Effects of Videogame Distraction using a Virtual Reality Type Head-Mounted Display Helmet on Cold Pressor Pain in Children

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Objective   To test whether a head-mounted display helmet enhances the effectiveness of videogame distraction for children experiencing cold pressor pain.   **Method**   Forty-one children, aged 6–14 years, underwent one or two baseline cold pressor trials followed by two distraction trials in which they played the same videogame with and without the helmet in counterbalanced order. Pain threshold (elapsed time until the child reported pain) and pain tolerance (total time the child kept the hand submerged in the cold water) were measured for each cold pressor trial.   **Results**   Both distraction conditions resulted in improved pain tolerance relative to baseline. Older children appeared to experience additional benefits from using the helmet, whereas younger children benefited equally from both conditions. The findings suggest that virtual reality technology can enhance the effects of distraction for some children. Research is needed to identify the characteristics of children for whom this technology is best suited.

Key words   children; distraction; pain; virtual reality.

A number of recent distraction interventions for acute pain in children and adolescents have employed virtual reality (VR) technology in conjunction with either a passive distraction stimulus, such as a movie (Sullivan, Schneider, Musselman, Dummett, & Gardiner, 2000), or an interactive distraction activity, such as a computer game (Dahlquist et al., 2007). However, the actual benefit of VR technology over and above the benefits of the distracting stimulus that is experienced through the VR equipment has not been adequately tested in children. Thus, it is unclear whether the use of VR technology, which can be very expensive, is cost-effective. The present study systematically tests whether distraction is enhanced by the use of a VR-type head-mounted display (HMD) helmet for children undergoing cold pressor pain.

According to McCaul and Malott (1984), distraction reduces pain perception because one must attend to the pain stimulus in order to perceive pain and experience associated distress. Given that an individuals' attentional capacity is finite, a distracting task that requires a great deal of the person's attentional resources should leave little attentional capacity available for processing painful stimuli. Moreover, multiple resource theory suggests that attentional resources within the different sensory systems function relatively independently; an activity that involves one sensory modality may not deplete the attentional resources in another sensory modality (Wickens, 2002). Thus, highly engaging and interactive distraction activities that involve multiple sensory systems are likely to be more effective than more passive distractors or distractors that involve only one or two sensory systems.

If these theoretical assumptions are accurate, videogames should be very effective distractors for children. Videogames engage multiple sensory systems. They provide vivid visual and auditory stimulation and typically require close attention to visual cues in order to execute various tasks. They also engage tactile and kinesthetic senses as the individual plays the game. Indeed, the limited research available suggests that both hand-held, interactive electronic toys (Dahlquist, Busby et al., 2002; Dahlquist, Pendley, Landthrip, Jones, & Steuber, 2002; Mason, Johnson, & Woolley, 1999; Pringle et al., 2001)

and videogames (Kolko & Rickard-Figueroa, 1985) can substantially reduce the distress children experience during acutely uncomfortable medical procedures.

Playing a videogame that is displayed through a VR helmet adds a sensory blocking component to the multi-sensory engagement intrinsic to videogames. VR helmets typically display visual stimuli on a screen ~2–3 in. in front of the individual's eyes, while obscuring the individual's external lateral visual field. VR helmets often also include integrated headphones, which serve to at least partially block external auditory stimuli.

Studies of VR technology-assisted distraction for acute pain management have primarily involved adults and small samples of older adolescents. The pioneering work conducted by Hoffman, Patterson and colleagues (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000; Hoffman, Patterson, & Carrougher, 2000; Hoffman, Patterson, Carrougher, & Sharar, 2001; Hoffman et al., 2004) demonstrated that young adults and older adolescents undergoing burn debridement reported less pain when provided distraction via immersive VR software and VR helmets equipped with tracking devices that change the visual field in response to head movement. Using similar VR equipment (i.e., a HMD with a tracking device that controlled the movement of a character in a 3D game and a hand-held trigger device that fired a gun), Steele et al. (2003) obtained reductions in self-reported pain in a 16-year-old boy with cerebral palsy undergoing painful physical therapy.

