Effects of different virtual reality environments on experimental pain threshold in individuals with pain following stroke

M J Simmonds and S Shahrbanian

School of Physical& Occupational Therapy, Faculty of Medicine, McGill University,
3654 Promenade Sir William Osler, Montreal, CANADA

maureen.simmonds@mcgill.ca, shahnaz.shahrbanian@mail.mcgill.ca

ABSTRACT

The objectives of this study were to determine whether different virtual reality environments (VR) had a differential effect on pain threshold (PT) in stroke patients with pain, and whether the patient's level of interest in the VR influenced PT. Ten stroke individuals with pain participated. PT to hot and cold stimuli was determined using Quantitative sensory testing within four different VEs; Hot, Cold, Neutral and no VR. After the VR exposure, subjects rated each VR condition based on their engagement. The results suggest that VR is more effective than no VR and all VR conditions were more engaging than no VR.

1. INTRODUCTION

Stroke is an injury to the part of the central nervous system due to either blockage in or bleeding from an artery that supplies blood to the brain, which causes destruction of a portion of the brain and can lead to loss of muscular control, weakening or loss of sensation or consciousness, dizziness, slurred speech, or other symptom. According to the World Health Organization 15 million people around the world suffer a stroke each year, with five million of those episodes resulting in death and a further five million people left with a permanent disability. Stroke is also the third leading cause of death and the leading cause of disability in high-income countries, such as United States (Swierzewski, 2007). Approximately 780,000 strokes, occur in the United States each year (The Stroke Association, 2008), and the Heart and Stroke Foundation of Canada (2003) has estimated that 40,000–50,000 new episodes of stroke occur in Canada annually.

Pain is a common problem after stroke. Approximately 8% of stroke individuals develop central post-stroke pain (Teasell, 2006). Central post stroke pain is a neuropathic pain syndrome. Most commonly pain occurs within the first 6 months (Bowsher, 2001). The pain has been described as burning, aching, or pricking in nature often accompanied by abnormal sensation in the affected body part such as the face, arm, leg, and trunk. It's usually constant, with a tendency to increase in intensity over time, and differs from other forms of musculoskeletal pain that commonly occur in stroke survivors. Movement, emotional stress, changes in temperature, or other unrelated stimuli may intensify the symptoms. This chronic pain can decrease quality of life, physical function and reduce the ability to concentrate. Chronic pain often leads to depression, and loss of self esteem.

Virtual reality (VR) has been used as a treatment for pain reduction. VR can provide a means of attracting attention to a specific virtual environment or alternatively distracting attention from a painful experience. Since an individuals' attentional capacity is limited, and a distracting technique requires a great deal of the person's attentional resources, this leaves little attentional capacity available for processing painful stimuli (McCaul& Malott, 1984). Attentional resources within different sensory systems act independently so that an activity that involves one sensory modality may not deplete the attentional resources in another (Wickens, 2002). However, pain tends to demand attention. In a series of studies, Hoffman has shown that patients with severe burns using VR have reported large reductions in worst pain, pain unpleasantness, and time spent thinking about procedural pain (Hoffman, 2000, 2001, 2004c). The more engaging and interactive the VR environment is, the more effective is the pain reduction. Overall, the more engaged and distracted patients are, the less they will feel their pain.

Sensory loss, different temperature and blood flow asymmetries between stroke and non- stroke arms are well known clinical problems after stroke. Spinothalamic functions (cold, warmth, pinprick) are most commonly impacted, albeit the impact is characterized by individual variability. As noted earlier, sensory

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abnormalities have been reported in patients post-stroke. For example, skin temperature is usually lower in the contralesional side in patients with stroke, thus sensation of cold on this side are probably influenced by this baseline temperature and thus account for side to side differences (Naver, 1995). It is believed that cold VR environments may reduce pain perception from warm stimuli, while warm environments may reduce pain perception from cold stimuli. Muhlberger (2007) tested young healthy females but found no difference in the type of virtual environment used for distraction (cold or warm) and no interaction with type of pain stimulus provided (warm or cold), and both environments reduced pain perception equally.

