Transfer of training from virtual to real environments

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ABSTRACT

Training is one of the most rapidly expanding areas of application of the technology of Virtual Reality (VR) with virtual training being developed in industry, commerce, the military, medical and other areas of education and in a variety of types of rehabilitation. In all cases such training rests upon the assumption that what is learned in the virtual environment transfers to the equivalent real world task. Whilst there is much anecdotal evidence there have been few systematic empirical studies and those that have been carried out do not lead to clear conclusions. This paper reports preliminary findings from a study, using a simple sensorimotor task, which seeks to establish not only the extent of transfer, but also the reliability and robustness of whatever transfers. The findings demonstrate a clear positive transfer effect from virtual to real training and suggest that the cognitive strategy elements and cognitive loads of the two types of training are broadly equivalent. However, caution is advised in the interpretation of these findings. The results are discussed in the wider context of models of transfer of training.

1. INTRODUCTION

One of the most rapidly developing applications of virtual environments (VEs) is in the field of training. Virtual training regimes have been devised not only for pilots but car, bus and train drivers, divers, firefighters, surgeons, quality control operators and space mission controllers (Durlach & Mavor, 1995). Moving closer to the disability focus of this conference, there has been much interest recently in using VEs in the training of people with learning disabilities (Cromby *et al.*, 1996; Mowafy & Pollack, 1995; Standen *et al.*, 1997; Stanton *et al.*, 1996; Strickland, 1997), in rehabilitation following brain damage caused by traumatic brain injury (Rose, 1996; Rose *et al.*, 1996, Rose *et al.*, in press), stroke (Rose *et al.*, submitted) and neurodegenerative diseases (Pugnetti *et al.*, in press), and in desensitisation training for people with phobias (Carlin *et al.*, 1997, North *et al.*, 1997). Several authors have argued that, because they can be so comprehensively controlled and trainees' responses to them so meticulously monitored, VEs represent an almost ideal training medium (Darrow, 1995; Rose, 1996; Schroeder, 1995; Rizzo, 1998). Seidel and Chatelier (1997) have even suggested that the use of VEs may be "training's future".

Crucial to these training applications of VEs is the issue of transfer of training. Does training carried out in a VE transfer to the equivalent real world situation? Within the VE training literature there is a wealth of more or less anecdotal evidence that transfer does occur. However, there have been relatively few attempts to investigate empirically the virtual to real transfer process in terms of what sort of training shows transfer, in what conditions, to what extent, and how robust the transferred training proves to be. Where the transfer process has been the focus of the investigation findings have been mixed. Regian (1997) has reported positive transfer in both a console training task and a spatial task. However, Kozak *et al.* (1993) in a much cited "pick and place" task failed to find transfer from virtual to real, although the methodology in this study has been questioned by Durlach and Mavor (1995) and the results disputed in a follow up investigation by Kenyon and Afenya (1995).

Clearly there is a need for further systematic investigation of transfer from virtual to real environments. However, it is important to recognise that all studies involving transfer cannot be taken together for the purposes of analysis and review. For example, within the studies referred to above the intended outcomes of the training process are very varied, including simple sensorimotor performance, complex sensorimotor skills, spatial knowledge of an environment, vigilance, memory, and complex problem solving. It would be

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surprising to find equivalence between them in terms of the extent and type of transfer which occurs. This brings us to an additional point.

A serious criticism which can be levelled at studies of transfer of training from virtual to real situations is that few authors have sought to analyse the process in terms of the well established literature on the transfer or training (Cormier & Hagman, 1987) which forms part of the more extensive literature on the psychology of learning. Modern psychological thought about transfer of training can be seen as having developed from concerns about the theory of formal discipline, dominant within education in the early part of the 20th century, which held that core mental skills embedded in learning disciplines such as Latin and Mathematics would automatically transfer to other subjects. Thorndike and Woodworth (1901) took issue with this assumption, suggesting that transfer of training between two sequential tasks would occur only to the extent that the two tasks shared identical elements. A similar view was espoused by Wylie (1919) and Bruce (1930), later known as the Bruce-Wylie laws. Later still Osgood (1949) sought to generate a predictive model (called a transfer surface) from which one could estimate the extent of transfer between two tasks on the basis of the degree of overlap between them in terms of stimulus and response elements.