Although the available research is limited, VR distraction also has been shown to be superior to other forms of distraction. In a study of two adults undergoing painful dental procedures, Hoffman, Garcia-Palacios et al. (2001) demonstrated that VR technology used in combination with an immersive virtual environment (i.e., Snowworld, Imprint Interactive Technology, Seattle, WA, USA) resulted in lower subjective pain ratings during painful dental procedures than watching a Movie (Casablanca) without VR technology. Hoffman (2004) also found that immersive VR distraction using Spiderworld (Imprint Interactive Technology) resulted in lower subjective pain ratings in two adolescents undergoing wound care for severe burns compared to trials in which they played Mario Kart® or Wave Race® on a Nintendo® (Nintendo Company, Ltd., Kyoto, Japan) without the addition of any virtual reality technology. However, the degree to which the virtual reality technology itself versus the Spiderworld or Snowworld software or some other aspect of the VR distraction experience accounted for the improved pain experiences of the participants in these two studies cannot be determined.

The magnitude of the effects of VR technology assisted distraction with younger children has been variable, due in part to small sample sizes and differences in distraction methodology (Wismeijer & Vingerhoets, 2005). For example, Wolitzky, Fivush, Zimand, Hodges, and Rothbaum (2005) used a HMD helmet and joystick to present an interactive Virtual Gorilla environment (Allison, Wills, Bowman, Wineman, & Hodges, 1997) to 20, 7- to 14-year-old children with cancer. Children who participated in the interactive VR condition showed significantly lower overt distress ($d = 1.9$), reported experiencing less distress, and had lower pulse rates during a subcutaneous port access than did children assigned to a no-VR control condition.

Comparably strong effects also have been demonstrated with experimentally induced pain. In a study of 46 healthy children undergoing cold pressor exposure, 5- to 13-year-old participants demonstrated significant increases in pain tolerance ($f = .50$) when distracted by videogame play presented via a HMD helmet (Dahlquist et al., 2007).

However, Gold, Kim, Kant, Joseph, and Rizzo (2006) only obtained lower child ratings of "worry and bother related to pain" (p. 208) in a study of 20, 8- to 12-year-old children who played a VR game ("Street Luge," 5DT, Irvine, CA, USA) via a HMD helmet with a head-tracker and headphones and a rumble pad (for tactile feedback), while having an intravenous needle placed. None of the nurse, parent, and child ratings of pain intensity were affected by the intervention. Given that only 10 children received the VR distraction intervention, it is difficult to determine if these findings are idiosyncratic or if there was something about the VR equipment or software that limited the effects.

The limited research available suggests that the nature of the distracting stimulus can affect treatment outcome. When VR technology has been used to provide a passive, rather than interactive, distraction stimulus, the resulting reductions in children's pain have been less impressive. Wint, Eshelman, Steele, and Guzzetta (2002), for example, reported only a modest trend for lower self-reported pain during lumbar punctures in a study of 30 adolescents who viewed a 3D movie through a VR visor than in adolescents who received standard care. In a direct test of interactive versus passive distraction via VR technology, Dahlquist et al. (2007) obtained significantly greater improvements in pain tolerance when children

used a VR helmet and actively played a videogame compared to when they merely used the VR helmet to watch videogame footage generated by another person playing the same videogame.

The only study to date to that specifically tested the benefits of using a VR helmet versus playing the same videogame without a VR helmet for acute pain in children was inconclusive. Gershon, Zimand, Pickering, Rothbaum, and Hodges (2004) used the same VR equipment and the Virtual Gorilla environment employed by Wolitzky et al. (2005) with 59 7-to 19-year-old patients receiving port access for chemotherapy. Children who used the VR helmet and software did have lower pulse rates than children who did not receive any distraction, but did not differ from the children who interacted with the Virtual Gorilla environment on the computer without a VR helmet. Moreover, the three experimental groups did not differ with respect to pulse rate, nurse ratings of how much pain the child experienced during the procedure, or experimenter ratings of observed pain behaviors. However, their failure to demonstrate stronger effects for the VR helmet condition may have been partially due to ceiling effects. The children in their study reported low levels of pain and anxiety at baseline [visual analog scale (VAS) scores ranged from 0 to 30 on a 100-point scale]; thus, the potential for improvement was limited.

