise them before and during use. However, it is not just technological products that require stabilisation; Flanagan and Johansson [18] found this to be a requirement of most everyday products. Furthermore, Clarkson *et al* [5] found pinch and power grip (grasp) to be two of the most critical functions for product interaction. See figures 1 and 2 for illustrations of power and pinch actions in product interactions.

Fig. 1 Interacting with a PDA using both power and pinch grips

Fig. 2 Grasping a key with a pinch grip

Fig 3 Inputting information using fine finger dexterity

After stabilisation, the majority of wireless technological products also require users to input information using either a set of physical buttons or a touch sensitive screen. This often involves precise movements of the fingers, which is known as fine finger dexterity (see figure 3). Also, computing and communication devices that require fine manipulation are now embedded in all sorts of everyday devices such as washing machines, televisions, ticket machines and even jewellery [38].

6 Materials and Methods

6.1 Objective performance measures

All performance objective measures and real world task were completed twice by the participants in two environments (thermo-neutral 19-24°C and Cold 5°C) then mean averaged. The performance objective measures were all conducted in accordance with the standardised instructions.

6.1.1 Power grip

Power grip is the maximal grip strength (kg) a person can exert with their hand (measured by squeezing together the middle joints of all 4 fingers and the palm). An objective measure of grip strength was obtained from a digital dynamometer (Takei Scientific Instruments - T.K.K.5401 Grip D [Digital Grip Dynamometer]) which has rubberised bars for gripping and a digital read out. The digital display provides accurate readouts that can be recorded precisely and more efficiently than having to read from an analogue display.

6.1.2 Pinch grip

Pinch grip is the maximal force that can be exerted between the index finger and thumb pulps. Just the dominant hand was measured in a standardised posture. The maximum force was measured in kg. Equipment used was the Baseline Hydraulic Pinch Gauge.

6.1.3 Fine finger dexterity: Purdue Pegboard

Yancosek and Howell [39] conducted a review of commercially available dexterity tests. The review focussed on the psychometric properties (reliability and validity of the tests) of fine and gross dexterity tests. Yancosek and Howell [39] concluded that the Purdue Pegboard demonstrated solid psychometric properties and would be the recommended test for measuring fine finger dexterity.

The Purdue Pegboard involves a series of 4 subtests which involve placing as many pins as possible into a pegboard with the right hand (R), then the left hand (L) and then both hands (B) – each in a 30 second period. The fourth subtest is a fine finger assembly task – this was not used in this experiment as the level of fine finger manipulation required to complete the task could not be likened to any form of real world product interaction. The participant’s score was calculated in accordance with the standardised method, i.e. R+L+B=total number of pins [40].

6.1.4 The Moberg Pick-up Test

The Moberg Pick-up test is a functional sensory test of the hand that uses a combination of pinch grip and fine finger dexterity [41]. The test requires participants to pick up a selection of 12 real world objects from a table and place them in a container as quickly as possible. The test was modified to use a selection of representative everyday items, including a mobile phone SIM card, paperclip, safety pin, AA battery, PDA stylus, match, UK 1p, UK 2p, credit card, key, bolt and wing nut.

6.2 Real world tasks

A range of representative real world tasks were also used in the experiment. The tasks selected were based on the products identified previously in the paper, i.e. wireless information and communication technologies and everyday objects used outside of the home environment. For each task, participants were given one practice go in order to minimise possible learning effects. The aim of incorporating these types of tasks was to determine the effect of the cold on product interaction and whether objective empirical performance measures were good predictors of real world product capability in the cold. The incorporation of these tasks into the experiment will allow for RQ2 and RQ3 to be answered.

6.2.1 Gardening secateurs

The gardening secateurs task required the exertion of a power grip. Participants were asked to cut through increasing thicknesses of wooden dowel (3, 5, 9, 10 and 12 mm diameters) using a pair of garden secateurs (B&Q Deluxe Branch and Thicker Stem Secateurs). The maximum thickness of dowel that they could cut through was recorded.

6.2.2 Mobile phone

The mobile phone task required fine finger dexterity. The time taken to enter an eleven digit number, in the style of a UK landline telephone number, into a mobile phone (NOKIA 3210e) was recorded.

6.2.3 Stylus task

The stylus task required participants to enter an 11 digit equation into a touch screen device (HP iPAQ 114 Classic Handheld) using a stylus. The task requires a pinch grip to stabilise the stylus and fine finger dexterity to manipulate it. This was a timed task that was repeated twice and then mean averaged.

6.2.4 Touch screen task

The touch screen task required participants to enter a short sentence (20 character spaces) using a QWERTY touch screen keypad on an i-pod touch. The task required participants to stabilise the product with a power grip and then input the sentence using fine finger dexterity. It was a timed task that was repeated twice and then mean averaged.

6.3 Everyday cold temperatures

The coldest outdoor temperatures in the UK are experienced through the winter months (December, January and February). Mean temperature across the country usually varies between -4°C to +8°C; however on average, mean temperatures lie around the 4-5°C mark [42]. Also, 5°C is the temperature threshold used by the Met Office to issue a cold weather warning (Goodwin, personal communication, 2009). Based on these national statistics and temperature thresholds, 5°C was the chosen temperature to represent everyday cold environmental conditions in the UK.