The use of immersive VR for post stroke chronic pain has not been previously tested. In addition, it is not clear whether different VRs have a differential effect on pain thresholds, and whether this effect is related to the interesting and engaging characteristic of the VR. This is an important question given that pain is known to be aggravated by heat and cold in (real) environments. The primary objective of this study was to determine whether different virtual environments had a differential effect on experimental pain threshold in stroke patients with moderate to severe persistent post-stroke pain. A secondary objective was to determine whether the patient's level of engagement or interest in the virtual environment influenced pain threshold. We hypothesized that all virtual environments would improve pain threshold compared to the control condition (no VR). We hypothesized that there would be a differential effect of virtual environments on experimental pain threshold based on their interesting and engaging characteristics.

2. METHOD

This study was part of a larger study, designed to determine the effects of different virtual reality environments, and type of stimulus on clinical and experimental pain perception and walking performance in thirty six individuals with stroke, with pain (n=12) and without pain (n=12) in comparison to an age and gender matched healthy cohort (n=12). The current paper is focused on the subjects with stroke and pain.

2.1 *Participants*

A convenience sample of 12 stroke patients with central post-stroke pain (> 2 on a 0 - 10 Numerical Rating Scale) in their upper limb were recruited for this part of study (see table 1). The study procedures were explained to all subjects and an informed consent was signed prior to participation.

Table 1. *Subjects Characteristics (n=12)*

Patients (Stroke & pain)	Age (years)	Gender	Stroke arm	Pain intensity (VAS)[1]	Pain affect (VAS)[1]	Mood (VAS)[1]	MPQ (PPI)[2]	MPQ (PRI)[3]	Years after stroke
Summary data	X± sd 61±7.2	M (n):7 F(n) :5	R (n):7 L (n):5	3.45 ± 1.4*	4.02 ± 1.9*	5.81± 1.5*	2.58 ± .9*	9.3 ± 3.6*	4.08 ± 2.5*

Gender (M: male, F: female)
Stroke arm (R: right, L: left)
[1]VAS: Visual Analog Scale: (0-10)
[2]MPQ: (PPI): McGill Pain Questionnaire (Present Pain Intensity): 0-5
[3]MPQ (PRI): McGill Pain Questionnaire (Pain Rating Index): 0-20 words
* X± SD (mean ± standard deviation)

2.2 *Materials and Equipment*

2.2.1 Quantitative Sensory Testing. QST was done using the method of limits standard test protocol and the NeuroSensory Analyzer Model TSA-II (MEDOC Ltd., Ramat Yishai, Israel) on the painful and contralateral, pain-free forearm in counterbalanced order to assess pain perception to thermal hot and cold stimuli. The TSA-II uses a 30mmX30mm thermode which was placed on the skin of the patients' forearm. Thermal stimuli were delivered by 15 brief (700ms) taps of stimuli via the thermode. Rate of temperature changes were between 0.3 ºC/ sec and 4.0 ºC/ sec. Temperatures between 36 - 47°C were used for hot stimuli and 30 ºC with a rate decrease of 1º C/sec and an automatic safety lower limit of 4.5ºC for the cold stimuli. In the methods of limits, stimuli (hot or cold) increased in intensity to a specific temperature for less than 1 second and then immediately returned to neutral temperature, in preparation for the next stimulus. Six clusters of stimuli were given, with up to six stimuli in each cluster, so a mean was taken in order to derive the pain threshold. Interval between stimuli started from stimulus end to onset of next stimulus which lasted 6 seconds.

