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Loughborough University SKInS: wearable simulations of Occupational Health – Defining specifications and product development

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ABSTRACT

A previous paper presented at CIB W099 2009 reported the authors' aim to develop wearable devices to simulate occupational health effects, and their consequential impacts on both working and home life, as experienced by older construction workers. The rationale for the research is that, when worn, the Loughborough University SKInS (Sensory and Kinaesthetic Interactive Simulations) will enable younger workers to directly experience age-related occupational ill-health conditions and so encourage behavioural change and improve future occupational health. Furthermore, other industry stakeholders (managers, architects, equipment designers, etc) should be able to better appreciate the challenges faced by older workers and, through this improved awareness, contribute to an attitude-shift to occupational health within the industry.

This paper describes the progress of the project in defining the specifications for five given health conditions that are frequently encountered in construction. The specifications were defined at mild, moderate and severe levels thereby enabling

wearers to appreciate the progression of the conditions and their resultant impacts at each stage. The paper further describes how the Loughborough University SKInS were then developed to meet these specifications and discusses the limiting factors which shaped the ultimate designs. Initial reviews by health professionals and industry representatives regarding their fidelity and potential contribution to the industry are also presented.

Keywords

Training; awareness-raising; attitude; behaviour; ergonomics; education; simulation;

INTRODUCTION

The ageing workforce

Most countries in the world are now facing the challenges posed by an ageing population. In the more developed countries, the 60 years old and above population sector will increase annually at 2.5% until to 2050, resulting in an increase from 274 million people in 2011 to 418 million in 2050. For the less developed countries, the rate of growth is more significant, estimated to be more than 3% resulting in an increase from 510 million in 2011 to 1.6 billion in 2050 (United Nations, 2011). The United Nations (2001) identifies declining mortality and fertility rates as key determinants in this demographic shift to an ageing global population. In many societies these factors are further compounded by the fact that the Baby Boomers (those born after World War II between 1946 and 1964) are now entering old age. Europe has the oldest population worldwide having a median age of nearly 40 in 2011 compared to 28 globally (the median age is that which divides a population into two halves) (United Nations 2011).

In terms of the impact of this trend, the European statistical agency, Eurostat, estimates that by 2060 the Potential Support Ratio, which measures those aged over 65 to those of employable age, will reduce to 1:2 compared to 1:4 in 2010 (Siemens, 2010). A mechanism for reducing the economic burden of an increasing older population, as recommended by The European Commission, is for the retirement age to be raised (Siemens, 2010) and this is a reality now being faced by many countries and industries. For example, in the UK, research conducted on behalf of the Department for Work and Pensions found that whilst overall employment within the construction industry is not anticipated to grow rapidly, an additional 577 000 workers will need to be recruited by 2014 unless there is a change in retirement patterns (McNair and Flynn, 2006). Increasing the retirement age however poses a new challenge, that of meeting the needs of the older worker. It is known that health problems increase with age which impacts on work e.g. just under a third of those aged 50-64 need urgent adjustments at work due to poor health (Ilmarinen, undated) and so as the workforce ages these effects may be exacerbated. This is more significant for the construction industry since, as already documented, older workers leave the industry due to the physical demands their work entails (Bremmer and Ahern, 2000). Indeed, a UK Health and Safety Laboratory report (cited in Whysall and Ellwood, 2006) found that although older workers are similarly distributed across industries, they are leaving at faster rates from construction.

Raising awareness of the role of occupational health

Improved occupational health within the construction industry therefore has a significant role to play in accommodating the older workforce since improved healthcare over workers' working lives should result in healthier future older workers. However, historically, occupational health has not received the same level of attention and

development as occupational safety; IOSH 2001 (cited in Benjamin and White, 2003) stated that a lack of focus on occupational health within current management systems makes its management difficult. They went on to say that preventing ill-health necessitates 'the careful design, selection and management of workplaces, work practices, processes, equipment and materials, as well as a trained, aware and motivated workforce'. Similarly, in an article commissioned by the European Agency for Safety and Health at Work to contribute to the European Year for Active Ageing and Solidarity between Generations 2012 entitled Promoting Active Ageing within the Workforce, one of the stated eight targets for age management is better awareness of ageing. The need to raise awareness of occupational health and the ageing workforce must be addressed in order to encourage an attitude shift within the construction industry which can then motivate changes to practice. An innovative mechanism for increasing understanding within the industry is through empathic modelling which is 'the method whereby an individual, using various props and scenarios, is able to simulate the deterioration of physical and perceptual abilities in everyday scenarios' (Nicolle and Maguire, 2003). The empathic modelling tools proposed within this paper for use are the Loughborough University SKInS: wearable simulations (Sensory and Kinaesthetic Interactive Simulations). These are devices which can be worn by non-sufferers to enable them to directly experience for themselves some aspects relating to the occupational health conditions most prevalent within the construction industry.

