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VISUAL FEEDBACK AND PSEUDO-HAPTIC FEEDBACK IMPROVE MANUAL LIFTING PERFORMANCE

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Abstract. This paper investigates the effect of visual feedback and pseudo-haptic feedback to enhance participant performance in virtual lifting simulation. The aim of this study was to reduce lower back pain by enabling participants to monitor their lower back condition in terms of Lifting Index (LI) values, whilst moving an object from one location to another. This work examines various types of visual feedback techniques to support lifting operation in Virtual Environments (VEs). Several factors were analysed and used to identify the appropriateness of each visual feedback technique. The results showed that the addition of visual feedback did introduce an improvement in manual lifting tasks. The results also revealed that the combined visual feedback techniques performed better than singular feedback techniques. This paper also studies the effect of introducing pseudo-haptic feedback (or tactile augmentation) to increase participant performance in virtual environments. It was found that the introduction of a real weight provides the participant with pseudo-haptic feedback without affecting their performance.

Keywords: Visual feedback; pseudo-haptic feedback; virtual rnvironments; lower back pain

Abstrak. Kertas kerja ini mengkaji kesan maklum balas penglihatan dan maklum balas pseudo-haptik untuk mempertingkatkan prestasi pengguna di dalam simulasi angkatan maya. Tujuan kajian ini adalah untuk mengurangkan sakit belakang dengan membolehkan pengguna memantau keadaan sakit belakang dari segi nilai indeks angkatan, semasa mengangkat objek dari satu lokasi ke lokasi yang lain. Kajian ini memeriksa pelbagai jenis teknik maklum balas untuk membantu operasi mengangkat pada persekitaran maya. Beberapa faktor dianalisis dan digunakan untuk mengenal pasti kesesuaian sesuatu teknik maklum balas penglihatan. Keputusan menunjukkan dengan tambahan maklum balas penglihatan, dapat menunjukkan penambahbaikan tugas angkatan insani. Hasil kajian ini juga menunjukkan kombinasi teknik maklum balas penglihatan memberikan prestasi yang lebih baik dalam tugas angkatan insani berbanding dengan teknik maklum balas tunggal. Kertas kerja ini juga mengkaji kesan memperkenalkan maklum balas pseudo-haptik (penambahan sentuhan) bagi meningkatkan prestasi pengguna dalam persekitaran maya. Hasil kajian menunjukkan dengan memperkenalkan berat sebenar, memberi pengguna maklum balas pseudo-haptik tanpa menganggu prestasi mereka.

Kata kunci: Maklum balas penglihatan; maklum balas pseudo-haptik; persekitaran maya; sakit belakang

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1.0 INTRODUCTION

Major causes of injuries to the lower back are the manual materials handling (MMH) tasks of lifting, lowering, pushing, pulling, holding and carrying. Some aspects of these tasks can be designed using the NIOSH (National Institute for Occupational Safety and Health) Lifting Equation [1 – 2]. Research has been conducted on lifting techniques [3 – 4], but the use of virtual environments (VEs) to simulate such tasks would give several important benefits. These include ergonomic improvements in the design of factory layouts, manufacturing cells, production equipment, and the implementation of new methods for educating and training employees, such as production operators. Ergonomic lifting [3 – 6] is crucial to avoid lower back pain (LBP) and other injuries. In this paper we are concerned with providing virtual feedback in real time to indicate lower back stress experienced by the participant during a manual lifting task. Two types of virtual feedback were studied; the first one was visual feedback. Real-time visual feedback allows a participant to make adjustments whilst a task is in progress. The second type of virtual feedback investigated was a pseudo-haptic feedback, where it observes the effect of using real object to provide the participant with tactile augmentation.