Figure 1. *Quantitative Sensory Testing device showing contact thermode (http://www.medoc-web.com).*

Figure 2. *Experimental set up. Note position of contact thermode for QST under forearm, computer mouse controls temperature changes.*

2.2.2 Virtual Reality Environments. The VR computer was equipped with the ultra-high end NVIDIA Quadro FX 4500 graphics card (512 MB of high-speed GDDR3memory). Each VE was presented through a head mounted display (HMD) (Kaiser Optical Systems, Ann Arbor, MI, USA). An ICUBE head-tracking system allowed for looking in any direction and at different parts of the virtual environments. The VE conditions (Figure 3) were randomly presented. They were as follows: 1) “Snow World” (cold) which has snowy mountain canyon scenes (Hoffman, 2004b), 2) Dante’s Canyon (hot) is a modification of “Snow World. It has hot volcanic scenes, 3) Neutral is comprised of alternating white pillars on a black background (Powell, 2006), and 4) No VE.

(A) *(B)* *(C)*

Figure 3. *Virtual environments used for experiment: (A) Snow World; (B) Dante’s Canyon world; (C) Neutral VE (alternating white pillars on a black background).*

2.3 Measures

2.3.1 Pain Threshold. During each VR condition, three hot stimuli and three cold stimuli were delivered via thermode on the participant’s arm. Stimuli (hot or cold) gradually increased or decreased in temperature. After receiving the hot or cold stimulus, participants clicked the mouse as soon as the feeling changed from hot to just painfully hot or from cold to just painfully cold. By clicking the mouse, the thermode temperature immediately returned to neutral temperature and the pain threshold was recorded. The procedure was repeated six times on the patient’s arm area (three hot and three cold stimuli). The mean pain threshold was calculated and used for analysis.

2.3.2. Engagement. After the VR exposure, subjects rated each VR condition on the basis of 0-100 Numerical Rating Scale of interest and engagement. Zero represented not at all engaging (i.e. boring) and 100 represented extremely engaging.

2.3.3 Mood. Since emotions, such as mood, influence the affective component of pain in chronic pain patients (Fernandez & Milburn 1994; Wade et al 1990), to control the effects of these confounding variables on patients’ pain perception subjects were presented to a 10 cm visual analog scales (VAS) anchored with 0 (extremely bad) and 10 (extremely good) with a mid-point of 5 labeled neutral to assess how were the mood of patients prior to the start of the experiment.

2.3.4 Clinical Pain Intensity

After the VR exposure, subjects rated each VR condition on the basis of 0-10 Numerical Rating Scale of pain perception intensity. Zero represented no pain at all and 10 represented worst pain imaginable.

2.4 Procedures

After obtaining information about subject characteristics of demographics, medical and pain history, the study procedures were explained and an informed consent obtained. The experiments took place in a quiet air-conditioned environment in which the ambient temperature was stable and comfortable (22°C). Participants were exposed to each VR in random order and QST was carried out. Each testing of the VR conditions was completed in approximately 3-5 minutes, and subjects were allowed to rest between each condition. Pain threshold judgments were obtained while subjects viewed the VEs, engagement judgments were obtained after each VE exposure.

2.5 Data Analyses

Summary descriptive statistics were computed and compared for all subjects to establish group homogeneity. Data of pain threshold were analyzed with two-way repeated-measures of ANOVA containing the within-subject factors (VR environments and type of stimulus) using SPSS software, version 15 ($p<0.05$) to analyze the significance of the main effect of VR condition and type of stimulus on pain threshold. To analyze the difference of engagement rating among different virtual conditions one way repeated-measures of ANOVA was used and Tukey HSD was used for post hoc analyses as appropriate.

3. RESULTS

Given that several asymmetries in sensory loss and temperature perception (cold, warmth) between stroke and non- stroke arms may exist, data of pain thresholds for the stroke and non-stroke arm of each subject were averaged separately for hot and cold stimuli and for each VR condition.