A previous paper presented at CIB W099 2009 (Cook et al, 2009) reported the authors' aim to develop these wearable devices with the intention of representing some of the symptoms of given occupational health conditions and their consequential impacts on both working and home life, as experienced by older construction workers. The rationale for the research is that, when worn, the Loughborough University SKInS will enable younger workers to directly experience age-related occupational ill-health conditions and so encourage behavioural change and improve the future occupational health of the workforce. Furthermore, other industry members (managers, architects, equipment designers, etc) will be facilitated in appreciating the challenges faced by older workers and, through this improved awareness, develop and implement more compatible working practices. Based on the authors' experience of using the Loughborough University SKInS relating to ageing and osteoarthritis within the automotive and related industries, as described in the same paper, it is believed that the Loughborough University occupational health SKInS have the potential to offer similar benefits to the construction industry.

AIM

The aim of this paper is to describe the progress of the research in defining and developing the simulations for five given health conditions (dermatitis, Hand-Arm Vibrations Syndrome (HAVS), musculoskeletal disorders (MSDs) of the lower back and knees, Noise-Induced Hearing Loss (NIHL) and occupational asthma). Specifications, which the simulations would be designed to meet, were defined at mild, moderate and severe levels thereby enabling wearers to appreciate the progression of the conditions and their resultant impacts at each stage. A key aspect of this research was to incorporate objective, as well as subjective, data into the specifications. The Loughborough University SKInS: occupational health simulations were then developed in line with these specifications subject to limiting factors which shaped the ultimate designs. Initial reviews by health professionals and industry representatives regarding their fidelity and potential contribution to the industry are also discussed.

SPECIFICATION DEVELOPMENT

Triangulated data collection

As previously described in Cook et al (2009), a triangulated approach to data collection regarding the five health conditions was adopted comprising:

- Literature/research review – to collate relevant data available in the public domain relating to the conditions generally, as well as their specific context within the construction industry. Academic papers, books, website and organisational literature were the main data sources accessed.
- Health professional consultations – to expand the knowledge base for the research by accessing non-published, expert information. A range of professionals were consulted who either had specific knowledge of occupational health within the construction industry or were specialists in the health conditions identified. They were able to contribute their appreciation of the health conditions based upon observations across a range of patients.
- Worker/sufferer interviews - to complement the previous two data sources by obtaining detailed, personal experiences of those who suffer the consequences of the conditions.

Taken together, these complementary methods provided a data-rich underpinning to the research.

Thematic analysis

Whilst the data synthesis was a subjective process, it was undertaken in a methodical manner to ensure that the most data were captured and systematically embedded into the specification. This was achieved via a thematic analysis in which data from the above sources for each of the five health conditions were collated and analysed under the following headings:

- Description, symptoms, severity progression, frequency, impact and severity measures which would be used to inform the design of the simulations.
- Causes, risk, industry prevalence, aggravating factors, avoidance and treatment which would be used to provide context/rationale for the simulations.

Development of the specifications

Using this refined data, a specification was developed for each of the five health conditions against which the simulations would be designed. To reflect the variability in the severity within each condition, three levels were defined, enabling each condition to be experienced in mild, moderate and severe forms. This was considered as an 'idealised' specification which, experience suggested, would not necessarily be met due to ethical, technical, cost and time considerations.

As stated, one of the aims of this research was to progress beyond simulations developed solely from subjective data to those underpinned by objective measures. Significant efforts were made within this research to identify such material and data of this nature were incorporated with the HAVS, NIHL and occupational asthma simulations.

Review of specifications

Given the critical role of the specifications with respect to the validity of the simulations, they were reviewed at this stage with an occupational health professional with specialist expertise within the construction sector. This process was of greater value to those specifications which were not underpinned by objective data, since it would enable the

authors' own subjective synthesis of the data to be independently verified. Minor amendments to specifications were suggested. These included a suggestion that the dermatitis specification be modified to show that the condition at the finger webs occurs on the palm side of the hand as well as the dorsum. Also, it was proposed for the lower back MSDs specification that tingling and/or numbness starting in the back and moving down the thigh and outside of the leg be considered as a moderate and severe, not mild, symptom of the condition. The review also provided the opportunity for any issues arising from the synthesis process to be explored and clarified with the occupational health reviewer e.g. confirmation of the extent to which the thumbs were affected by HAVS.