The present study examined the utility of using a VR HMD helmet with children experiencing experimentally induced cold pressor pain. Using each subject as his/her own control, the visual and auditory nature of the distraction activity was held constant, and the use of the HMD helmet was experimentally manipulated. Children were expected to demonstrate improvements in pain threshold and pain tolerance relative to baseline during both distraction conditions (with and without the helmet). Improvements were expected to be greatest when the children used the VR helmet.

The present study also examined whether individual child factors such as age and anxiety level would affect children's responses to distraction. A number of studies have documented that younger children (i.e., under the age of 7 or 8 years) tend to show more overt distress than older children during painful medical procedures (Carlson, Broome & Vessey, 2000; Fanurik, Koh, & Schmitz, 2000; Jay, Elliott, Katz, & Siegel, 1987). Although few studies have considered age as a moderator of pain management intervention, there is some indication in the literature that age can affect the child's response to some interventions, with younger

children demonstrating poorer responses to distraction (Fowler-Kerry & Lander, 1987; MacLaren & Cohen, 2005; Manne, Bakeman, Jacobsen, Gorfinkle, & Redd, 1994) and to cognitive–behavioral coping strategies (Dahlquist, 1999).

The child's age also can influence the type of pain management intervention that is likely to be optimally effective. Piira, Hayes, Goodenough, and vonBaeyer (2006) found that children aged 7–9 years benefited more from a distracting imagery intervention than from a sensate-focusing intervention during a cold pressor task. In contrast, children aged 10–14 years responded equally well to both interventions.

Based on the literature, we predicted that the child's age would moderate the effectiveness of interactive distraction, with older children showing the greatest benefit from the distraction intervention. In addition, we conducted exploratory analyses to examine whether the age of the child would differentially affect the child's responses to the use of a VR helmet during distraction.

An extensive adult literature demonstrates that negative emotional states such as anxiety and depression can increase the severity of chronic and acute pain in both laboratory and clinical settings (Edens & Gil, 1995). Although fewer studies have been conducted with children, emerging evidence suggests similar relations. For example, Tsao, Myers, and Craske (2004) found that ratings of anticipatory anxiety regarding an impending experimental pain task accounted for about 35% of the variance in 8- to 18-year-old girls' reports of pain intensity across thermal, cold pressor, and pressure pain tasks. Task-specific anxiety also was significantly correlated with thermal pain tolerance scores, accounting for 10% of the variance. Other investigators have noted that children with very high levels of baseline distress sometimes do not respond well to distraction (Manne et al., 1994). In light of these findings, we conducted exploratory examinations of task-specific and general anxiety in relation to children's baseline pain tolerance and pain threshold and also as possible moderators of children's responses to interactive distraction. More anxious children were expected to demonstrate poorer pain tolerance. In keeping with Jeffs' (2007) finding that lower state anxiety was associated with greater engagement with a self-selected distractor (i.e., music, books-on-tape, and movies) for adolescents aged 11–17 years undergoing allergy testing, we also predicted that lower self-reported anxiety would be associated with greater improvements in response to both of the interactive distraction conditions.

Method

Participants

Participants were recruited from a suburban community and from a university summer day camp via flyers. Forty-nine children and their parents agreed to participate. Two children subsequently were unable to participate due to scheduling difficulties. One child was excluded from analyses because the baseline pain tolerance exceeded the 4 min study limit. Five additional children were excluded from analyses because their pain tolerance exceeded the 4 min study limit during both intervention trials, thus making it impossible to identify differential responses to the two experimental conditions. Of the final sample of 41 children, 60% ($n = 25$) were female. The ages of participants ranged from 6 to 14 years, with a mean age of 9.9 ($SD = 1.93$). Twenty-five participants (61%) were Caucasian, 14 (34%) were African American, 1 (2%) was biracial, and 1 (2%) was Asian/Pacific Islander. Children for whom exposure to cold temperatures is contra-indicated (e.g., Raynaud's disease, sickle-cell disease), with known mental retardation, hearing or vision impairments, vestibular difficulties, and motor disability that would interfere with using the VR equipment were not eligible to participate in this study, although none of the children who volunteered met any of these criteria.