2.0 VIRTUAL FEEDBACK

Sensory feedback enhances the ability of a participant to sense the environment and perform a task much quicker. Virtual Reality (VR) is a powerful tool to simulate new situations, especially to test the efficiency and the ergonomics. For example, VR may produce immersive simulations of airports, train stations, metro stations, hospitals, work places, assembly lines, cockpits, machine and vehicle control panels. VR may help the participant to understand the job procedure prior to actually executing the task. It would also help the participant in training to perform the task correctly. This study will utilize visual display feedback and pseudo-haptic feedback in VR to provide information about the stresses on the participants lower back whilst performing manual lifting tasks.

2.1 Visual Feedback in Virtual Lifting

Several factors need to be considered if visual feedback were to be employed in a virtual lifting task. The first factor involves the degree to which feedback is integrated within the environment. Full integration occurs when the feedback takes the form of a 3D object that is embedded within the environment, and one example is an object that shows the prescribed position during a virtual lifting task [7]. Feedback may also be classified as external to the environment. An example would be when the feedback is displayed on a graph or presented as textual messages. Another alternative is for text messages or graphical information to be superimposed on objects that are contained within the environment (for example, feedback is superimposed on the object to which it refers) and this is known as partial integration.

The colour of the displayed feedback is another factor that can be considered. Selection of the colour to be used as feedback must be associated with the feedback being given (for example, red representing dangerous or green representing safe) [8]. Furthermore, the chosen colour must be easy to remember by the participants and yet it must not merge with the background of the environment [9]. The other factor is a location of the feedback to be placed within the environment The feedback must be easily seen by the participant [7]. Visual feedback should also be symmetrically displayed to avoid any visual bias, visible in a participant's Field of View (FOV) and visible from a number of different viewing angles.

NIOSH Lifting Equation would be used as guidance to measure Recommended Weight Limit (RWL), the maximum weight that should be lifted for a particular task and the Lifting Index (LI). LI expresses the weight that will actually be lifted (the load weight) as a ratio of the RWL.

The equations are as follows [10]:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

$$LI = \frac{L}{RWL} \quad (2)$$

Where:

LC = load constant (23 kg)
HM = horizontal multiplier (25/H)
VM = vertical multiplier (1-(0.003*|V-75|))
DM = distance multiplier (0.82 + (4.5/D))
AM = asymmetric multiplier (1-0.0032*A)
FM = frequency multiplier
CM = coupling multiplier (good = 1, fair = 0.5, poor = 0.9)
L = Load Weight

H, V, D and A values can be obtained from Tables for Multiplier [10].

2.2 Pseudo-Haptic Feedback in Virtual Lifting

Methods of providing visual and auditory feedback in virtual environments are relatively well developed and attract a great deal of research. In contrast, the feedback associated with touch (or haptic) remains a challenging research problem. Several researchers agree that the principle reasons why no device has been fully capable of supporting the haptic system are the complicated structure of the underlying physiology of these processes, expense, their complexity and limited workspace [11].

Many researchers have suggested other replacement solutions [11] such as pseudo-haptic feedback, which combined visual feedback with the use of a passive input device. These can produce a sense of touch with minimal cost and without complex mechanical devices. Static haptics, tactile augmentation, and instrumented objects are among the alternative terms used to refer to approaches using rigid objects in the real world to provide a sense of touch to participants interacting with virtual environments [12]. Boud [13] presented a method of providing haptic feedback using real instrumented objects, where the participant can grasp, pick and manipulate objects, thus providing the participant with tactile, force and kinaesthetic feedback.

3.0 EXPERIMENTAL SET-UP AND PROCEDURE

The VE software was a C-based application that was designed and programmed by the authors using CAVELib API. An Onyx 300 visualization server was used to generate the images on a Portico Workwall (a large-scale display device). Stereoscopic 3D images were created through the use of LCD shutter glasses with refresh rate of 120 Hz (60 Hz update for each eye). Tracking for head and box position and orientation was performed using six degrees of freedom sensors together with Trackd software. Detail of the system architecture is given in Figure 1.