'Idealised' specification

Using this information the specifications were amended into the final form of the 'idealised' specification. An extract from this, pertaining to objective data relating to NIHL is shown in Table 1.

Table 1: Loughborough University SKInS: wearable simulations - Occupational Health specifications

	Symptoms - Level of severity		
	Mild	Moderate	Severe
NIHL (Objective data)	Selective hearing loss (around 4000 Hz) – only some words are missed. Hearing loss at 21-40dB. (40dB equivalent to talking in a quiet voice).	Hearing loss progresses to middle frequencies (3000 – 6000 Hz) Hearing loss at 41-70 dB.	High frequency hearing lost, low frequency hearing impaired (500-2000Hz). Hearing loss at 71-95 dB.

SIMULATION DEVELOPMENT

Development of the simulations is a creative and iterative process which, whilst driven by the specification requirements, needs to encompass additional important design considerations including: goodness of fit; ethics; cost; materials and technology; durability; hygiene; etc. The development process varied across the simulations as described below.

Dermatitis, HAVS, MSDs relating to the lower back and knees and occupational asthma simulations

Identification of potential components

The start of the development process commenced by brainstorming what items could be used to meet the requirements of the specifications. These could be existing items transferred from other applications; combinations of existing items; parts of existing items or bespoke developments. The brainstorming occurred via: communications within the project team and other relevant colleagues; conducting web searches; exploring various retail outlets as well as real world observations of work, domestic and other environments for items which may offer suitable characteristics. In addition to identifying items which would deliver the 'symptomatic' requirements of the simulations, further components were required to maintain these items in the appropriate position relative to the wearers' body e.g. gloves to which symptomatic elements for dermatitis and HAVS were secured.

Developmental workshops

Upon gathering sufficient items, developmental workshops were held with a small number of project team members to explore the extent to which the gathered items could suitably be included within the simulation. The primary concern was whether the item delivered the desired effect in a safe manner; this filter acted as a first level screening mechanism for accepting items for use within the simulation. For instance, using itching powder within the dermatitis simulation, whilst ideal in terms of meeting the specification, was not included since an adverse reaction to the powder by the wearer could occur. The items were then further screened for inclusion against criteria of: goodness of fit; cost; anticipated robustness; ease of fitment/attachment within the simulation and hygiene. The item which best met these criteria was then selected for use within the first prototype. Where an item didn't meet these criteria, the researchers considered the relative merits of: 1) adopting the item which offered the nearest, although not ideal, match, 2) adapting and/or combining one or more of the items to obtain a better fit against the requirements, 3) undertaking another search process for items of potential use or 4) developing a bespoke item. A number of workshops were undertaken until all the components which could be feasibly included within the prototype had been identified.

Prototyping

The aim of the prototyping stage was to combine the individual items which had been selected to address specific aspects of the simulations into a combined whole. Until this point, the items had been verified singly, however to apply each item in this way e.g. apply five devices to restrict knuckle movement in the fingers and then five devices to reduce sensitivity in the finger tips would be awkward and time-consuming, so a mechanism for locating all of the elements quickly and accurately in place had to be developed. Typical problems arising at this stage included: 1) Sizing – Whilst ideally one-size-fits-all solutions are required e.g. for gloves and belts, this is not always practicable. 2) Precision fit – For some symptomatic items it was either not possible to embed them within the simulation or only in a manner which would reduce their effectiveness e.g. some items would only work if located precisely over a knuckle however since wearers dimensions are variable, fixing the location of the device within the simulation meant that it was incorrectly positioned for some wearers. 3) Undesirable interactions – Some items although achieving the required symptoms also introduced other effects which were not part of the given health condition e.g. items which effectively reduced sensation in the fingertips also significantly increased the size of the fingertip which introduced an additional set of effects to those intended when interacting with everyday objects. Past experience in simulation development proved invaluable to the team at this stage and reduced the number of iterations needed to achieve a final version.

Reviews

The prototypes for each specification were initially reviewed within the wider project team to confirm that whilst the simulations did not meet the specification fully, they were as close as was practicable given the developmental constraints. The majority of the comments made related to modifications to the level of severity imposed by the simulations e.g. a need for greater immobilisation and greater discomfort. Examples of the final prototype version of the simulations are shown in Figure 1.