Design

All participants underwent a baseline cold pressor trial followed by two cold pressor trials in which distraction with the VR helmet (distraction + helmet) and distraction without the VR helmet (distraction-only) were presented in counterbalanced order. During the distraction + helmet condition, participants used a joystick to play a video-game displayed through a 3D HMD helmet with integrated headphones. During the distraction-only condition, participants used a joystick to play the same videogame displayed on a computer screen. The visual and auditory stimuli presented in both conditions were identical. Only the use of the VR helmet varied across the two distraction conditions. To allow for the examination of the effects of repeated exposure and possible habituation to the cold pressor, a subgroup of participants ($n = 14$) underwent a second baseline cold pressor trial before participating in the two distraction conditions in counterbalanced order. Children were stratified by age and gender and randomly assigned to one of the following orders of experimental intervention using the urn randomization method described by Wei and Lachin (1988): (a) single trial baseline, distraction-only first; (b) single trial baseline, distraction + helmet first;

(c) two-trial baseline, distraction-only first; and (d) two-trial baseline, distraction + helmet first. Elapsed time until the child reported pain (pain threshold) and total time the child kept his/her hand in the cold water (pain tolerance) were measured in each cold pressor trial.

Materials and Equipment

Cold Pressor Apparatus

A Thermo Electron Corporation (Newington, NH, USA) Neslab RTE17 refrigerated bath circulator ($60.0 \times 28.9 \times 47.9\,cm^3$) was used as the cold pressor. The unit was set to maintain the water temperature at $5°C$ ($\pm 0.1°C$). In pilot testing, this water temperature elicited a range of pain tolerance scores with only minimal ceiling effects. Warmer water temperatures have been reported to cause greater problems with ceiling effects. For example, 93% of 10- to 14-year-old subjects demonstrated ceiling effects (tolerated the full 4 min) at a water temperature of $10°C$ (Goodman & McGrath, 2003). Similar ceiling effects using warmer water have been reported by other investigators (Miller, Barr, & Young, 1994; Piira, Taplin, Goodenough, & von Baeyer, 2002).

Thermal Feedback System

A Bio-feedback Systems, Inc. (Boulder, CO, USA) Thermal Feedback System (Model DT-100; Power ID-91) was used to measure hand temperature at baseline and between each trial, in order to ensure that the child's hand temperature at the start of each trial was comparable.

Virtual Reality Equipment

An adjustable HMD helmet with integrated headphones was used in this study. Manufactured by Interactive Imaging Systems, Inc. (Irvine, CA, USA), the VFX3D Interactive Personal Display System was connected to a Dell Dimension 8400 desktop computer. Upon connection, the videogame could be viewed through the HMD. The stereoscopic 360,000 pixel color display was projected through the goggles, which were adjusted to the individual's inter-ocular distance in order to reduce eye strain. Auditory effects of the game were delivered via headphones built into the HMD. Smaller children or children with very short hair occasionally preferred to wear a soft stocking cap under the helmet for comfort.

Videogame Equipment

A Dell (Round Rock, TX, USA) Dimension 8400 desktop computer with a Radeon X850XT, Platinum Edition video card and a Dell 19 in. flat screen monitor

(1024 × 768 resolution) with integrated 7.1 channel audio speakers was used to generate the videogame. The monitor was placed ∼3 feet from the child. A Logitech (Freemont, CA, USA) Freedom 2.4 cordless joystick was utilized so that children could manipulate the joystick with one hand while the other hand was in the cold water. A prototype version of the videogame Free Dive© (Breakaway Games Limited, Hunt Valley, MD, USA) that had not yet been commercially released, and therefore was novel for all participants, was utilized as the interactive distraction activity. Free Dive provided an 800 × 600 resolution, 360° 3D underwater virtual environment in which the participant scuba dives with sea turtles and tropical fish while searching for treasure chests. Auditory stimulation provided through computer or helmet headphone speakers mimicked the sounds of breathing through scuba equipment.

Measures

Parent Ratings of Child Anxiety

The State-Trait Anxiety Inventory for Children: Parent Report, Trait Version (STAIC-P-T; Strauss, 1987) was used to obtain a general estimate of child trait anxiety. This 26-item parent report measure has been shown to have high internal consistency (α's >.72) and concurrent validity with the Child Behavior Checklist (CBCL) anxiety/depression, withdrawal, and somatic complaints scales (Southam-Gerow, Flannery-Schroeder, & Kendall, 2003). Possible raw scores range from 26 to 78.

