Have I just pressed something? The effects of everyday cold temperatures on dexterity

Chapter X

Have I just pressed something? The effects of everyday cold temperatures on dexterity

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X.1 Introduction

This paper details work on the effect of physical context of use on inclusive product interaction. Context of use refers to a set of circumstances which relate to the Users, Tasks, Equipment/Tools and Environment (both Physical and Social) (ISO, 1997). In particular, the physical context of use refers to factors such as lighting levels, temperature, weather conditions, vibration, noise, the built environment, etc.

Consideration of the context of use is an integral, although sometimes implicit, part of any product design process. When a mismatch between context and a product occurs, it is unlikely that the benefits of a product will be realised (Maguire, 2001). Recent evidence suggests context of use can have a multi-faceted impact on product use (e.g. increasing or decreasing user capability and/or increasing product demand) particularly with older adults who have significantly reduced capability due to their age (Elton et al, 2008). Specifically, it is the physical environment that significantly affects capability. The vast majority of product interactions make demands on the visual and dexterous (arm, hand and finger) capabilities of the user. Whilst other capabilities are also used, it is these that are most common. Several studies (Riley and Cochran, 1984; Havenith et al, 1995; Boyce, 2003) have reported the effect of the physical environment on vision and dexterity. However, such studies focus on the body's physiological response to such conditions and generally investigate extremes, e.g. freezing temperatures. Whilst these studies indicate the extent to which the physical environment can affect capability, they have very little relevance to everyday scenarios where products are used.

Previous research investigated the effect of everyday lighting levels on visual capabilities (Elton and Nicolle, 2009). This paper reports the findings from a pilot study that investigated the effect of an everyday winter temperature on dexterity and how this can affect product interaction.

X.2 Dexterity

Dexterity is referred to as a motor skill that is determined by a range of arm, hand and finger movements and the possibility to manipulate with hand and fingers (Heus et al, 1995). Dexterity comprises both manual dexterity and fine finger dexterity. 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. writing, dialling a number, picking up a coin, fastening a button, etc. Manual dexterity involves less refined and less precise movements of the hand and fingers (Desrosiers et al, 1995). The object is usually larger and manipulation requires more gross movements, e.g. digging, opening a door, placing a saucepan on the hob, etc.

Dexterity is extremely important in carrying out everyday product interactions and nearly all products in today's marketplace require dexterity in one form or another. Functioning of the hands is determined by several physiological parameters that are described in Table X.1

Table X.1. Factors that influence dexterity (Heus et al, 1995)

Component of dexterity	**Description**
Reaction time	The time between a stimulus being presented and the start of motor response
Sensibility (sensitivity)	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

X.3 Effects of the cold on dexterity

When people are in cold environments the temperature of their body's extremities reduces initially, caused by cold air coming into contact with the skin. When the skin cools, the blood flow to that area decreases, which results in less heat being dispersed to that part of the body (Edwards and Burton, 1959). This then lowers temperature of the skin further. 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 manual and fine finger) is significantly reduced due to physiological effects of the cold on the human body (Heus et al, 1995). However, little is known about the extent typical everyday cold temperatures affect the functioning of the human hand and what effect this can have on a user's capability to interact with a product. Is it just extreme temperatures that cause these physiological changes to occur, thus reducing dexterity, or could being outside for 20 minutes on a winter's day have a significant effect?

X.4 Aims and objectives

The overall aim of this research is to produce a capability dataset that can be used by designers to produce products that are inclusive in the contexts in which they will be used. The specific objectives of this pilot study are to:

- obtain an indication of which forms of dexterity are affected by the cold (approximately 5°C) and to what extent;
- determine the likely effect on product interaction;
- idenify which tests are good predictors of product interaction capability;
- identify appropriate dexterity tests for a larger scale study.

X.5 Methods

X.5.1 Dexterity tests

Objective measures were used to assess dexterity as they have the advantage of providing direct measures of human response (Parsons, 2005). Manual and fine finger dexterity were measured using a combination of empirical tests and representative real world tasks. The aim of the pilot study was to identify from these tests which form(s) of dexterity are affected by the cold. The empirical tests chosen are detailed in table X.2.

Table X.2 Empirical dexterity tests used in experiment

Test	Description
Purdue Pegboard	A test of fine finger dexterity. The assessment involves a series of 4 subtests which involve placing as many pins as possible into a pegboard with the right hand, then the left hand and then both hands – each in a 30 second period. The fourth subtest is an assembly task using pins, collars and washers – this was not used in this experiment
Power grip strength	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). Just the dominant hand was measured by following the standard protocol as provided with the dynamometer (Takei Scientific Instruments - T.K.K.5401 Grip D [Digital Grip Dynamometer]). The test was repeated three times and mean averaged
Pinch grip strength	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 and was repeated three times then mean averaged. Equipment used was the Baseline Hydraulic Pinch Gauge

The representative real world tasks chosen are detailed in table X.3

Table X.3 Representive real world tasks used in experiment

Real world task	Description
The Moberg Pick-up Test	A real world timed test that uses a combination of pinch grip and fine finger dexterity. 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 products, 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. The test was repeated a second time and then mean averaged
Using a mobile phone	The task requires 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
Using gardening secateurs	The task requires the exertion of a power grip. Participants were asked to cut through increasing thicknesses of wooden dowel (3, 5, 6, 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

The rationale for selecting these particular dexterity measures will be detailed in another paper that is currently in preparation.