Following the team review, the simulations were then, where possible, assessed by relevant health professionals to obtain their views as to the fidelity of the simulations within the constraints the team was working to. Minor adjustments only were suggested for the dermatitis simulation; more immobilisation and more discomfort for the lower back MSD simulation along with a recommendation to distinguish between mechanical back pain and sciatic nerve pain; the severity of the knee MSD simulation was considered to

be too severe and the occupational asthma simulation needed further consideration of exhalation issues and for increases in chest tightening and back discomfort.

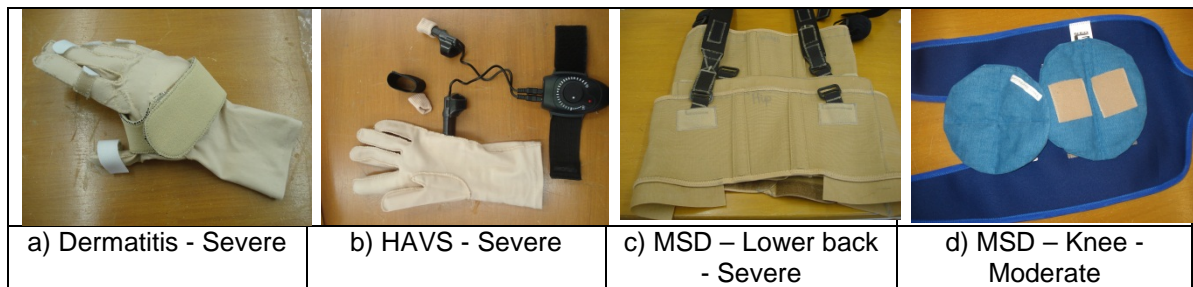


Figure 1: Examples of the Loughborough University SKInS: wearable simulations for occupational health

Dermatitis and HAVS – Visual simulations

To date previous simulations, and most of those within this research project, were concerned with conveying the somatosensory aspects of the symptoms to the wearer. However, with respect to dermatitis, the psychological impact of the condition was also significant e.g. some sufferers had a very restricted social life because they were too embarrassed to go out. For this reason it was considered by the team that this was an aspect which should be addressed within the research. Photos, representative of dermatitis at mild, moderate and severe levels, in conjunction with diagrams as to where the visual representations had to occur on the simulations, were provided to a special effects film modeller with the requirement to provide three pairs of gloves; one for each severity level. The glove format for realising the visual simulation was chosen since it was considered to be the mechanism which would offer most realism to the wearer. However there were problems in the glove's development including the need to incorporate sufficient elasticity to accommodate a range of sizes since generally such work is bespoke to a specific actor. In addition, a further issue with this form of simulation related to the cost since each glove needs to be hand finished.

Given the cost of the 'glove' form of simulation, the HAVS visual simulation was developed in the form of three 3-D silicone models showing the progression of the condition from mild to severe. Commissioning both forms of visual representation, glove and solid model (refer to Figure 2), within the research provided opportunities for future research to evaluate the relative merits of both forms in an educational context within the construction industry.

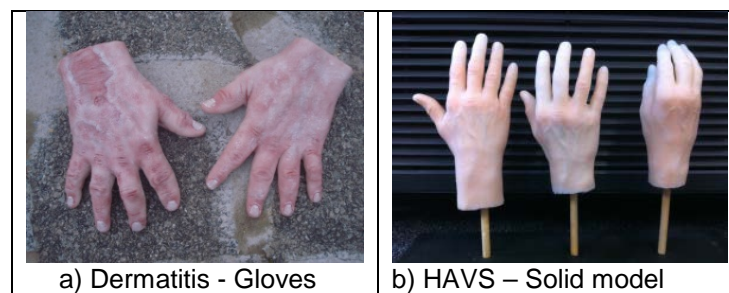


Figure 2: Examples of the Loughborough University SKInS: visual simulations for occupational health