3.1 Pain Threshold (Stroke arm)

For the stroke arm in patients with stroke and pain, and with a hot stimulus, all VR environments increased pain threshold in comparison to no VR condition ($F_{3,\ 1} = 2.7$, $p<.05$). Dante's canyon (hot condition) was most effective ($F_{3,\ 1} = 9.08$, $p< .05$). In contrast, and with a cold stimulus, no VR environments reduced pain threshold ($F_{3,\ 1} = .6$, $p>.05$). In addition, visual analysis of the graph of each stroke subject with pain showed when the stimulus was 'hot' pain threshold was most stable across all VR conditions, whereas when the stimulus was cold, pain threshold showed less stability.

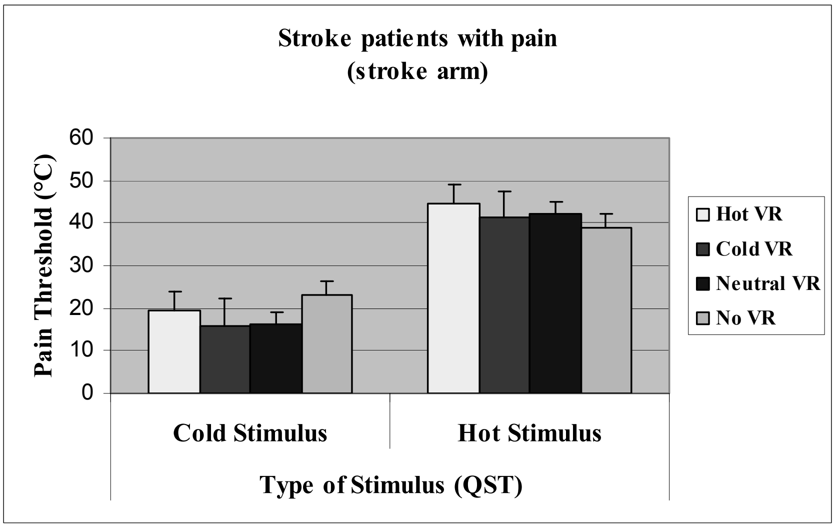

Figure 4. *Mean pain threshold of the cold and hot pain stimuli of the stroke arm of patients with pain during presentation of the virtual worlds.*

3.2 Pain Threshold (Non-stroke arm)

For the non-stroke arm, there was no significant or differential effect of VR condition on pain threshold to hot or cold stimuli ($F_{3,\ 1}$ = 1.73, p> .05) (see table 2). Preliminary analysis showed a trend that Neutral environment resulted in increased pain threshold to both hot and cold stimuli.

Table 2. *Data of pain threshold for the non-stroke arm and stroke arm in stroke patients with pain were averaged separately for hot and cold stimuli and for each VR condition.*

	Stroke with pain (n=12)			
	Non- stroke arm		**Stroke arm**	
	Stimulus		***Stimulus***	
Virtual Environments	***Cold***	***Hot***	***Cold***	***Hot***
Hot (Dante's canyon)	20.14±4.8	49.02±4.9	19.6±5.4	44.5±5.8
Cold (Snow world)	19.84±7.9	47.36±9.1	15.73±8.1	41.2±8.2
Neutral (White pillars)	24.46±5.2	55.27±5.5	16.4±5.8	42.3±5.02
No VR (Control condition)	23.59±7.3	52.36±8.1	23.2±8.5	39.03±7.2

*Values are mean ± SE

3.3 Engagement

One way repeated-measures of ANOVA was used to analyze engagement ratings across VR conditions. VR engagement was significant across stroke patients with pain ($F_{8,\ 3}$ =17.39, p<0.05). All VRs were more engaging than the control (no VR) condition. Dante's Canyon was the most engaging VR environment, whereas the Neutral condition was least engaging (see table 3). Further, there was a strong and direct correlation between engagement rating of each virtual condition and pain threshold (r = .68; P=0.015).