Participants were told to perform the task to the best of their ability. Ergonomic functions were crucial as an indicator of a virtual lift condition. The functions utilised a modified NIOSH equation to provide real-time lifting index information. This was

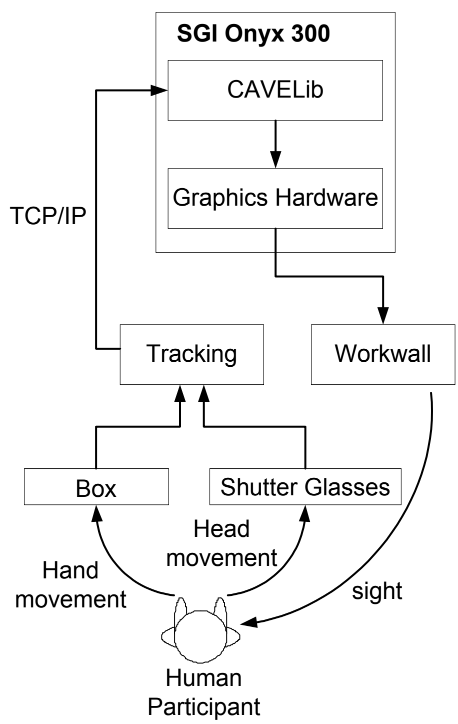

Figure 1 System architecture

done by continually setting the current height to the starting lifting position in Equation 1. The functions were also used to calculate the NIOSH Lifting Index values, which indicate the safety of the movement (as in Equation 2). The Lifting Index (LI) value varied between 0.00 and 0.99 for safe lifts, and values equal to or greater than 1.00 indicating harm to the participant. In this experiment, two thresholds were assigned: lower LI threshold and upper LI threshold. These two thresholds divide the LI values into three regions. LI values below lower LI threshold representing "Safe," LI values between lower LI threshold and upper LI threshold were categorised as "Risky" and LI values above upper LI threshold were categorised as "Danger" (refer Table 1).

Two sensors were used for this experiment, one for tracking hand movements and the other for tracking head movements in real-time. A Task Completion Time

Table 1 Lifting Index (LI) Regions

REGION	LIFTING INDEX (LI)
Safe	LI < Lower LI Threshold
Risky	Lower LI Threshold < LI < Upper LI Threshold
Danger	LI > Upper Threshold

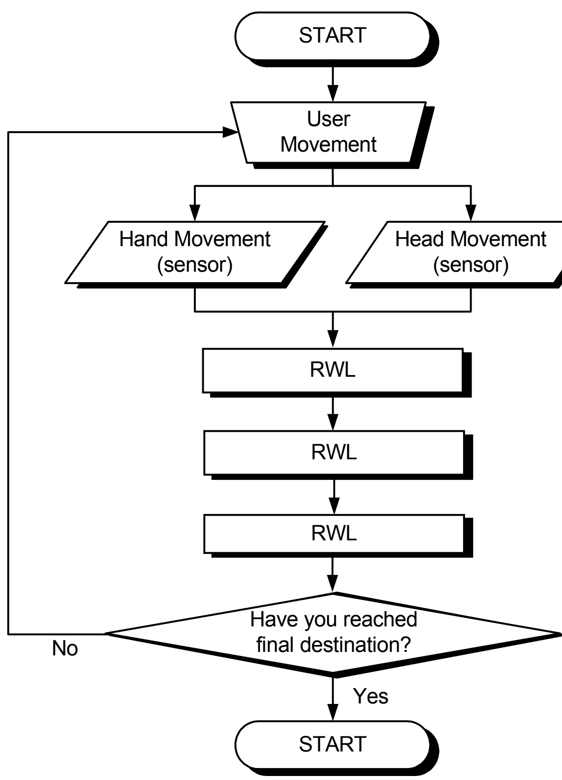

Figure 2 Flow diagram for visual feedback techniques

(TCT), time taken to complete each task and the corresponding Lifting Index (LI) values were also recorded by the application. The participant's objective was to carry out the task in the "Safe" working zone to the best of their ability. Figure 2 shows the flow diagram for this experiment. From this figure, it can be seen that the data from the sensors are processed and used to calculate the forces being applied on the participant's lower back.