X.5.2 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 (Met Office, 2009). 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 cold environmental conditions.

X.5.3 Procedure

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. Thermo-neutral testing (an environment that keeps the body at an optimum point) was conducted within a room adjacent to the climatic chamber which was regulated between 19°C-24°C.

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 (1993), it was found that wearing gloves decreased fine finger dexterity by up to 70% and hand dexterity by up to 40% in comparison to ungloved 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 2009).

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.

X.5.4 Sample

Since there is a lack of specific information on the prevalence of disorders affecting dexterity in the UK, it was not possible to recruit a random proportionate sample. An initial purposive sampling strategy to recruit a highly variant sample of users with mixed dexterity abilities was therefore adopted.

A total of 14 participants (6 male/8 female), aged between 65-75 years (mean age=69.57, SD=3.756) completed the pilot study. A minimum age criterion for the sample was set at 65 years old as significant reductions in hand functions are seen after this age (Shiffman, 1992). It is these users who are already working to the limits of their ability; therefore any reduction in capability due to context would result in their being excluded. A dataset that details this reduction and variation in capability will allow for the design of mainstream products that are accessible to, and usable by, as many people as reasonably possible, without the need for special adaptation or specialized design (Clarkson et al, 2007).

X.5.5 Ethical consideration

Ethical clearance for the study was obtained from Loughborough University's Ethical Advisory Committee. 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 to ensure they did not exceed safe levels based on expert and medical advice.

X.6 Results

The results in this section detail the findings from the pilot study. All participants completed the battery of tests in both thermo-neutral (mean temperature=21.5°C, SD=0.75) and cold (mean temperature=5.7°C, SD=1.25) environments. Mean finger skin temperature in the warm was 30°C, and in the cold mean finger skin temperature reduced to 19°C. Outliers were removed and the data was tested for normality. Data for nearly all tests was normally distributed (parametric) apart from the Secateurs test, in both warm and cold conditions. Thus, median values and non parametric tests have been used to analyse the results for the Secateur data sets. The average performance for all dexterity tests in both the thermo-neutral and cold environments is detailed in table X.4.

Table X.4 Average dexterous performance in thermo-neutral and cold environments

Dexterity Test	Thermo-neutral Average (SD)	Cold Average (SD)	% Difference in Performance
Purdue Pegboard (R+L+Both = no. pins)	Mean = 35.50 (SD = 1.46)	Mean = 33.14 (SD = 1.02)	-7%
Power Grip Strength (kg)	Mean = 29.7 (SD = 11.29)	Mean = 28.87 (SD = 11.14)	-3%
Pinch Grip Strength (kg)	Mean = 5.75 (SD = 1.64)	Mean = 5.52 (SD = 1.53)	-4%
Moberg Pickup Test (sec)	Mean = 13.79 (SD = 2.21)	Mean = 15.74 (SD = 4.84)	14%
Mobile Phone (sec)	Mean = 13.35 (SD = 4.28)	Mean = 14.20 (SD = 3.60)	6%
Secateurs (max. diameter of dowel cut = mm)	Median = 5 (IQR = 5)	Median = 5 (IQR = 5)	0%

A reduction in mean dexterity was observed on the Purdue Pegboard (7% reduction), Moberg Pick-up test (14% reduction) and the Mobile Phone task (6% reduction) when in the cold environment. A slight reduction was observed with grip strength performance (Power 3% and Pinch grip 4%) when in the cold environment. However, mean performance on the real world grip strength test using the Secateurs did not appear to be affected by the cold.

Paired t-tests were used, on the normally distributed data, to determine whether there was a significant difference in performance between the two environments. The results from this analysis are detailed in table X.5

Table X.5 Paired t-test results between the thermo-neutral and cold environment

Dexterity Test	Mean Difference (SD)	Sig. (2-tailed) $p<0.05$
Purdue Pegboard	- 2.36 pins (3.5)	0.026
Power Grip Strength	- 0.83 kgs (2.5)	0.227
Pinch Grip Strength	- 0.23 kgs (0.6)	0.189
Moberg Pick-up Test	1.95 secs (1.0)	0.024
Mobile Phone	0.85 secs (2.3)	0.188

Results from the paired t-test analyses revealed the cold environment had a significant ($p<0.05$) effect on performance with the Purdue Pegboard ($p=0.026$) and the Moberg Pick-up Test ($p=0.024$). However, the cold environment did not significantly affect dexterous performance on the grip strength tests (Power and Pinch).