Child Anxiety Self-report

The Revised Children's Manifest Anxiety Scale (RCMAS; Reynolds & Richmond, 1978) is a 37-item self report measure used to assess anxiety in children and adolescents (28 items measure anxiety and contribute to a total anxiety score, whereas nine items measure social desirability). Scores are standardized for the child's age and ethnicity. T-scores of 60 are considered clinically elevated. The scale has been found to have a four-factor structure composed of three anxiety factors (worry–oversensitivity, physiological anxiety, and social concerns–concentration) and a social desirability factor labeled *Lie* (Reynolds & Paget, 1983; Reynolds & Richmond, 1979). RCMAS scores correlate with other child anxiety measures, such as the State-Trait Anxiety Inventory for Children (STAIC; Spielberger, Edwards, Montuori, & Lushene, 1973) ($r = .85$). The RCMAS also has been shown to have good test–retest reliability, with total anxiety scores correlating .68 after a 9-month period (Reynolds, 1981).

Prebaseline Self-reported Anxiety

A 100 mm VAS anchored "not at all worried or nervous" and "very worried or nervous" was used to assess how anxious the children were feeling prior to the start of the first cold pressor trial. Similar VAS scales have been shown to be valid indices of state anxiety in children within the study age range, correlating significantly with other anxiety measures and showing sensitivity to changes in affective state following psychological treatment (Cohen, Blount, Cohen, & Johnson, 2004; Tsao, Lu, Kim, & Zeltzer, 2006).

Poststudy Questionnaire

Qualitative data were collected to determine whether the participants noticed external visual or auditory stimuli while wearing the helmet and playing the game. Participants were asked the following open-ended questions after completing both distraction trials: "What kind of noise (other than what was in the game) did you hear while you were playing Free Dive?" "What other things did you see (other than the game) while you were playing Free Dive?"

Procedure

This study was approved by the university Institutional Review Board. Informed consent was obtained from the parent at the time of recruitment. Assent was obtained from child participants prior to conducting experimental procedures.

The experiment was conducted in a 4.88 m × 3.66 m carpeted laboratory room that was maintained at a temperature between 21°C and 22°C. The child participant and two graduate or undergraduate student experimenters were present. The following procedures were followed for each cold pressor trial. The child was seated with the nondominant arm next to the cold pressor apparatus. The temperature sensor was taped to the index finger of the child's nondominant hand. After a 1 min adaptation period, the child's finger temperature was measured.

Before the first trial the experimenter told the child that the water would be cold and that after a while his/her hand would start to feel uncomfortable or hurt. The child was instructed to say, "It hurts now" when his/her hand began to feel uncomfortable or hurt, and to remove the hand from the water when it became too uncomfortable or hurt too much. Children were given the option to discontinue the study at any time [e.g., if the child experienced any symptoms of motion sickness/simulator sickness that are sometimes associated with VR (Schultheis, Himelstein, & Rizzo, 2002)].

Participants were asked to repeat the instructions before each trial to make sure they understood that the trial could be terminated at any time without any negative repercussions. None of the participants asked to stop the experiment. No motion sickness symptoms were reported.

The child was seated so that the child's nondominant arm could be comfortably extended downward at his/her side with the hand placed in the circulating water bath to wrist level. Timing began as soon as the participant's hand was submerged to wrist level and ended when the hand was removed. The time at which the child said, ''It hurts now'' was used as the measure of pain threshold. The total time the hand was submerged was used as the measure of pain tolerance. At the end of the trial, the child's hand was placed in a warm water bath (32°C) for ~5 min, and warmed to within 1°C of the baseline temperature.

During the baseline trial, participants were informed that the experimenter would need to test how well their body liked cold temperatures before playing the video game by placing their hand in cold water. The experimenter read the instructions described earlier to the child and then placed his/her hand in the cold water circulator.

Before the first distraction trial, the experimenter explained the Free Dive game. The participant was instructed to try to find five treasure chests hidden at the bottom of the ocean and to take pictures of each treasure chest to make it open. The experimenter then modeled the correct use of the joystick, and ensured that the child understood how to operate the joystick, take pictures, and open treasure chests by allowing him/her to play the game for 30 s before the first experimental trial.