These forces were calculated using the NIOSH equation which resulted in a value for Recommended Weight Limit (RWL) and Lifting Index (LI) (refer to Equation 1 and Equation 2). LI provides a single value that indicates the level of safety or acceptability for a particular lifting task. Snapshots of VEs using Colour, Text and COMBI Feedback techniques are shown in Figure 3 (a, b & c). As seen, the box is ready to be placed on the shelf when the shelf changes colour from grey to purple. This colour change indicates that the box has reached the final destination.

Figure 3(a) Snapshots of lifting in VEs for colour feedback techniques

Figure 3(b) Snapshots of lifting in VEs for text feedback techniques

Figure 3(c) Snapshots of lifting in VEs for COMBI feedback techniques

The results from the sensors and the time recorded by the software together with the LI values were extracted and processed from the written software. The raw data had to be processed in order to be able to obtain only one LI value for every change of LI made throughout the lifting task.

3.1 Experiment 1: Visual Feedback

The experimental design had four experimental conditions; one was experiment with No Feedback (neutral) and the remaining three conditions were provided with "Visual" feedback techniques being displayed in real-time. Three types of visual feedback were used in this study, which were: Text, Colour and COMBI (Combination of Colour and Text).

For trials with No Feedback (Neutral), the participant does not see any feedback relating to their LI value. In trials with Text Feedback, the participant receives feedback as Text for their LI results as well as the lifting grade designated as Safe, Risky or Danger. For trials with Colour Feedback, the box would change colour according to the LI values. Three colours were chosen: Green representing a Safe Lift, Yellow representing a Risky Lift and Red representing Dangerous Lifts. In COMBI Feedback trials, the participant is exposed to both Colour and Text Feedback simultaneously.

3.1.1 Experimental Procedure

Each trial was performed separately for each participant and lasted approximately one hour. Upon arrival, they were provided with a verbal overview of the experiment and were required to sign a health consent form before the trial could commence. The experimenter (the authors) explained and described the task to each participant. Each participant was measured and weighted; this information was recorded in a data file.

Participants were invited to perform the lifting task as if this were their daily routine working on an eight-hour shift. Participants were required to conduct four experimental conditions: No Feedback, Text, Colour and COMBI. The presentation order of the four conditions was controlled by using the Latin Square Design for minimizing learning effect. Participants were required to lift a box using the four techniques in visual feedback from a lower shelf (Shelf 1) to an upper shelf (Shelf 2). It can be assumed for all experiments in this paper that the virtual box is intentionally made large enough for the participant to see the visual feedback irrespective of lifting location.

Participants were required to carry out 10 trials for each condition. They were then required to pause and hold the box static for 2 seconds for every trial, before proceeding on to the next. This delay allowed the experimenter to identify that the lifting task was complete, while monitoring the action of the participant during data

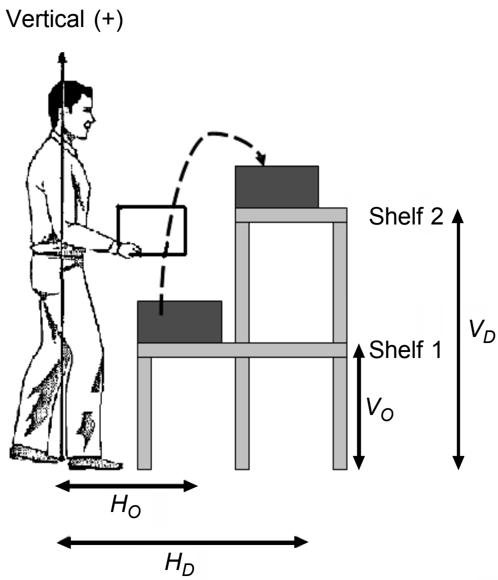

Figure 4 Schematic representation of shelving position

analysis. A detailed schematic representation is depicted in Figure 4. V_O and H_O show vertical and horizontal positions of the box at the start of the trial, denoted as "original." V_D and H_D illustrate vertical and horizontal positions of the box at the end of the trial, denoted as "destination."