The theories of transfer so far described were firmly rooted within the Behaviourist tradition within psychology and, as cognitive psychology gained greater influence within the discipline so interpretations of transfer took on a more cognitive slant (e.g. Newall, 1980). In particular the emphasis was now placed upon the extent to which two tasks were similar in terms of cognitive processing demands (i.e. using the same knowledge in a similar way) in predicting how much transfer will occur between them.

In terms of predicting transfer of training effects within training and retraining programmes for those with disabilities, especially for those with brain damage, one attempt to combine the best of both the identical elements models and the more recent cognitive models is that proposed by Parenté, Anderson-Parenté and DiCesare (Parenté & Anderson-Parenté, 1990; Parenté & Dicesare, 1991). According to this model a good rehabilitation programme must have significant similarity with the real world situation in which those it is designed for will be operating, both in terms of stimulus and response elements but also the cognitive strategies which need to be employed.

In the present paper we report the preliminary stages of an attempt to systematically investigate the nature of the transfer process occurring between a virtual and real training environment in terms of the extent and robustness of what transfers, within the theoretical framework of the model proposed by Parenté *et al.* Using a simple steadiness tester wire loop task we have sought to produce a high level of overlap in both stimulus and response elements between the virtual and real training conditions. In this way we have sought to focus on the cognitive strategies involved in virtual and real training (i.e. if there is ample overlap in terms of sensorimotor elements any failure to transfer is likely to be due to a lack of overlap in terms of the cognitive strategies needed for virtual and real training). In addition to investigating the extent of transfer of training in this case (experiment 1) we are interested in the possibility that the cognitive loads associated with training in virtual and real situations may be different (experiment 2). In other words, even if superficially similar in terms of conventional measures of transfer, virtual training may be in some respects less robust than real training. We have investigated this by introducing different types of interference into the real loop task after participants have been trained either in the real or virtual versions of the task. Our specific hypothesis is that motor and cognitive interference will have differential effects on real and virtually trained performance.

2. EXPERIMENT 1

2.1 Method

2.1.1 Participants. 150 university staff and students. (mean age =37.6, SD=4.97, 97 women and 53 men). All were unpaid volunteers recruited through poster announcements.

2.1.2 Tasks

Real-world task: The real world version of this test consisted of a curved wire, 450mm in length and 2mm in diameter, suspended between two vertical side supports at a height of 140mm above the table. Using the non-preferred hand, the participant held a rod on the end of which was a circular wire loop (80mm diameter) and was required to guide the loop along the wire as quickly as possible but without touching it. Contact between the loop and the wire (an error) produced feedback in that the background screen lit up

Virtual reality task: The virtual environment was created using dVISE, and was run via a HP 715 workstation, using dVS. In the virtual version of the task the participant viewed a computer generated three dimensional simulation of the wire and its supports via a head mounted display. Participants controlled their movement along the wire by moving a 3-D mouse, and feedback was produced by lighting up the background in the VE.

2.1.3 Procedure. Participants were randomly allocated to one of three equal sized groups. All three groups were tested on the real world wire loop task before and after training but differed in terms of the type of training given in between. For Group 1 training consisted of eight trials on the real-world wire loop task. Each trial consisted of moving the loop along the curved wire from left to right and then returning along the wire to the start position. Between each trial each participant had a one minute rest. Group 2 training consisted of eight trials on the virtual version of the task. As in the real-world task, participants completed eight trials interspersed with one minute rest periods. Participants in the Group 3 no-training control spent the period between pre and post training measures on a non-related task (this time period was based upon pilot data which showed that 15 minutes was the average time taken to complete either real-world or virtual training).

2.2 Results

As the pre-test error scores (baseline) had a wide between participants variation (range 10 to 127) the baseline scores were partialled out from the analyses.