During the distraction + helmet condition, the participant was told that he/she would be playing Free Dive while wearing a VR helmet and using a cordless joystick, while his/her nondominant hand was placed in the cold water. The child was told that he/she would see the video game through the viewer in the helmet and hear the game through the earphones in the helmet and that the game would end when the child removed the hand from the water. The experimenter placed a surgical cap on the child's head for hygienic purposes. The VR helmet was then placed on the child's head and the game was started. After 30 s of play to allow the child to become engaged in the game, the child's nondominant hand was placed in the water. All other procedures were the same as baseline.

During the distraction only condition, the participant was told that he/she would be playing Free Dive while viewing the game on the computer screen and hearing the game through the computer speakers, while his/her nondominant hand was placed in the cold water. The participant was told that the game would end when the participant removed the hand from the water. After 30 s of playing the game, the participant's nondominant hand was placed in the water. All other procedures were the same as in the distraction + helmet condition.

After all trials were completed, the child received a $5.00 Blockbuster Gift card and was allowed to pick a prize from a bag of trinkets valued under $2.00 apiece. Prizes included items such as key chains, pens, and bracelets.

Results
Preliminary Analyses

Descriptive Analyses
Baseline pain threshold scores ranged from 1 to 45 s, with an overall mean of 16.31 s ($SD = 10.50$). Baseline pain tolerance scores ranged from 4.93 to 57 s, with an overall mean of 24.30 s ($SD = 14.30$). Younger children (age 10 and under) demonstrated significantly lower baseline pain tolerance ($M = 20.32$, $SD = 13.48$) than older children ($M = 30.11$, $SD = 13.77$) ($t = 2.21$, $p < .05$). Parent-reported child trait anxiety (STAIC-P-T) scores ranged from 28 to 61 ($M = 36.26$, $SD = 6.83$). Child RCMAS t-scores ranged from 28 to 63 ($M = 44.74$, $SD = 9.45$). Child-reported pre-trial VAS anxiety ratings ranged from 0 to 98 ($M = 24.79$, $SD = 26.53$). One-way analyses of variance (ANOVAs) revealed no significant differences in child age, baseline child-reported anxiety, parent-reported child anxiety, baseline pain tolerance, or baseline pain threshold between children who received the distraction + helmet intervention first, those who received it second, or those who underwent two baseline trials, all p's $>.10$.

Habituation
Participants who underwent two baseline trials showed no evidence of habituation to the cold pressor task. Their pain threshold scores did not change significantly from Trial 1 to Trial 2 ($M = 19.05$, $SD = 7.86$ vs. $M = 17.87$, $SD = 7.84$, $p = .34$). Similarly, their pain tolerance scores showed no significant change from Trial 1 to Trial 2 ($M = 25.26$, $SD = 9.20$ vs. $M = 24.21$, $SD = 13.98$, $p = .73$).

Order Effects

Prior to conducting within-subject analyses, independent t-tests were conducted to determine whether the order in which children participated in the experimental conditions affected their scores. Neither pain threshold nor pain tolerance scores differed as a result of order of participation in the experimental conditions (all p's >.23). Therefore, data were collapsed across the two orders of presentation for the subsequent within-subjects analyses.

Relative Effectiveness of Distraction with and Without the HMD Helmet

The children's performance during the last baseline trial (Trial 1 for single baseline subjects; Trial 2 for two-baseline subjects) was then compared with their performance during videogame distraction with and without the VR helmet. Children were divided into two groups: Younger (i.e., between the ages of 6 and 10; $n = 24$) and Older (i.e., between the ages of 11 and 14; $n = 17$). (Although approximately equal numbers of older and younger children were recruited, older children were more likely to reach the ceiling of 240 s and were therefore more likely to be excluded from the analyses.) Separate 2 × 3 (age by experimental condition) repeated measures ANOVAs were conducted on pain threshold scores and pain tolerance scores across the three experimental conditions (baseline, distraction + helmet, distraction-only) in order to examine the relative effects of distraction with and without the VR helmet.