3.2 Experiment 2: Pseudo-Haptic Feedback

Two conditions need to be conducted: lifting with a virtual weight and lifting with a real weight. For the virtual weight condition, a subject would lift an empty box, having dimensions of 30 cm wide, 15 cm deep and 40 cm long fitted with a handle. Three different weights were used for these conditions which were 2 kg, 4 kg and 6 kg. For the condition with virtual weight, the virtual weight of 2 kg, 4 kg and 6 kg were applied to the virtual box. For the real weight conditions, real weights (real loads of 2 kg, 4 kg and 6 kg) were lifted in the box of the same dimension. Each participant performed lifting in "Combined Colour and Text" feedback technique.

Eighteen different subjects took part in this experiment. There were fifteen men and three women with a mean age of 31.2 years and a standard deviation of 2.6 years. All participants for the experiment were in good health, had no history of any back problems, no vision (after correction) or hearing impairments. The software was a CAVELib application, which was programmed by the author.

Subjects were told to perform the task to the best of their ability. All lifts had to be conducted in a safe lifting range. Participants were provided with "Combined Colour and Text" feedback techniques in real-time to provide real-time information about the forces on the participant's lower back utilising a revised NIOSH equation. From NIOSH equation, the Lifting Index (LI) value can be calculated. The acceptable LI value varied between 0.00 and 0.99 for safe lifts, with values equal to or greater than 1.00 indicating harm to the participant. For this experiment, three levels of feedback which monitor participant's back pain have been provided according to the calculated LI value. Three sets of LI values, each for a different weight, have been used as shown in Table 2.

Participants were told to conduct all lifts in a safe manner, within the "Safe lifting zone" throughout all lifts. If they found that they were outside this range, they were instructed to react by changing the location of the box to keep it in the safe working zone. Therefore, they must always perform the safe lift according to the supplied feedback.

Table 2 Details of colour and text feedback

Weight	**LI values**		
	Safe	**Risky**	**Danger**
2kg	< 0.3282	0.3282 < LI < 0.3704	> 0.3704
4kg	< 0.6507	0.6507 < LI < 0.7536	> 0.7536
6kg	< 0.900	0.900 < LI < 0.9999	> 0.9999

1.2.1 Experimental Procedure

Each participant was run individually taking approximately one hour to complete. They were required to read and sign a health consent form; only those in good health were allowed to participate in the experiment. Participants were presented with a description of the task to be performed. The experimenter also explained and demonstrated the lifting procedure to be carried out by the participants. Participants' detailed information was recorded in a data file. At the end of the experiments, the participants were given a participantive questionnaire including rating scales. The participants were told that they could ask to have a rest before commencing the next experiment.

The participants were asked to lift the box from a starting position (shelf 1) and place the box in a designated area on an upper shelf (shelf 2), guided by the feedback (see Figure 5 and Figure 6). They were then required to pause and hold the box static for 2 seconds for every trial, before proceeding on to the next. This delay was for the experimenter to identify that the lifting task has been completed and helped in monitoring the action of the participant during data analysis.