6.4 Procedure

Dexterity tests and real world tasks were measured under two climatic conditions:

1. Thermo-neutral 19-24°C (an environment that keeps the body at an optimum point)
2. Cold 5°C.

The thermo-neutral environment acted as the control condition. For the cold environment, a climatic chamber was used to regulate the desired temperature of 5°C. This had the advantage of ensuring consistency in testing conditions and elimination of experimental noise. In order to replicate real world scenarios as closely as possible, each participant was asked to bring their own winter clothes (suitable for temperatures of 5°C) to wear in the climatic chamber. The only item of winter clothing they did not wear was gloves as the experiment was concerned with the effect of the cold on the hand/dexterity. Gloves are another variable that are known to influence dexterity. In a study conducted by Havenith and Vrijkotte [43], it was found that wearing gloves decreased fine finger dexterity by up to 70% and hand dexterity by up to 40% in comparison to un-gloved hands. Currently, there is no data that simultaneously details the effects of the cold and gloves on dexterity. However, in relation to this study, measuring the effects of the cold and gloves in one experiment is not practical, i.e. participants would have to spend prolonged time in the cold and would have to conduct double the number of tests which could easily result in fatigue, discomfort and significantly increased blood pressure. When in the climatic chamber participants were asked to sit for 20 minutes, prior to undertaking the battery of dexterity tests, in order to let their hands cool. In the thermo-neutral environment participants dressed in their 'normal' clothing for the time of year (summer 2010).

A repeated measures design was chosen to provide the best comparison between the two types of environments. The order of experiencing the two environments and the dexterity tests was varied systematically using a balanced Latin square. This counter balancing of the conditions and tests mitigated against any order or carry over effects.

6.5 Relevant measures

6.5.1 Skin temperature

Finger and hand skin temperatures were measured during the cold exposure part of the experiment in order to assess older adult's physiological response to the cold. Specifically, these two objective measures were chosen as losses in dexterity in the cold has been shown to have a close dependent relationship with hand and finger skin temperatures [16, 44]. For example, Hellstrom [45] reported a loss in finger dexterity at a finger skin temperature of 20°C, and a significant reduction in dexterity when hand temperatures reach 15°C.

Skin temperatures were monitored on the palm side of the hand on the middle phalanx of the index finger and on the centre of the back of the hand. The measures were recorded at 10 second intervals into a data-logger (Squirrel. Grant, UK).

6.5.2 Environmental measures

Air temperature was monitored in both the neutral and cold environments to ensure environmental parameters were consistent for all participants. Air temperature was recorded into a data-logger (Squirrel. Grant, UK) every 60 seconds. Other environmental parameters such as humidity were kept within an optimum range (40%-50%), and air velocity was negligible (~0ms^{-1}). This helped to ensure the validity of the experimental findings, i.e. whether reducing the ambient air temperature to 5°C causes a decrease in older adults' dexterity.

6.6 Sample

Since there is a lack of specific information on the prevalence of dexterity disorders affecting older adults (+65 years) in the UK, it was not possible to recruit a random proportionate sample. However, as previously detailed, arthritis is the most common condition affecting dexterity; with approximately nine million sufferers in the UK [29]. Unfortunately, up-to-date prevalence figures for older adults (+65 years) suffering from arthritis is not available. Thus, the prevalence statistic that 'arthritis affects 1 in 5 adults in the UK' (i.e. 20%) [46] was used to ensure the sample consisted of approximately the correct proportion of arthritis sufferers in relation to the UK population.

A purposive sampling strategy was used to recruit a highly variant sample of users with mixed dexterous abilities. A total of 31 participants (11 male/20 female), aged between 65 to 81 years (mean age = 70) completed the study. A total of 6 participants (20% of the sample) had arthritis. A minimum age criterion for the sample was set at 65 years as significant reductions in hand functions are seen after this age [22]. It is these users who are already working to the limits of their ability; therefore any reduction in capability due to context could result in their being excluded from using everyday products.

6.7 Ethical consideration

Ethical clearance for the study was obtained from Loughborough University's Ethical Advisory Committee (Ref No: R09-P60). All participants answered a health screening questionnaire to ensure they had no conditions that could be adversely affected by the cold. They received a participant information pack that contained full details of the study prior to their arrival. During the study blood pressure and finger skin temperature was monitored during cold exposure to ensure they did not exceed safe levels based on expert and medical advice (i.e. blood pressure no higher than 100/180mmHG and skin temperatures ≤12°C).

7 Results

Prior to analysis, all data was checked for errors and outliers. The simple and relatively effective rule of $z = 3$ was used to identify potential outliers in the data [47]. Only one outlier was identified and removed (n=30). The type of data gathered for the Purdue Pegboard (number of of pins), Moberg Pick-up test (seconds), Power Grip (kilograms), Pinch Grip (kilograms), Mobile Phone (seconds), Stylus (seconds) and Touch Screen (seconds) tasks, can be classed as continuous data, thus appropriate for parametric statistical analysis. Prior to analysis all of these datasets were checked for normality. A significant skewness calculation detailed by Howitt and Cramer [48] was used, i.e. skewness / SE of skewness = <1.96 normally distributed data. All datasets in both neutral and cold environments were normally distributed, i.e. the significance of the skew was <1.96. The data generated from the Secateurs task is ordinal data as the participant scores (values) can only be put in order from easiest (3mm) to hardest (12mm) , thus non-parametric methods were used for analysis.

7.1 Skin temperature and air temperature

Both hand and finger skin temperatures significantly reduced during cold exposure. Mean finger skin temperature (FST) in the neutral environment was 31°C. When completing the dexterity measures in the cold, mean FST ranged between 25.1°C to 16.8°C. Mean hand skin temperature (HST) in the neutral environment was 31.3°C. When completing the dexterity measures in the cold, mean HST ranged between 27.1°C to 22.3°C. Generally speaking, finger skin temperature was always lower than hand skin temperature, as shown in figure 3.