Results revealed a significant main effect for experimental condition, $F(2,78) = 7.84$, $p < .001$, $f = .62$, and a significant age by experimental condition interaction effect for pain tolerance, $F(2,78) = 3.82$, $p < .05$, $f = .43$. According to the guidelines set forth by Cohen (1992), the effect sizes for both of these analyses are large. As can be seen in Fig. 1, although the pain tolerance scores of both young and old children improved during both of the distraction conditions, the older children appeared to benefit much more from the VR technology than did the younger children, demonstrating significantly higher pain tolerance while using the HMD helmet ($M = 70.08$, $SD = 71.22$) than the younger children did ($M = 31.74$, $SD = 40.36$; $t = 2.193$, $p < .05$). In contrast, the pain tolerance scores of the two age groups did not differ during the distraction-only condition in which they played the VR game but did not wear the helmet ($M = 41.12$ vs. $M = 45.10$, $p > .30$. Relative to their baseline scores, both age groups demonstrated a significant increase in pain tolerance during the distraction-only condition ($t = 2.308$, $p < .05$).
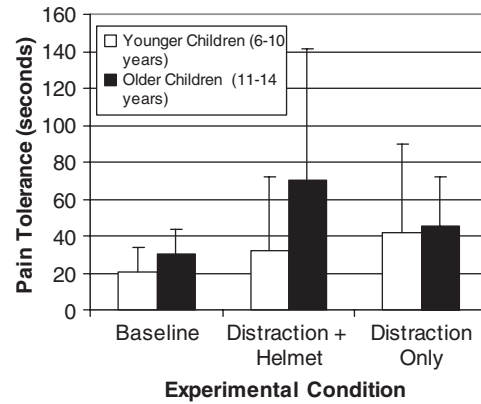

Figure 1. Estimated means and standard deviations for pain tolerance scores across experimental conditions.

For pain threshold, there was a significant main effect for experimental condition, $[F(2,64) = 16.95$, $p < .001$, $f = .91]$. The magnitude of this effect is large (Cohen, 1992). Post hoc analyses indicated that pain threshold was significantly greater during both the distraction + helmet condition ($M = 23.27$, $SD = 15.22$, $t = 4.446$, $p < .001$) and the distraction-only condition ($M = 28.14$, $SD = 20.27$, $t = 4.690$, $p < .001$) when compared to baseline ($M = 16.31$, $SD = 10.50$). Pain threshold during the distraction-only condition was significantly higher than in the distraction + helmet condition ($t = 2.683$, $p < .01$). There were no significant age or age by experimental condition effects ($p > .10$).

Exploratory Anxiety Analyses

Contrary to expectation, none of the parent or child anxiety measures was significantly related to baseline pain tolerance or pain threshold scores. The relation between baseline pain tolerance and children's report of anxiety specific to the cold pressor task was in the expected direction ($r = -.30$), but did not reach significance ($p = .06$). Three separate 2 × 3 (anxiety by experimental condition) repeated measures ANOVAs were conducted to explore the relations between scores on the three child anxiety measures and children's responses to the experimental interventions. However, none of the resulting anxiety by condition interactions was significant ($p > .40$). Neither parent-report of child trait anxiety (STAIC-P-T), child-reported trait anxiety (RCMAS), nor child-reported pre-trial state anxiety (VAS) significantly moderated children's responses to the experimental conditions.

Qualitative Analysis

Twenty-seven participants (65%) reported that they did not see anything other than the game when wearing the

helmet; 26 participants (63%) reported that they did not hear anything other than the game when wearing the helmet. The remaining 35–37% of participants reported seeing one or two of the following visual stimuli: the cold pressor machine, the wall, the joystick, a desk, their hand, wires, the computer, people, pants, papers, and boxes. They reported hearing one or two of the following auditory stimuli: the cold pressor machine, people talking, beeping, and the joystick moving.

Discussion

When compared to their performance during baseline, the children in this study demonstrated significantly higher pain thresholds and greater pain tolerance when engaged in interactive distraction. This finding cannot be explained by mere habituation to the cold pressor pain stimulus; the children who were exposed to repeated cold pressor trials without distraction did not improve. The present results are consistent with previous studies with children (Dahlquist et al., 2007) in which interactive distraction has been shown to improve pain threshold and pain tolerance in the laboratory. Interactive distraction via videogames appears to be an effective intervention for children experiencing short-term, acute cold pressor pain.