Table 3. *Descriptive statistics for engagement rating.*

Subjects (n=12)	Engage. Rate **Hot** (0-100)	Engage. Rate **Cold** (0-100)	Engage. Rate **Neutral** (0-100)	Engage. Rate **No VR** (0-100)
Stroke with pain	81.25 ± 5.06	70.83 ± 4.48	66.25 ± 7.72	32.33 ± 8.22

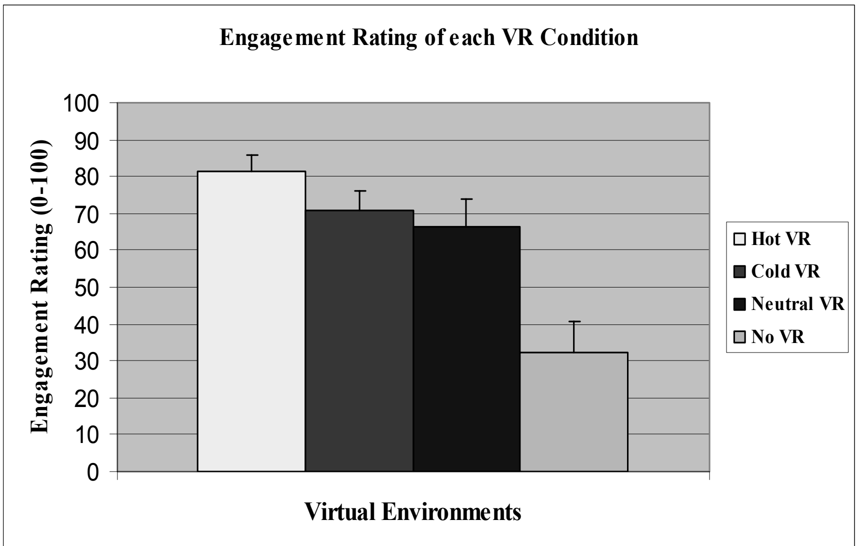

Figure 5. *Mean engagement rating of the stroke patients with pain during presentation of each virtual environment.*

3.4 Clinical Pain Ratings

One way repeated-measures of ANOVA to analyze pain ratings across VR conditions (table 4) showed a significant effect of VR condition ($F_{6,\ 3}$ = 11.67, p< .05,). Among VR environments, both Hot (Dante's Canyon World), and Cold (Snow World) conditions were equally effective ($F_{6,\ 3}$ =12, 13.89, p = 0.01 respectively), whereas Neutral condition was the least effective ($F_{6,\ 3}$ = .25, p= 0.87).

Table 4. *Descriptive statistics for clinical pain rating*

Subjects (n=10)	Clinical pain **Hot VR** (0-10)	Clinical pain **Cold VR** (0-10)	Clinical pain **Neutral VR** (0-10)	Clinical pain **No VR** (0-10)
Stroke with pain	1.75± 1.05	1.75± 1.13	3.83± 2.24	3.75 ± 2.37

3.5 Mood

Correlation between pain threshold and mood was moderate to strong (r range .35 to .75).

4. DISCUSSION

This study compared the relative effectiveness of different VR conditions on pain threshold to thermal (hot and cold) pain stimuli in stroke patients with pain. In line with our hypotheses, the results indicated that all VR conditions increased pain threshold compared to the control condition (no VR). In addition, virtual reality appeared to differentially influence experimental pain threshold to both hot and cold stimuli in patients with stroke and pain. Dante's canyon (Hot environment) was the most effective environment in increasing pain threshold to both hot and cold stimuli when tested on the stroke arm. On the other hand, when tested on the non- stroke arm the Neutral environment was most effective. It is possible that this is due to the oft described mesmerizing effect of the Neutral environment. Certainly, the differential effect between arms is indicative of sensory abnormalities post-stroke. Not surprisingly, all VR conditions were more engaging than the control condition and reduced pain ratings. There was a direct correlation between pain threshold and patients' mood. This is important because it supports the idea that increasing or decreasing mood can modify pain responses in chronic illness, and reflects the importance of using VR in rehabilitation. It is possible that VR may reduce pain in part through its effect on mood. Clearly further investigation is needed.