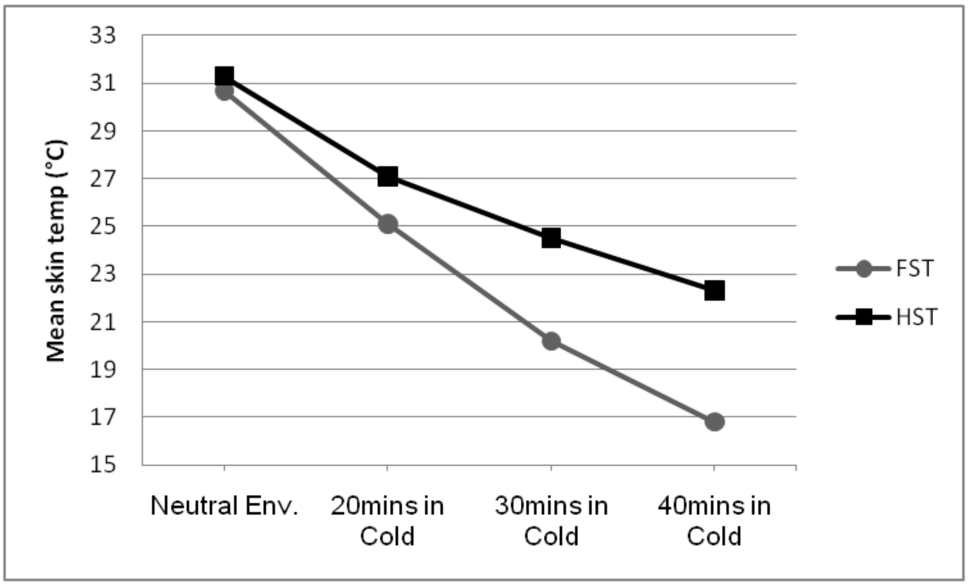

Fig. 4 Mean finger and hand skin temperatures

Air temperature was also monitored in the neutral and cold environments. In the neutral environment mean air temperature was 21.5°C (SD = 0.75), and in the cold environment it was 5°C (SD= 0.25).

7.2 Statistical analysis

Paired sample t-tests were used on the parametric datasets to establish whether there were any significant differences in dexterous performance between the two thermal environments. The Wilcoxon Signed Ranks test was used to analyse the Secateurs data. In particular, these methods were considered suitable as the dependent variable(s) was repeated across the participants in two different conditions. The 1-tailed significance values have been quoted in the results, as evidence from previous studies reviewed all show a reduction in dexterity due to the cold (see section 3.2 dexterity in the cold).

7.3 Performance results

The average performance scores for all dexterity measures in both the neutral and cold environments are detailed in table 3, along with the 95% confidence interval of the difference.

Table 3 Average dexterous performance in neutral and cold environments

Dexterity measure	Average performance Neutral (SD)	Cold (SD)	% difference in performance	95% Confidence Interval of the Difference Lower (%)	Upper (%)
Power Grip (kg)	M = 29.7 (SD = 11.3)	M = 28.9 (SD = 11.1)	-2.5%	0.6 (2%)	-2.4 (-8%)
Pinch Grip (kg)	M = 5.8 (SD = 1.6)	M = 5.5 (SD = 1.5)	-5%	0.1 (2%)	-0.6 (-10%)
Purdue Pegboard (R+L+B = no. Pins)	M = 37 (SD = 4.7)	M = 34 (SD = 3.4)	-8%	-1.7 (-4.5%)	-4 (-11%)
Secateurs (1=easiest – 5=hardest)	Med = 2 (IQR = 2)	Med = 2 (IQR = 2)	0%		
Moberg Pick-up test (secs)	M = 13.7 (SD = 2)	M = 15 (SD = 1.9)	9%	0.7 (5%)	2.0 (14.5%)
Mobile Phone (secs)	M = 11.2 (SD = 2.6)	M = 11.9 (SD = 2.7)	6%	0.06 (0.5%)	1.4 (12.5%)
Stylus (secs)	M = 11.6 (SD = 2.4)	M = 11.6 (SD = 2.8)	0%	0.7 (6%)	-0.8 (-7%)
Touch Screen (secs)	M = 16.1 (SD = 3.9)	M = 16.2 (SD = 3.6)	0.5%	1.5 (9%)	-0.8 (-5%)

For certain dexterity measures a decrease in score represents a reduction in performance (Power Grip, Pinch Grip, Purdue Pegboard and Secateurs measures). For the timed measures (Moberg Pick-up test, Mobile Phone, Stylus and Touch Screen) the opposite is true: an increase in score or a positive value represents a decrease in performance and vice-versa for negative values. Thus, by plotting decrements in performance on a graph it is possible to compare performance across tasks on one scale, i.e. % change in performance (see figure 5).

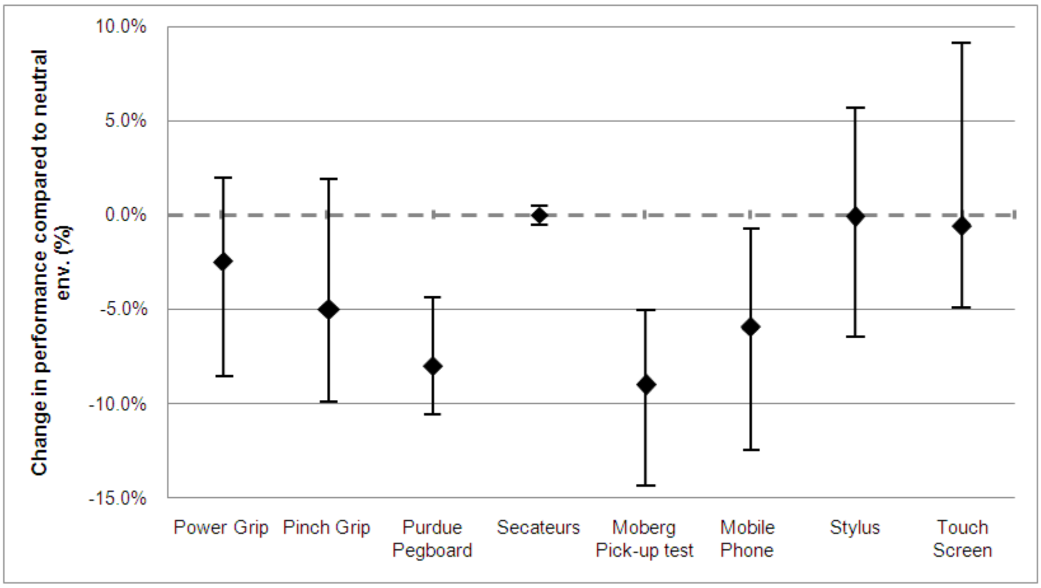

Fig. 5 Mean reduction in performance with 95% confidence intervals compared to the neutral environment