Contrary to expectation, the addition of the VR helmet did not appear to uniformly enhance children's pain tolerance. Although both age groups benefited from the interactive distraction without VR technology, only the older children (over the age of 10) demonstrated greater improvement while engaging in distraction and wearing the VR helmet compared with distraction without the helmet. This finding is consistent with the limited empirical literature that suggests that developmental differences may moderate children's responses to acute pain interventions (Kleiber & Harper, 1999; Piira et al., 2002). To our knowledge, this is the first study to identify possible developmental differences in children's responses to VR interventions for acute pain.

The more positive response of the older children to the helmet may have been due, in part, to the fact that the VR helmets available at the time of this study were all designed for adults. Although we attempted to accommodate the size of the child's head by adding a soft stocking cap for smaller children, the helmet still may not have been optimally comfortable. In addition, the integrated earpieces may not have fit as tightly and thus may not have blocked or transmitted sound as effectively for some of the younger children.

It is also possible that the novelty of the helmet and the unfamiliar sensations associated with it may have had an unanticipated effect of initially drawing the children's attention away from the videogame. Since older children are likely to have better attention regulation abilities than younger children (Smith, Kemler, & Arnonfreed, 1975), they may have been able to more quickly or more effectively redirect their attention away from the novel sensory stimuli of the helmet itself and engage more fully in the videogame.

Finally, it is important to note that VR technology is very new and constantly evolving. There are dozens of HMDs on the market, ranging in price from $350 for simple visors without integrated headphones to around $40,000 for very high-quality units. The quality of the equipment available at the time of this study that was within our $5000 budget and was likely be comfortable for children to wear was very limited. The HMD screen of the helmet we used was slightly less vivid than the TV screen. Thus, the helmet may not have provided as engaging visual images as the TV screen. This limitation may have offset the benefits of sensory blocking in the younger children. As demonstrated by Hoffman et al. (2006), in a study of 77 adults undergoing experimentally induced thermal heat pain, more adults reported clinically significant decreases in pain intensity, pain unpleasantness, and time spent thinking about pain when they used a virtual reality helmet that had a larger field of view and a clearer picture than adults who used a VR helmet with a smaller field of view and a poorer picture. Further research is needed to determine how crucial the technical quality of the VR helmet is for children of different ages.

The use of the VR helmet did not appear to improve pain threshold in this sample of children. Instead, pain threshold was 5 s longer in the distraction-only condition than in the distraction + helmet condition. However, these findings should be interpreted with caution, since seven (17%) of the children in the study forgot to report the onset of pain during at least one trial, despite being reminded to report pain onset before each trial. Further study is needed to replicate this finding and determine whether distraction using VR technology has less of an impact on the initial perception of pain and more of an impact on children's ability to tolerate pain.

Interactive distraction has the potential to be a very effective acute pain intervention for children. However, the present study findings suggest that simply adding ''high tech'' equipment to a distraction task will not necessarily make the intervention more effective. Moreover, findings obtained with one type of equipment

may not generalize to another type of VR equipment. Further study is needed to identify the aspects of technology that can enhance the effectiveness of interventions and to identify the individual characteristics of the children who will benefit the most from such technological advancements.

Further research also is needed to determine whether the present findings generalize to acute clinical pain. As noted by Dahlquist et al. (2007), cold pressor pain differs from clinical pain in terms of perceived controllability (children can stop an experimental procedure at any time) and in terms of the level of anxiety that is likely to associated with the pain stimulus and the clinical environment. The majority of the children in the present study reported relatively low levels of anxiety regarding the impending cold pressor trial, which may explain why child anxiety did not appear to differentially affect their responses to the distraction intervention. Using HMDs to deliver interactive distraction interventions may prove to offer even more powerful enhancement of the effects of distraction in the stressful and more stimulating clinical environment.

The clinical applicability of the present findings also is limited by the fact that children underwent only one cold pressor trial while using the VR helmet. Studies of children undergoing multiple exposures to painful stimuli are needed in order to rule out the possibility that the effectiveness of VR-assisted distraction is primarily a novelty effect, and to document whether VR distraction remains effective over time.

Acknowledgments

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