It is generally acknowledged that cold or warm pressor pain differs from clinical pain in terms of perceived controllability (subjects can stop an experimental test at any time) and in terms of the level of anxiety associated with clinical pain. In the present study, subjects with stroke and with pain reported a significant increase in their experimental pain threshold and a significant decrease in their clinical pain perception during VR exposure, which is consistent with previous reports in subjects using an experimental pain paradigm and acute pain (Hoffman, 2004b, 2004c). It is an important finding because it shows that VR distraction not only increases pain threshold (experimental pain), but also decreases clinical pain.

The results are also generally consistent with those of Muhlberger (2007) who showed the pain perception was reduced in both hot and cold virtual environments compared to the control condition. Muhlberger (2007) also indicated that hot stimuli were always perceived as less painful than cold stimuli, regardless of which VR condition was presented. This is in the line of the results of the present study which showed when the stimulus was hot patients showed a higher pain threshold (less pain perception) in all VR conditions. It is possible that the novelty of the VR environment and helmet as well as the unfamiliar sensations associated with the system may have had an unanticipated effect of initially drawing the patients' attention away from the thermal stimuli.

Not surprisingly, there was a strong and direct correlation between engagement rating and pain threshold which means the more engaged patients were, the less pain they felt. This is in the line of the results of Hoffman et al (2001) that showed highly engaging VR environments are effective in pain reduction. Engagement involves active attention to a stimulus and thus less attentional capacity is available for attending to pain. Active attention (i.e. primary attention due to preference) to a non-pain auditory or visual stimulus (e.g. VR) is known to be a more effective and a longer lasting strategy that passive distraction (i.e. attending to a non-pain stimulus – not out of interest but as an attempt to distract from pain). Thus making VR environments engaging is a potentially important consideration, relative to their use in pain management.

It is generally acknowledged that mood modifies pain in a predictable direction (Walters & Williamson, 1999; Zautra, Burleson, Matt, Roth, & Burrows, 1994). Both experimental and correlational evidence from this study suggests a direct association between mood states and subsequent changes in pain threshold as depressed mood altered pain responses in the expected direction. This is contrary to the results of the study by Edens and Gil (1995) who indicated that negative emotional factors such as depressed mood can increase the severity of chronic in both laboratory and clinical settings. However, this was not conducted in the context of the attentional capacity of VR, nor in the post-stroke pain population.

The small sample size in this study limits the generalizability of VR analgesic efficacy to larger populations of stroke patients. Individual differences and personal characteristics such as degree of ability to concentrate and immerse in VR environment may also mediate the effectiveness of VR. In addition, interactivity of VR environments may influence effectiveness. It is also known that factors such as rate of change of stimulus temperature, reaction time, and method of measurement of psychophysical thresholds significantly influence the measure of the threshold value (Yarnitsky and Ochoa, 1990). The method of limits, as routinely used for threshold determination through the QST, does include reaction time in the measurement, leading to artefactual elevation of thresholds (Fruhstorfer et al. 1976), and sensation of heat-induced pain (Yarnitsky and Ochoa, 1990). Thresholds obtained by this method are therefore bound to be of higher value than those obtained by the method of levels. Although that may influence the magnitude of response it is unlikely to influence the overall results.

5. CONCLUSION

The purpose of this study was to determine whether different virtual environments had a differential effect on experimental pain threshold in stroke patients with moderate to severe persistent post-stroke pain, as well as to determine whether the patient's level of engagement or interest in the virtual environment influenced pain threshold. The main findings were that virtual reality appeared to differentially influence experimental pain threshold to hot and cold stimuli in patients with stroke and pain, with Dante's canyon was considered as the most effective environment. In addition, all VR conditions were more engaging than no VR control. Again Dante's canyon was the most engaging. For perceived pain ratings, both Hot (Dante's Canyon World), and Cold (Snow World) conditions were equally effective. More research is needed on whether people with chronic pain from different conditions respond similarly. Further research is needed to identify the aspects of VR that can enhance effectiveness and increase patients' engagement. Understanding the interaction between individual subject characteristics, (e.g. age, gender, interests, and preferences) and specific VR environments may help tailor treatments more effectively.