A Wilcoxon Signed Ranks Test was used to compare performance on the non parametric data (Secateurs data). Results from the analysis revealed no significant difference on the Secateurs task (p=0.102) when comparing performance between the thermo-neutral and cold environments.

Pearson correlation coefficients (r) were calculated to determine whether the chosen dexterity tests (with parametric data) were good predictors of real world product capability in the cold. Spearman's rho was used to correlate the non parametric data (Secateurs). Results from these analyses are detailed in the table X.6

Table X.6 Correlation coefficents for dexterity tests and real world tasks

	Pearson's correlation		**Spearman's rho**
	Mobile Phone	**Moberg Pick-up**	**Secatuers**
Purdue Pegboard	-0.665 (p=0.013)	-0.269	
Pinch Grip		-0.199	0.749 (p=0.002)
Power Grip			0.771 (p=0.001)

Results from the Pearson's correlations suggest a strong negative relationship exists between the Purdue Pegboard and the Mobile Phone task (r=-0.665), which was significant ($p<0.05$). Relationships between the Purdue Pegboard and the Moberg Pick-up test were weak (r=-0.269), so were relationships between Pinch grip and the Moberg Pick-up test (r=-0.199). Results from the Spearman's rho analysis suggest a strong positive relationship exists between Pinch Grip and the Secateurs task (r_s=0.749) and a strong, approaching very strong, relationship exists between Power grip and the Secateurs task (r_s=0.771). Both the Spearman's rho correlations were significant ($p<0.01$).

X.7 Discussion

The pilot study has provided an indication of the types of dexterity that are affected by everyday cold temperatures. Fine finger dexterity as measured by the Purdue Pegboard was found to be significantly affected (p=0.026). On average, performance on the Purdue Pegboard decreased by 7%. Findings from a similar study by Riley and Cochran (1984) found that performance on fine manipulative tasks, such as the Purdue Pegboard, can decrease by up to 15% on average when the ambient temperature is reduced from 23.9°C to 1.7°C. For the grip strength tests only minor differences were observed and these were not significant (Power p=0.227, Pinch p=0.189).

Dexterous performance was also measured on a selection of real world products in both environments. The tasks/products selected were: (1) a modified Moberg Pick-up Test, (2) entering an 11 digit number into a mobile phone, and (3) cutting through different thicknesses of dowel with a set of garden secateurs. Fine finger dexterity is required to complete the tasks 1 and 2, and a power grip is required in task 3. The greatest decrease in performance across all tests was observed with the Moberg Pick-up Test. A 14% decrease in performance in the cold was observed with this test, which was significant (p=0.024). For the mobile phone task performance decreased on average by 6% in the cold; however this was not found to be significant (p=0.188). For the secateurs task, no difference in performance was observed.

Results from the correlation analysis suggested that a person's capability on the the Purdue Pegboard is a good predictor of their ability to use a mobile phone when in the cold. The same was found for both the Power and Pinch Grip measures in relationship to the Secateurs task when in the cold. However, due to the limited sample size a greater number of correlations is needed to ensure this relationship is not down to random noise or error.

The results from the pilot study suggest that fine finger dexterity is affected by everyday cold temperatures. In reality this means such tasks either take substantially longer (upto 14%) or the same work rate is not possible in the cold. This reduction in capability is particulary pertinent with users who may already be working to the limits of their capability in the warm, thus a significant reduction in capability in the cold would result in their being excluded.

The cause of performance decrements may be due to 11°C mean reduction in skin temperature which may have caused the synovial fluid in the joints to thicken and the loss of sensibility in the finger tip receptors to occurr (Mackworth, 1953; Heus et al, 1995). Results from the pilot study suggest that such physiological changes to the hand can occur at 5°C. No significant differences in performance were observed with the gripping tests. A possible explanation for this is 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 are kept warm by the clothing insulation, thus not exposed to the cold temperature and its physiological effects.

X.8 Conclusions and Future Work

Results from the pilot study indicate that grip strength is not significantly affected by everyday cold temperatures. Therefore, obtaining an accurate measure of this capability in the cold is not necessary for the purpose of ensuring products are inclusively designed. The results suggest a standard measure of this form of dexterity could be used, unless the intended product is likely to be used after prolonged periods in the cold.

Fine finger dexterity has been shown to be affected by average winter temperatures and not just extreme conditions. Results from both empirical tests and real world tasks are significant. In relation to product interaction it is likely that such tasks as using a mobile phone, pressing a sequence of buttons on a screen or key pad, using a stylus to interact with a touch screen, picking up and placing objects such as keys, nuts, coins, bank-cards etc are likely to be affected.

The pilot study has established which forms of dexterity are affected by cold temperatures and which tests are good predictors of real world product interaction capability. From this study it was possible to identify which tests (Purdue Pegboard and the Moberg Pick-up test) provide a relevant and accurate measure of dexterity in relation to product interaction in the cold. The larger scale study will utilise these tests to gather further capability data to inform and guide the design process. Once this data has been gathered, it will then be translated into a tool that can be used to inform/guide designers in the development of inclusive outdoor products.

X.9 References

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