A reduction in mean dexterous performance was observed with Power Grip (-2.5%), Pinch Grip (-5%), Purdue Pegboard (-8%), Moberg Pick-up test (-9%) and the Mobile Phone task (-6%). A very slight reduction in Touch Screen task performance was observed (-0.5%). However, average performance with the secateurs (0%) did not alter, neither did performance on the Stylus task (0%).

Paired t-tests and a Wilcoxon Signed Ranks test was used to determine whether any of these differences were statistically significant. The results from this analysis are detailed in tables 4 and 5.

Table 4 Significance results for parametric dexterity measures

Dexterity measure (Neutral – cold)	Sig (1-tailed)	t	Eta squared
Power Grip	p =0.11	1.267	0.1
Pinch Grip	p = 0.1	1.387	0.12
Purdue Pegboard	p = 0.00	4.984	0.45
Moberg Pick-up	p = 0.00	-4.094	0.38
Mobile Phone	p = 0.02	-2.232	0.15
Stylus	p = 0.46	0.118	0.00
Touch Screen	p = 0.24	-0.721	0.03

The effect size criteria given by Cohen [49] for parametric statistics of 0.01 = small effect, 0.06 = moderate effect and 0.14 = large effect has been used.

Table 5 Significance results for non-parametric dexterity measure

Dexterity measure (Neutral – cold)	Sig (1-tailed)	Z	Eta squared
Secateurs	p = 0.08	-1.414	0.27

The effect size criteria given by Cohen [49] for non-parametric statistics of 0.1 = small effect, 0.3 = medium effect and 0.5 = large effect has been used.

Results from the paired t-test analysis revealed that the cold environment had a significant ($p<0.05$) effect on performance with the Purdue Pegboard, Moberg Pick-up test and the Mobile Phone task. However, results also showed the cold environment did not significantly ($p>0.05$) affect dexterous performance on either of the grip strength tests (Power and Pinch), even though a mean decrease in performance was observed with both tests. Also, the cold did not significantly affect performance with the real world gripping task (Secateurs) either. Furthermore, performance on the Stylus and Touch Screen task were not significantly affected by the cold ($p>0.05$).

7.4 Correlations between empirical tests and real world tasks

Correlation coefficients were calculated to determine whether the empirical dexterity tests used were good predictors of a person's dexterous capability to use real world products in both thermo-neutral and cold environments. For the parametric datasets, Pearson's correlation coefficients (r) were used to calculate the strength of the relationships, and, for the comparisons with the non parametric data (Secateurs) Spearman's rho correlation coefficients (r_s) were calculated.

For the gripping tasks (Power Grip, Pinch Grip and Secateurs task), only the thermo-neutral environment data was analysed, as the results show there being no significant changes in performance on any of these measures as a result of the cold. The results from correlations analysis are detailed in tables 6, 7 and 8. Prior to the analysis, all data was checked for outliers using scatter plots. Outliers were identified as points which were either very high, very low or away from the main cluster of points [50].

Table 6 Pearson's (r) correlations between dexterity tests and real world tasks in the thermo-neutral environment

	Mobile Phone		Stylus		Touch Screen	
	(r)	CoD	(r)	CoD	(r)	CoD
Purdue Pegboard	-0.5	0.25	-0.2	0.04	-0.4	0.16
Moberg Pick-up	0.3	0.09	0.2	0.04	0.4	0.16

CoD = Coefficient of Determination (shared variance between the two variables)
Grey shaded areas = $p<0.05$ (2 tailed)

Table 7 Spearman's rho (r_s) correlations between grip strength tests and the Secateurs task in the thermo-neutral environment

	Secateurs	
	(r_s)	CoD
Power Grip	0.7	0.49
Pinch Grip	0.8	0.64

Grey shaded areas = $p<0.05$ (2 tailed)

Table 8 Pearson's (r) correlations between dexterity tests and real world tasks in the cold

	Mobile Phone		**Stylus**		**Touch Screen**	
	(r)	CoD	(r)	CoD	(r)	CoD
Purdue Pegboard	-0.4	0.16	-0.3	0.09	-0.5	0.25
Moberg Pick-up	0.1	0.01	0.2	0.04	0.1	0.01

Grey shaded areas = $p<0.05$ (2 tailed)

For the purposes of this research, guidelines detailed by Cohen (1988) have been used to interpret the correlation/relationship values resulting from this analysis. Cohen [49] suggests r = 0.1 to 0.29 as a small relationship, r = 0.3 to 0.49 as a medium relationship, and r = 0.5 to 1.0 as a large/strong relationship.

Results from Pearson's correlations in the thermo-neutral environment showed that:

- A large/strong (negative, r=-0.5) relationship exists between the Purdue Pegboard and Mobile Phone - the correlation was significant (*p*<0.05);
- A medium strength relationship was found between Purdue Pegboard and the Touch Screen task (r = -0.4), the Moberg Pick-up Test and the Mobile Phone (r=0.3), and the Moberg Pick-up Test and the Touch Screen (r=0.4) – none of these correlations were significant (*p*>0.05);
- Small (r=.02), non significant (*p*>0.05) relationships were found between both the Purdue Pegboard and Moberg Pick-up test and the Stylus task.