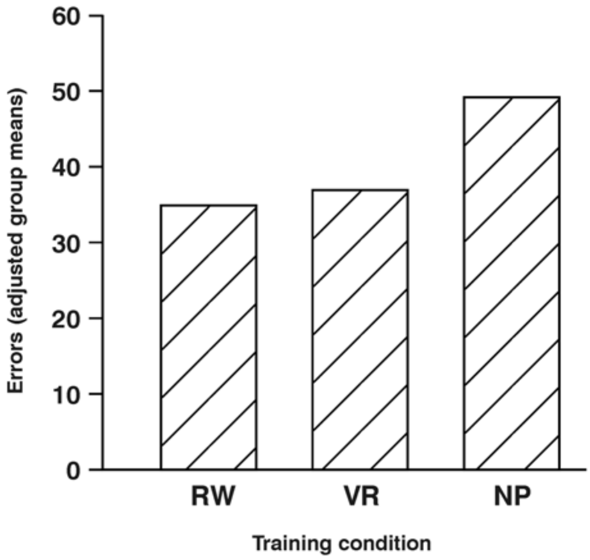

Figure 1. Adjusted group mean error performance scores (after baseline error scores were partialled out) for real, virtual and no training groups.

As can be seen from the adjusted group means in Figure 1, more errors were made in the no practice training condition than in the other two conditions. A one-way analysis of covariance, using baseline error scores as the covariate, showed that there was a significant difference between training conditions $F(2,147)=17.00$, $p>0.0001$. Planned comparisons showed that significant differences existed between the real-world practice condition and the no practice condition ($p>0.01$), and between the VR condition and the no practice condition ($p>0.0.01$). There was no significant difference between the real-world practice and VR conditions ($p<0.05$).

3. EXPERIMENT 2

3.1 Method

3.1.1 Participants. 100 university staff and students (mean age=30.9, SD=6.3, 60 women and 40 men). These participants had taken part in Experiment 1.

3.1.2 Procedure. Participants were randomly allocated to one of two groups, a concurrent motor task condition or a concurrent cognitive task condition. The task was concurrent with the carrying out of a single trial on the real-world loop task. As before, the trial consisted of moving the loop along the curved wire from left to right and then returning along the wire to the start position with their non-preferred hand.

Participants in the concurrent motor task condition tapped a Morse-code key with the middle finger of their preferred hand. The key had to be tapped at the same tempo (two per second) as that heard on a pre-recorded audio-cassette tape.

Participants in the cognitive concurrent task condition listened to a pre-recorded audio-cassette tape which presented 40 words at three-second intervals. Interspersed with these words were names of fruit. Each time the participant heard the name of a fruit they had to say yes.

3.2 Results

For the purposes of analyses, participants' post-test error scores following real-world or VR training undergone in study 1 were used as the baseline to measure the effect of the concurrent task variable. As this baseline also had a wide between participants variation (range 3 to 79) the baseline scores were partialled out from the analyses.

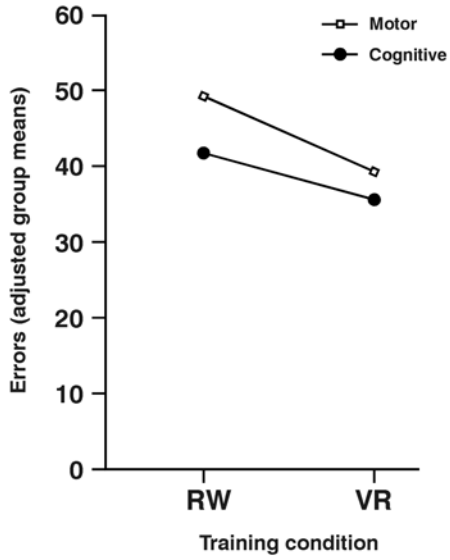

Figure 2. Adjusted group mean error performance scores (after baseline error scores were partialled out) for real and virtual training groups when carrying out either a motor or cognitive concurrent task.