Noise-Induced Hearing Loss simulation

The aim was to produce a wearable, mobile simulation which would provide real-time interactions enabling the wearer to appreciate the impacts to hearing of NIHL at mild,

moderate and severe levels. The specification and an example of audiogram data representative of hearing loss at these levels was provided to an electronics engineer with experience in hearing research. A digital based system offered greatest flexibility in terms of the shape, number and accuracy of the audiograms which could be replicated and would enable the highest level of fidelity. However this approach was rejected in terms of cost and a simplified, linear system employing a number of fixed filters adopted instead. It was designed such that audio inputs received via a lapel-positioned microphone would be channelled through a selected filter and the simulated output then delivered directly to the wearer via earphones. A working prototype was developed (refer to Figure 3a) but the full impacts of the condition were not realisable due to the direct conductance of external sounds through the skull and foam eartips. This was particularly noticeable at the moderate and severe levels of simulation since the filters associated with these levels attenuate the electrical signal to a point equal to, or greater than, the passive attenuation of the earphones. (The headphones used within the study had a claimed isolation of 40dB which was verified as part of the system validation process, hence once the electrical signal was attenuated by 40dB some of the sound could be heard directly and so impeded the full effect of the simulated output). Removing the opportunity for direct conductance would necessitate the person speaking to the simulation wearer to be in a separate room, and so whilst the 'face-to-face' conversation scenario would not be achievable as was the original aim, a good simulation of holding a mobile phone conversation when suffering from NIHL would be possible. This is shown in Figure 4.



Figure 3: The Loughborough University SKInS: NIHL simulation



Figure 4: Using the NIHL simulation with a mobile phone

PRESENTATION TO INDUSTRY

The dermatitis, HAVS and lower back and knee MSDs simulations were presented to the National Construction College and the UK Health and Safety Executive to solicit their opinions as to the simulations' likely benefits in raising awareness and increasing understanding and also to identify any design improvements. (The NIHL and occupational asthma simulations were still under development at this time). A presentation was given to provide attendees with an understanding of the context of the simulations. This comprised: a summary of the aim of the research; a review of the research undertaken and a description of previous wearable simulations developed by Loughborough University and their applications. Attendees who wished to try the

simulations were permitted under the guidance of the project team following informed consent and health screening.

The National Construction College is the largest training provider in the UK and Europe providing courses for new entrants to the industry, health and safety professionals and management. The Loughborough University SKInS were presented at a Trainers' Day where the health conditions and the rationale for the simulations were explained and an opportunity for 'hands-on' use of the simulations was provided. The simulations were observed to be highly engaging amongst the course participants and enlivened their learning. Upon completion of the session, the nine attendees completed a short questionnaire probing their opinions as to the potential value of the simulations within their training courses. All considered that the simulations would be an 'extremely useful' training aid for them. They considered that the benefit of the simulations was that they could increase learner awareness and so could change worker mindsets. This was because the simulations presented health information in a unique way. One trainer summarized the simulations contribution as providing "some representation of the symptoms that cannot be presented in any other way - Has huge potential benefit for the industry".

At the request of the UK Health and Safety Executive, a similar presentation was also given to Construction Inspectors within part of their training programme. The Inspectors were provided with the opportunity to trial the simulations which provoked much interaction and discussion amongst the team members concerning the health conditions represented, in much the same manner as the National Construction College session. The Head of the Health Risk Management Unit, who organised the training stated that the "session was very well-received and illustrated the potential for using various simulation exercises as a means to convey messages to construction workers about the consequences of failing to control health risks at work".

CONCLUSION

This paper illustrates how the Loughborough University SKInS: occupational health wearable simulations have been developed to meet, as far as is practicable, the specifications developed from relevant literature, health professional consultations and sufferer interviews. The simulations produced within this research demonstrate advancements on previous SKInS since 1) where possible, they were developed using objective, as well as subjective, data and 2) it was the first time simulations had been developed to illustrate the visual appearance of a condition in addition to its somatosensory impacts. The simulations can be considered to have been successful in terms of 1) the extent to which they conveyed somatosensory impacts representative of the conditions as judged by relevant health professionals although this was variable across the simulations and 2) the extent to which the simulations might act as innovative tools within a training context.

Research regarding the occupational health simulations is continuing with a study to evaluate the effectiveness of current training methods in enhancing the occupational health of younger construction workers. Within this study, it is intended that the simulations are more formally assessed with representative end users within the construction industry including young workers, their managers and industry trainers. In addition, further work needs to be undertaken to refine the simulations in line with the recommendations of the reviewers and from there investigate the means by which the simulations can be progressed from prototypes to commercial products. These have the potential to impact across a range of industries e.g. the dermatitis simulation can be applied within the hairdressing and health sectors in which, like construction, this

condition is prevalent. In this way, the real benefits to improved occupational health of wearable simulations to wider industry can be realised.

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