Results from the Spearman's rho correlations indicated a large/strong relationship between both Power and Pinch Grip and the Secateurs task (r=0.7 and r=0.8 respectively). Both of these correlations were significant (p<0.05).

Finally, the Pearson's correlation coefficients for the cold environment showed:

- A large/strong (negative, r=-0.5) relationship exists between the Purdue Pegboard and the Touch Screen task - the correlation was significant (*p*<0.05);
- A medium strength (negative, r=-0.3) relationship was found between the Purdue Pegboard and the Stylus task, and the Purdue Pegboard and Mobile Phone task (r=-0.4) – only the Mobile Phone correlation was significant;
- All correlations between the Moberg Pick-up Test and real world tasks were small (r≤0.2) and not significant (*p*>0.05).

The coefficient of determination values will be discussed under RQ3 within the discussion section of this paper.

8 Discussion

The purpose of this study was to answer the three research questions posed; each will be discussed in turn.

8.1 RQ1: Which forms of dexterity will be affected by everyday cold temperatures and to what extent?

This experiment focused on three forms of dexterity, which were power grip, pinch grip and fine finger dexterity. As mentioned in the literature review, these forms of dexterity are continuously required to use the majority of wireless information and communication technologies and everyday objects used outside of the home environment. The results of this study showed fine finger dexterity, as measured by the Purdue Pegboard, was found to be significantly affected (p=0.00) by the cold. The eta squared statistic (0.45) indicated the cold had a large effect on this type of dexterity. On average, performance on the Purdue Pegboard decreased by 8%. The results in this study indicate (95% confidence) that older adults' fine finger dexterity will reduce between 4.5%-11% when exposed to everyday cold temperatures (5°C) for periods of approximately 40 minutes. Also, results showed a significant (p<0.05) reduction in performance on the Moberg Pick-up test, which requires a combination of both fine finger dexterity and pinch grip. The eta squared statistic (0.38) again indicated the cold had a large effect on this combination of dexterous capabilities. On average, performance on the Moberg Pick-up test decreased by 9%, which is of a similar magnitude to performance on the Purdue Pegboard. The results in this study indicate (95% confidence) that older adults' capability to carry out tasks which require a combination of fine finger dexterity and pinch grip will reduce between 5%-14.5% when exposed to everyday cold temperatures (5°C) for periods of approximately 40 minutes.

These findings support previous research in terms of the magnitude that fine finger dexterity decreases as a result of the cold. For example, the current study found that fine finger dexterity decreased, on average, by 8% to 9%, when exposed to a cold temperature (5°C). Daanen [32] found it decreased by 12%, Riley and Cochran [8] found it decreased by 15.7% and Schieffer *et al* [31] found it decreased by an average of 20% when exposed to cold conditions. The findings from these past studies are based on young healthy adults; however, the decrements reported in all of these studies are slightly higher than those reported here. However, it is not possible to make direct comparisons to such studies in order to determine whether older people are at a greater or lesser disadvantage in the cold. The reason for this is that a vast number differences in study parameters exist, which include exposure time, temperature level and clothing worn. For example, in the Riley and Cochran [8] study, participants wore fewer clothes (i.e. jeans, a long sleeved shirt, socks, shoes and normal undergarments) and were exposed to a lower temperature (1.7°C) for around 15 minutes longer. All these parameters are known to have an impact on the human body's physiological reaction/response to the cold, which in turn affects dexterity.

Past studies [16, 44, 45] have attributed the loss of fine finger dexterity to reductions in hand and finger skin temperatures. Both Heus *et al* [16] and Hellstrom [45] reported decrements in fine finger dexterity at a finger skin temperature of 20°C, and at a hand skin temperature of 15°C. Results from this study indicate that reductions in older adults' fine finger dexterity can occur at a finger skin temperature of 25.1°C and a hand skin temperature of 27°C. Both values are considerably higher than those found in the previous studies. It can thus be hypothesized that decrements in older adults' fine finger dexterity can occur at much higher finger and hand skin temperatures than adults younger than themselves. Reductions in older adults' fine finger dexterity at a much higher skin temperature may be due to the morphological effects of ageing. In particular, their reduced strength (caused through a decrease in muscle mass and muscle fibre length) may mean overcoming the effects of viscous synovial fluid in the joints is a lot harder; thus, decreases in fine finger dexterity occur at higher skin temperatures. Decrements in older adult's fine finger capability may occur at an even higher skin temperature than those reported in this study; however, due to the experimental protocol adopted (i.e. 20 minutes cooling time prior to conducting the dexterity tests) it was not possible to gather this data.

For the power and pinch grip strength tests slight decrements in performance were observed, 2.5% and 5% respectively. Surprisingly, the paired t-tests revealed these were not significant ($p > 0.05$), even though the eta squared statistics (0.1 and 0.12) indicated the cold had a moderate effect on test performances. A possible explanation for this is that participants were dressed warmly in their winter clothes, leaving only their hands exposed to the cold. Grip strength, both power and pinch, is controlled by the extrinsic hand muscles in the forearm, which in this study were kept warm by the clothing insulation, thus not exposed to the cold temperature and its physiological effects. These findings are consistent with Daanen [32] who investigated the effect freezing temperatures had on the grip strength of 12 healthy males (mean age 27 years) from the Royal Netherlands Air Force. The participants wore standard winter clothing and gloves and were exposed to -10°C for 30 minutes; only a 3% reduction in maximal grip strength was recorded. Again, extrinsic hand muscles in the forearm were kept warm by clothing. A number of studies [51, 52] have investigated what effect cooling the extrinsic forearm muscles had on the grip strength of young healthy adults (18-24 years). Cooling of the muscles was achieved through immersing the participant's hand and forearm in cold water. Vincent and Tipton [51] exposed participants to a series of five intermittent two minute cold water (5°C) immersions. They found grip strength decreased significantly ($p < 0.01$) by 16% following the immersions. Holewijn and Heus [52] investigated the effects 30 minutes forearm cooling (15°C) and warming (40°C) had on maximal gripping force. Results from the study showed that in contrast to warming, cooling resulted in a significant ($p < 0.05$) decrease of 20% maximal gripping force. Based on the current study findings, and in addition to previous research, it would appear that grip strength can remain unaffected by cold temperatures providing extrinsic hand muscles in the forearm can be kept warm by clothing or other means.