The adjusted group means in Figure 2 indicate that carrying out a concurrent motor task led to a greater number of errors in the loop task than carrying out a concurrent cognitive task. It also appeared that introducing a concurrent task had a greater effect on the performance of participants previously trained on the real task than on the performance of those previously trained on the virtual task. However, this effect was not statistically significant. A two by two analysis of covariance, using post-test error scores as the covariate, showed that there was a main effect of type of concurrent task (motor vs. cognitive) $F(1,95)=4.22$, $p=0.043$, but no main effect of training condition (real vs. virtual) $F(1,95)=0.734$, $p=0.394$. No significant interaction occurred between the training condition and concurrent task $F(1,95)=1.313$, $p=0.255$.

4. DISCUSSION

In predicting transfer of training from a rehabilitation programme to subsequent real world performance Parenté and Hermann (1996) have drawn a distinction between "task elements" (broadly speaking the sensory and motor elements of a task referred to in the introduction), and "organisational set" (the cognitive processing demands of a task previously referred to). Thus the best possible transfer is predicted when both the task elements (A) and the organisational set (B) in the rehabilitation programme and in the real world environment in which the patient must subsequently operate are identical. An example would be retraining a stroke patient with prospective memory problems in the sequence of actions needed to cook a meal in his/her own kitchen. For resource reasons it is rarely possible for rehabilitation to be individualised in this way. The nearest approximation which is usually possible is when the real world task elements and the organisational set are similar but not identical to those rehabilitation situation (A' and B' rather than A and B). These two situations are represented below:

Rehabilitation Programme		Real World		Transfer
Task elements	Organisational set	Task elements	Organisational set	
A	B	A	B	Very high
A	B	A'	B'	High

In this study we have made the task elements in the virtual and real training situations, not identical, but as similar as possible. For example, as well as making real and virtual visual displays almost identical we modelled the handle of the metal ring the participants had to move along the wire on the handle of the 3-D mouse they used in the virtual task. In this way we have sought to focus on the organisational sets required in the virtual and real tasks. Since we obtained very high levels of transfer it is reasonable to conclude that, within the constraints of the investigation, the organisational set (or cognitive processing strategy) required to learn the virtual and real versions of the steadiness tester are very similar.

This finding does not exhaust the questions we need to answer regarding virtual to real transfer if virtual training is to become a reliable tool. Although the organisational set involved in learning in the virtual and real worlds may be similar enough to support high levels of transfer of training, the cognitive loads associated with operating the organisational set may differ between the two situations. More specifically we predicted that the "cognitive cost" associated with virtual training would be greater than real training and that this might be reflected in post training real world performance being less reliable or "robust" in virtual trained participants than in those trained throughout on the real task. If true this would clearly be an important factor to take into account in deciding when to use virtual training. We sought to investigate this cognitive load hypothesis by introducing both motor and cognitive interference into a post-training test trial.

In the event we found that the motor interference was more disruptive than the cognitive interference. This is perhaps unsurprising given that the steadiness tester task has a high sensorimotor component. With a more obviously cognitive task the effect may have been reversed. There was no evidence that either type of interference was more disruptive for those participants trained in the virtual task than those trained in the real task. The results do not support our "differential cognitive load" hypothesis, therefore, and taken at face value would lead us to be reassured that virtual training is as reliable as real training. We recommend caution, however. Firstly, and as we have just observed, the task employed in this investigation is predominantly a sensorimotor task. With a task which could be considered more demanding in terms of cognitive load, a different result might have been obtained. Secondly, within the constraints of this study we were only able to investigate the disruptive effects of one motor and one cognitive interferer. Just as training task nature and difficulty need to be varied, so it is necessary to examine a range of levels of intrusiveness of the interference. In the absence of a more complete, parametric, investigation we believe firm conclusions would be premature.

Currently we are extending our investigations to take account of these considerations in healthy volunteers as well as studying transfer of training from virtual to real environments in people with definable cognitive impairments.

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