Participants were run in both conditions; the first is to perform lifting tasks with virtual weights, which varied from 2 kg, 4 kg and 6 kg, and secondly lifting with real weights, with the same set of weights (2 kg, 4 kg and 6 kg). Participants practised and

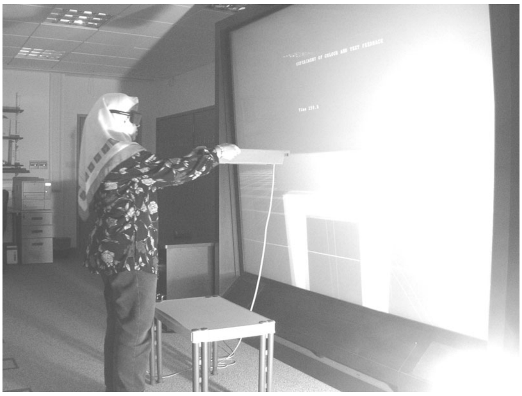

Figure 5 Participant conducting a lifting task

Figure 6 Combined colour and text feedback

perform five trials for each condition of experiment, starting with virtual weight followed by real weight. The presentation order was randomised in a Latin Square Design. Attached sensors recorded position and orientation of the participants and the box. Time taken to complete the task and Lifting Index values were also recorded. Upon completion of the experiment, the participants were required to fill in a simple questionnaire regarding their feeling of realism in having tactile augmentation.

4.0 RESULTS

Results from the trials were extracted and processed. A one-factor (technique) ANOVA was used for analysis of Task Completion Time (TCT) and Percentage of Harmful Lifts (PHL).

4.1 Visual Feedback

4.1.1 Task Completion Time (TCT)

The time taken to accomplish each task was measured successfully. Trials without feedback showed the shortest Task Completion Time. This was because the participants did not have to monitor any feedback regarding the forces acting on their lower back. This may result in potentially harmful lifts if an improper lift is used. The results showed that there was no main effect of feedback technique [$F(3,76) = 2.35$, $p = 0.01$] on task completion time. However COMBI feedback gave superior results compared to both colour and text feedback techniques (mean = 8.7. s.d. = 6.6). From Figure 7 it can be seen that Colour feedback (with mean = 10.3 and s.d.= 6.2) outperformed Text feedback (mean = 13.7 and s.d.= 8.8).

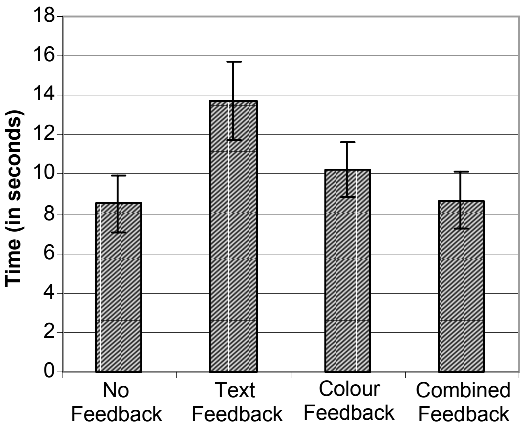

Figure 7 Task completion time as a function of the type of feedback

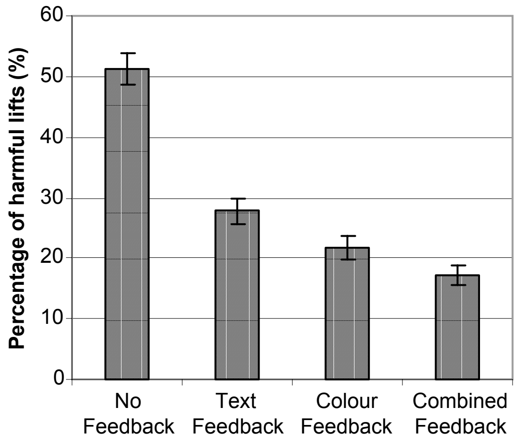

Figure 8 Percentage of harmful lifts (PHL) for visual feedback techniques

4.1.2 Percentage of Harmful Lifts (PHL)

Figure 8 shows Percentage of Harmful Lifts (PHL). The results from ANOVA analysis showed that there was a main effect of technique on PHL. A post-hoc Tukey test reveals that the percentage differed significantly between "Text and COMBI ($P < 0.05$)," and between NF and all of the techniques. The plotted graph also shows that Combined Colour and Text gave the lowest PHL with mean = 3.45 and s.d. = 0.83. Colour feedback outperformed Text feedback with mean = 4.35 and s.d. = 1.09 and mean = 5.55 and s.d. = 1.2, respectively.