8.2 RQ 2: What will be the effect on product interaction?

A total of four representative real world tasks were used in this experiment. These were:

1. Secateurs - using gardening secateurs to cut through varying thicknesses of dowel;
2. Mobile Phone - entering an 11 digit number into a mobile phone;
3. Stylus - entering an 11 digit equation into a touch screen device using a stylus;
4. Touch Screen - entering a 20 character sentence into a touch screen device using their fingers.

The gardening secateurs was a real world task that required the exertion of a power grip. Results from the analysis showed there was no change in average performance (*Md* = 2) between the two environments. Obviously, there was no significant (p>0.05) difference in performance between the neutral and cold environments. The eta squared statistic (0.27) indicated the cold had a small effect on task performance. It is interesting to note that in both the performance measure and the real world task, power grip was not affected by the cold. Again, results would suggest that on a typical winter's day, clothing worn by older adults is sufficient to prevent everyday cold temperatures having a physiological effect on the extrinsic muscles in the forearm.

Entering an 11 digit number into a mobile phone was a representative real world task that required fine finger dexterity. Results from this analysis were consistent with the fine finger performance measures. In particular, performance when completing the task decreased by an average of 6%, which was significant (p <0.05). The eta squared statistic (0.15) showed the cold had a large effect on performance. Surprisingly, a significant difference in performance on the Touch Screen task (p>0.05) was not found. The dexterous actions required to complete the task are more or less the same as that required to complete the Mobile Phone task, i.e. gripping the product with one hand and using a finger or thumb to input the information with the other. This result may be explained by the unfamiliar nature of the task, which required participants to use a QWERTY keypad on touch screen. Not only was this unfamiliar to most participants, but they were also required to adopt a ‘hunt and peck’, or ‘thumbing’ (using one or both thumbs) method to input the text. A number of participants commented that this was unfamiliar and therefore had to find each key by sight as opposed to by touch. Taken together, it would appear that potential learning effects (even after a practice) and cognitive processing (searching for letters) required to complete the task, meant other factors apart from the cold contributed towards task performance.

The final real world task was the Stylus task, which required participants to enter an 11 digit equation into a touch screen device using a stylus. The result from this task showed there was not a significant difference (p>0.05) in performance and the eta squared statistic (0.00) showed the cold had a small effect. This can possibly be explained by the input method adopted by the participants; the stylus, held using a pinch grip, was manoeuvred using more gross movements which involved the arm and wrist as opposed to the stylus being manipulated with fingertips. Thus, such movements are controlled by extrinsic hand muscles in the forearm, which are kept warm due to the clothing being worn.

8.3 RQ3: Which dexterity tests are good predictors of product interaction capability?

Correlations were conducted on the data to determine the strength of the relationship between empirical tests and product interaction capability. More specifically, the focus was to determine whether empirical test measures with good psychometric properties can accurately predict older adults’ dexterous ability to interact with wireless technological devices in everyday environments.

The results from the correlations have provided a mixture of findings from large/strong significant (p<0.05) relationships to small non significant (p>0.05) ones. The strongest relationships were found between Power and Pinch Grip tests and the Secateurs task (r=0.7 and r=0.8 respectively). Both of the correlations were significant, indicating confidence can be had with the result. Also, the coefficient of determination indicates Power Grip shares 49% variance with the

Secateurs task and Pinch Grip shares even more variance at 64%.
These results indicate that empirical Power and Pinch Grip measures are good predictors, in both thermo-neutral (19°C to 24°C) and cold (5°C) environments, of product interaction capabilities that require the exertion of a power gripping action.

Results from Pearson's correlations also showed further large/strong relationships exist. These were between the Purdue Pegboard and the Mobile Phone task in the thermo-neutral environment (r=-0.5), and between the Purdue Pegboard and Touch Screen task (r=-0.5) in the cold environment. The coefficient of determination value indicates that the Purdue Pegboard can account for 25% of the variance with both the Mobile Phone task in the thermo-neutral environment and the Touch Screen task in the cold environment. Both of these correlations were significant, indicating confidence can be had with the results. Thus, these findings suggest that:

- In a thermo-neutral environment (19°C-24°C) the Purdue Pegboard is a good predictor of an older adult's ability to input information (numbers) into a keypad on a mobile phone;
- In a cold environment (5°C), the Purdue Pegboard is a good predictor of an older adult's ability to input information (characters) into a touch screen.

Further findings from the Pearson's correlations showed there were a total of five medium strength (r=0.3 to 0.49) correlations which existed between:

- Purdue Pegboard - Touch Screen (r=-0.4) thermo-neutral env.
- Moberg Pick-up test - Mobile Phone (r=0.3) thermo-neutral env.
- Moberg Pick-up test - Touch Screen (r=0.4) thermo-neutral env.
- Purdue Pegboard - Mobile Phone (r=-0.4) cold env.
- Purdue Pegboard – Stylus task (r=-0.3) cold env.

Whilst these correlation results are encouraging, they need to be interpreted with caution, as only the Purdue Pegboard and Mobile Phone correlation in the cold environment was significant (p<0.05), thus others may be a result of coincidence. Coefficient of determination results from the Purdue Pegboard and Mobile Phone correlation show that the Purdue

Pegboard can account for 16% of the variance in the Mobile Phone task in the cold. Furthermore, results from the correlation analysis show that there is a significant correlation between the Purdue Pegboard and the Mobile Phone task in both the thermo-neutral and cold environment. However, the strength of the relationship does decrease slightly in the cold compared to the thermo-neutral environment (i.e. from -0.5 to -0.4).