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6. REFERENCES

American Stroke Association, (2008), http://www.sacred-heart.org/pressbox/default.asp.

D Bowsher (2001), Stroke and central post-stroke pain in an elderly population, *The Journal of Pain, 2,* 5: 258 – 261.

Canadian Stroke Network (CSN), (2006), Evidence-based Review of Stroke Rehabilitation, (http://www.ebrsr.com).

J L Edens and K G Gil (1995), Experimental induction of pain: Utility in the study of clinical pain, *Behavior Therapy, 26* (2): 197-216.)

E Fernandez and T W Milburn (1994), Sensory and affective predictors of overall pain and emotions associated with affective pain, *Clinical Journal of Pain* 10:3-9.

H Fruhstorfer, U Lindblom and W C Schmidt (1976), Method for quantitative estimation of thermal thresholds in patients, *Journal of Neurology, Neurosurgery, and Psychiatry, 39:* 1071-1075.

H G Hoffman, D R Patterson and G J Carrougher (2000), Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: A controlled study, *The Clinical Journal of Pain, 16,* 244–250.

H G Hoffman, D R Patterson, G J Carrougher and S Sharar (2001), The effectiveness of virtual reality based pain control with multiple treatments, *Clinical Journal of Pain, 17,* 229-235.

H G Hoffman, T L Richards, B Coda, A R Bills, D Blough, A L Richards et al (2004a), Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI, *Neuroreport, 15,* 1245-1248.

H G Hoffman (2004b), Virtual-reality therapy, *Scientific American*, *291*, 58-65.

H G Hoffman, D R Patterson, J Magula, G J Carrougher, K Zeltzer, S Dagadakis et al (2004c), Water-friendly virtual reality pain control during wound care, *J Clin Psychol 60,* 189- 195.

K D McCaul and J M Malott, (1984), Distraction and coping with pain, *Psychol Bull, 95*: 515–533.

A Muhlberger, M Wieser and B Wiederhold (2007), Pain modulation during drives through cold and hot virtual environments, *Cyberpsychology & Behavior, 10* (4), 516- 522.

H Naver, C Blomstrand, S Ekholm and C Jensen (1995), Autonomic and Thermal Sensory Symptoms and Dysfunction after Stroke, *Stroke,* 26:1379-1385.

W Powell, S Hand, B Stevens and M Simmonds (2006), Optic flow in a virtual environment: influencing speed of locomotion, *CyberPsychology & Behaviour, 9*(6), 710-710.

S J Swierzewski (2007), Stroke, http://www.neurologychannel.com/stroke/index.shtml

R W Teasell (2006), *Stroke, 37*: 766.

J B Wade, D D Price, R M Hamer, S M Schwartz and R P Hart (1990), An emotional Component analysis of chronic pain, *Pain* 40:303-310.

A S Walters and G M Williamson (1999), The role of activity restriction in the association between pain and depression: A study of pediatric patients with chronic pain, *Children's Health Care*, *28,* 33 –50.

C Wickens (2002), "Multiple resources and performance prediction", *Theoretical Issues in Ergonomics Science*, 3(2): 150-177.

D Yarnitsky and J L Ochoa (1990), Studies of heat pain sensation in man: perception thresholds, rate of stimulus rise and reaction time, *Pain,* 40, 85-91.

A J Zautra, M H Burleson, K S Matt, S Roth and L Burrows (1994), Interpersonal stress, depression, and disease activity in rheumatoid arthritis and osteoarthritis patients, *Health Psychology*, *13,* 139 –148.