4.2 Pseudo-haptic Feedback

Figure 9 shows the time taken to complete the lifting task. As can be seen, time to complete the lifting task between real weight and virtual weight were not significantly different. Mean comparison using the two-tailed paired t-test reveals no significant main effect on the weight condition of participants' task completion time for 2 kg ($t = -1.61$, $df = 179$, $p = 0.116$), 4 kg ($t = -1.95$, $df = 179$, $p = 0.052$) and 6 kg ($t = -1.91$, $df = 179$, $p = 0.057$). This suggests that participants' lifting performance in virtual weight and real weight with regard to speed was almost identical because only small differences can be seen on the graph. Therefore, ergonomists may use virtual lifting techniques to train humans how to lift safely in order to minimise their lower back pain. However, participants took slightly longer to complete the lifting task in real weight, and this can be observed in all weights.

Another factor studied in this experiment was the Lifting Index (LI) value. Figure 10 shows the differences between LI in Virtual Weight and Real Weight. Lifting Index values for Virtual Weight were compared with Lifting Index values for Real

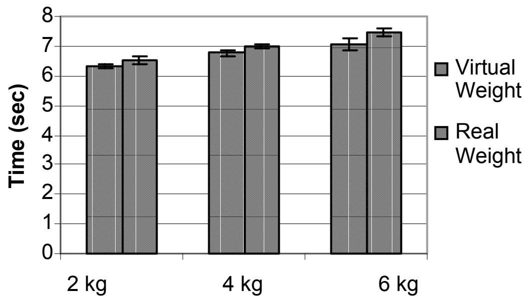

Figure 9 Task completion time (TCT) between virtual weight and real weight

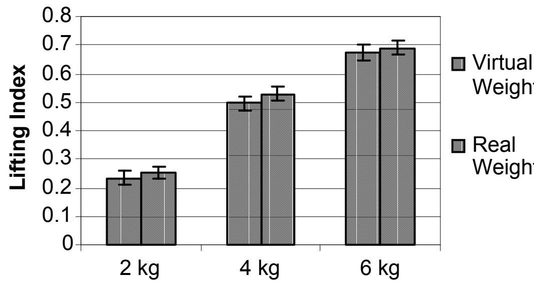

Figure 10 Lifting index value between virtual weight and real weight experiment

Weight and the differences were found to be not significant: 2 kg ($t = -1.72$, $df = 179$, $p = 0.095$), 4 kg ($t = -1.85$, $df = 179$, $p = 0.067$) and 6 kg ($t = -1.89$, $df = 179$, $p = 0.084$). This also supports the fact that lifting a virtual weight can mimic a lift with a real weight. The reason might be due to the fact that the virtual feedback given was easy to follow no matter whether the participant performed the lift using real or virtual weight. A similar pattern was found in participants' performance, which was better achieved in virtual weight. However, since the differences were small which only 3.0, 3.1 and 5.6 percent for 2 kg, 4 kg and 6 kg respectively, training humans to lift in VEs would be an alternative.

Responses from the questionnaire given to the participants reveal that 33 percent of the participants who answered preferred lifting with real weights as a training tool, as they feel more realistic, while 67 percent of them suggested virtual weights should be used to train humans to perform manual lifting. The majority of the participants suggested that virtual feedback alone is sufficient for them to monitor their lower back condition as it provides specific results according to NIOSH algorithm in real time.