Surprisingly, one unanticipated outcome to emerge from this set of results is the lack of consistency in the strength of the correlations between the two conditions. In particular, out of the 12 Pearson's correlations conducted, only one correlation is the same strength in both conditions, i.e. the Moberg Pick-up Test and Stylus(small, r=0.2). All other correlations vary in strength, for example, the Purdue Pegboard and Touch Screen correlation is of medium strength in the thermo-neutral environment, but in the cold environment this increases to a large/strong relationship. Unfortunately, there is also no consistency in the direction that these relationships change between conditions, thus, indicating that certain empirical measures may be good predictors of a certain type of product interaction capability in one type of environment but not another.

9 Conclusions

This paper has focussed on the effect an everyday cold temperature (5°C) can have on older adults (+65 years) dexterous capabilities and the implications for design. A total of three types of dexterity were investigated: fine finger, power grip and pinch grip. These were chosen as the majority of wireless information/communication technologies and everyday products continuously require such actions to be used.

This study has found that when older adults (+65 years) are exposed to 5°C for periods between 20- 40 minutes, their:

- Fine finger capability will reduce between 4.5%-11%,
- Ability to pick up and place/manipulate objects such as keys, nuts, money, batteries, SIM cards, bank cards, etc. will reduce by 5% to 14.5%,
- Power and Pinch Grip strength will not be affected - this can possibly be explained by the fact that such actions are controlled by

the extrinsic hand muscles in the forearm, which are kept warm by the clothing insulation.

- Ability to input information (numbers) into a keypad on a mobile phone (that has physical buttons) will reduce by 0.5% to 12%,
- Ability to use a touch screen and stylus will not be affected, however these results need to be interpreted with caution as a number of extraneous variables were identified as possibly contributing to task performance.

It is important to conclude with the point that no participants were unable to complete the specified tasks in the cold; thus it is unlikely that exposure to 5°C for between 20 to 40 minutes is likely to lead to older adults becoming excluded from using such products/completing such tasks. However, the tasks completed by participants in this experiment were relatively short in duration, i.e. less than one minute. Further research in this field could explore task duration in the cold and whether this could lead to product exclusion.

In this study the aim was to produce design guidance that can be used by designers to develop products that are inclusive in everyday environments. Based on the findings of this study, the following guidance would be offered for products used outside in an everyday cold environment:

- Minimise the number of product interactions that require precise fine finger movements;
- Try to avoid small controls that have to be pressed in a sequence;
- Maximise the number of product interactions that can be operated through either exerting a gripping action (power or pinch grip) or by gross hand and arm movements.

The next stage of this research is to incorporate this guidance into a tool that can be used to inform and guide designers for the development of inclusive products for everyday environments.

10 References

1. Keates S, Clarkson PJ (2004) Countering design exclusion: An Introduction to inclusive design. Springer-Verlag, London

2. Persad U, Langdon P, Clarkson PJ (2006). Exploring user capabilities and health: A population perspective. In: Contemporary Ergonomics 2006, proceedings of the Annual Conference of the Ergonomics Society, London, pp 373-377

3. British Standards (2005) BS 7000-6:2005 Design Management Systems. Managing Inclusive Design. British Standards Institution, London

4. Marshall R, Case K, Gyi DE, Oliver R, Porter JM (2002) HADRIAN: An Integrated Design Ergonomics Analysis Tool. In: Proceedings of the XVI Annual International Occupational Ergonomics and Safety Conference, Toronto, Canada, pp1-5

5. Clarkson PJ, Coleman R, Hosking I, Waller S (2007). Inclusive Design Toolkit, Engineering Design Centre, University of Cambridge

6. Elton E, Nicolle C (2010b) The importance of context in inclusive design. In: M Anderson (Ed) Contemporary Ergonomics and Human Factors 2010. Taylor and Francis, London.

7. Elton E, Nicolle C (2009) Now you see it, now you don't. In: *Proceedings of Include 2009 conference*, RCA, Helen Hamlyn Centre, London.

8. Riley M, Cochran D (1984) Dexterity performance and reduced ambient temperature. Human Factors, 26(2), pp 207-214.

9. Baker W, Mansfield N (2010) Task performance during standing exposure to whole-body vibration. In: M Anderson (Ed) Contemporary Ergonomics and Human Factors 2010. Taylor and Francis, London.

10. Morris J, Mueller J, Jones M (2009) Tomorrow's elders with disabilities: what the wireless industry needs to know. Journal of Engineering Design, 21(2), pp 131-146

11. Maguire M (2001) Context of use within usability activities, International Journal of Human Computer Studies, 55(4), pp453–484

12. Waller S, Langdon P, Clarkson PJ (2008) Converting disability data into a format suitable for estimating design exclusion. In P Langdon, PJ Clarkson, P Robinson (eds.) Designing inclusive futures: Proceedings of CWUAAT 2008, Springer-Verlag, London. pp 3-13

13. Thomas C, Bevan N (1995) Usability context analysis: A practical guide, Version 4. National Physical Laboratory, Teddington, UK

14. Farber SD (1991) Assessing neuromotor performance enablers. In Christian C, Baum C (eds) Occupational Therapy, Overcoming Human Performance Deficits. Thorofare, NJ Slack, pp 376-385

15. Trombly CA, Scott AD (1989) Evaluation of motor control. In Tromobly CA (ed.) Occupational Therapy for Physical Disfunction, 3rd edn. Williams & Wilkins, Baltimore

16. Heus R. Daanen H.A.M, Havenith G (1995) Physiological criteria for functioning of hands in the cold: A review. Applied Ergonomics, 26 (1), pp 5-13

17. Desrosiers J, Hébert R, Bravo G, Dutil E (1995) The Purdue Pegboard Test: Normative data for people aged 60 and over. Disability & Rehabilitation, 17(5), pp 217 – 224

18. Flanagan JR, Johansson RS (2002) Hand movements. In: VS Ramashandran (ed.) Encyclopedia of the Human Brain, 2, pp 399-414

19. Tyldesley B, Grieve JI (2002), Muscles, Nerves and Movement: In Human Occupation. Blackwell Science Ltd. Oxford, UK

20. Jones LA, Lederman SJ (2006) Human Hand Function. Oxford University Press. Oxford New York

21. Carmeli E, Patish H, Coleman R (2003) The Aging Hand, *Journals of Gerontology Series A: Biological and Medical Sciences,* 58(2), pp 146-152

22. Shiffman LM (1992) Effects of aging on adult hand function, The American Journal of Occupational Therapy. Official Publication of the American Occupational Therapy Association, 46(9), pp 785-792

23. Ranganathan VK, Siemionow V, Sahgal V, Yue GH (2001). Effects of Aging on Hand Function. Journal of American Geriatrics Society. 49(11), pp 1478-1484

24. Hébert R (1997) Functional decline in old age. Canadian Medical Association Journal, 157(8), pp 1037-1045

25. Marieb EN (2004) Human Anatomy & Physiology, 6th Ed. Pearson Benjamin Cummings, San Franciso, USA

26. Kallman DA, Plato CC, Tobin JD (1990) The Role of Muscle Loss in the Age-Related Decline of Grip Strength: Cross-sectional and Longitudinal Perspectives. The Journal of Gerontology, 45(3), pp M82-M88

27. MacKenzie CL, Iberall T (1994) *The Grasping Hand.* Amsterdam, Netherlands

28. Office for National Statistics (ONS) (2006) *Focus on Health.* National Statistics, London

29. Arthritis Research UK (2010) Arthritis in the UK – the facts: http://www.arthritisresearchuk.org/arthritis_information/arthritis_types__symptoms.aspx Accessed 26th August 2010

30. Estes JP, Bochenek C, Fassler P (2000) Osteoarthritis of the fingers. Journal of Hand Therapy, 13, pp 108-123

31. Schieffer RE, Kolk R, Lewis MI, Meese GB (1984) Finger skin temperature and manual dexterity: some inter-group differences. Applied Ergonomics 15(2), pp 135-141

32. Dannen H.A.M (2009) Manual performance deterioration in the cold estimated using the wind chill equivalent temperature. Industrial Health, 47, pp 262-270

33. Edwards M, Burton A (1959) Correlation of heat output and blood flow in the finger, especially in cold-induced vasodilation. Journal of Applied Physiology, 15(2), pp 201- 208

34. Smolander J (2002) Effect of cold exposure on older humans. International Journal of Sports Medicine, 23(2), pp 86-92

35. Smith S, Norris B, Pebbles L (2000) OLDER ADULTDATA: The Handbook of Measurements and Capabilities of the Older Adult - Data for Design Safety. Department for Trade and Industry, London

36. Johnson D, Clarkson J, Huppert F (2009) Capability Measurement for Inclusive Design. Journal of Engineering Design, 21(2&3), pp 275-288.

37. Parsons K (2005) The environmental ergonomics survey. Chapter 22 & 23. In JR Wilson, R Corlett (eds.) Evaluation of human work, 3rd edition. Taylor & Francis Group, Boca Raton Florida

38. Benyon D, Turner P, Turner S (2005) Designing Interactive Systems: People, Activities, Contexts and Technologies. Pearson Education Limited, England.

39. Yancosek K, Howell D (2009) A narrative review of dexterity assessments. Journal of Hand Therapy. 22 (3), pp 258-270

40. Tiffin J, Asher EJ (1984) The Purdue Pegboard: Norms and studies of reliability and validity. Journal of Applied Psychology, 32, pp 234–247

41. Moberg E (1958) Objective Methods for Determining the Functional Value of Sensbility in the Hand. The Journal of Bone and Joint Surgery. 40B(3), pp 454-476.

42. Met Office (2009) Coldest winter for a decade. Available at: http://www.metoffice.gov.uk/corporate/pressoffice/2009/pr20090225.html Accessed 13th August 2009

43. Havenith G, Vrijkotte TGM (1993) Effectiveness of personal protective equipment for skin protection while working with pesticides in greenhouses. Part III, Comfort and Ergonomics. Report TNO Human Factors Research Institute.

44. Havenith G, Heus R, Daanen H.A.M (1995) The hand in the cold, performance and risk. Arctic medical research, 54(1.2), pp 1-11

45. Hellstrom B (1965) Local effects of acclimatization to cold in man. Universitetsforlaget, Oslo

46. McCormick A, Fleming D, Charlton J (1995) Morbidity statistics from general practice. 4th national study 1991-1992. HMSO, London

47. Osborne JW, Overbay A (2004). The power of outliers (and why researchers should always check for them). Practical Assessment, Research & Evaluation, 9(6). http://PAREonline.net/getvn.asp?v=9&n=6 Accessed 15th September 2010

48. Howitt D and Cramer D (2008) Introduction to Statistics in Psychology, Fourth Edition. Prentice Hall, England

49. Cohen JW (1988) Statistical power analysis for the behavioural sciences, 2nd edn. Hillsdale, NJ:Lawrence Erlbaum Associates

50. Pallant J (2007) SPSS Survival Manual, 3rd Edition. Open Univeristy Press. McGraw Hill, England

51. Vincent MJ, Tipton MJ (1988) The effects of cold immersion and hand protection on grip strength. Aviation, space and environmental medicine 59(8), pp 738-741

52. Holewijn M, Heus R (1992) Effects of temperature on electromyogram and muscle function. European Journal of Applied Physiology and Occupational Physiology 65, pp 541–545