5.0 DISCUSSION

In visual feedback experiment, COMBI feedback showed consistently good results given that this technique was the best for all aspects that have been analysed, which were TCT and PHL. The ranking for the results also followed the same path, where Colour Feedback was better than Text Feedback. Despite the fact that no significant difference was found in TCT, COMBI seems good for alerting the participant of their lower back condition while carrying out a manual lifting task. As a matter of fact the NF condition showed the shortest time to complete the task in TCT analysis but demonstrated the highest number of poor and potentially harmful lifts. This could be dangerous to a human participant as lower back problems develop over time and are difficult to correct. This highlights the need to minimise poor lifting methods and encourage safe lifting approaches.

Based on the results of this study, it is recommended that with a good selection of visual feedback techniques a participant can perform well while monitoring their LI values. The COMBI feedback technique was the best in performance when compared to both Colour and Text feedback schemes. In addition, it was found that COMBI was the easiest and most intuitive because the participant could gauge and control coarse and fine LI. For example, if the participant needs to drastically lower their LI value they seem to rely on Colour changes for coarse control. However, if only small changes, i.e. fine control, is required then the participant usually prefers to use Text feedback as this allowed the box to be placed more accurately.

In pseudo-haptic experiment, Task Completion Time (TCT) and Lifting Index (LI) values for experiments of real and virtual weight conditions were not significantly different. The introduction of a real weight provides the participant with real haptic feedback without affecting their performance. Results from the questionnaire suggest that with the application of a real weighted object, a participant has the added information of tactile augmentation as a technique for adding texture and force feedback cues to the box lifted. It has been demonstrated that participants were able to achieve almost similar performance with three different weights (2 kg, 4 kg and 6 kg). Virtual Reality is intended to avoid handling difficult and dangerous tasks. This experiment was carried out to differentiate between participants' performance in lifting with virtual weight and lifting with real weight augmented with information of tactile feedback. The results suggest that the learnt virtual feedback technique can be applied in a real situation after participants have been trained with any specific technique.

A simulated environment is also less dangerous than training in a "live" environment, where the feedback provided may alert the participant of their back pain risks. However care must be taken when considering the time spent as lifting real weight is usually found to take slightly longer when compared to lifting a virtual weight. This was found in all the experiment conditions.

6.0 CONCLUSIONS AND FUTURE WORK

Visual display feedback has been proved to aid participants in carrying out safe manual lifting tasks by giving immediate indications of the forces acting on their lower back. The NIOSH equation which calculates RWL and LI was applied as a guideline to categorise the lifting regions of Safe, Risky and Danger. The visual feedback displays the changes according to LI values processed in real-time from the electromagnetic position sensors. Three types of visual feedback were tested: Colour, Text and COMBI. All of the feedback techniques were capable of being used for a manual lifting task, but COMBI was found to be the best according to the results of TCT, PHL and RTF. Colour was slightly lower in performance when compared to COMBI while Text was poor and performed far less favourably when compared to both COMBI and Colour.

The effects of using a real object to provide the participant with tactile augmentation feedback, has also been evaluated. The findings showed that results of the participants perform lifting with tactile augmentation were similar when compared to a lift done without tactile augmentation. Participants were able to monitor their LI values from the visual feedback given when conducting the real and virtual weight lifting tasks. There was no significant difference in Task Completion Time (TCT) between lifting with a real weight and lifting with a virtual weight. The same applied to Lifting Index. Therefore, we may conclude that the introduction of tactile augmentation did not affect human performance in carrying out manual lifting tasks. Participants mostly depend on the virtual feedback (Combined Colour and Text feedback) given to them as they indicate precise measurement of their lifting performance. These findings also showed that the introduction of a real weight provides the participant with real haptic feedback.

Further research is required to determine whether other mixed visual feedback actually improves participant performance in VEs, and also adding another types of visual feedback such as symbols and graphs. The possibility of adding audio together with visual would also be an advantage as a participant can benefit from both feedback techniques.

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