Videogame Distraction using Virtual Reality Technology for Children Experiencing Cold Pressor Pain: The Role of Cognitive Processing

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Objective This study examined whether increasing the demand for central cognitive processing involved in a distraction task, by involving the child in ongoing, effortful interaction with the distraction stimulus, would increase children’s tolerance for cold pressor pain. Methods Seventy-nine children ages 6–15 years underwent a baseline cold pressor trial followed by two cold pressor trials in which they received interactive distraction (i.e., used voice commands to play a videogame) or passive distraction (in which they merely watched the output from the same videogame segment) in counterbalanced order. Both distraction conditions were presented via a virtual reality-type helmet. Results As expected, children demonstrated significant improvement in pain tolerance during distraction relative to baseline. Children showed the greatest improvement during the interactive distraction task. Conclusion The effects of distraction on children’s cold pressor pain tolerance are significantly enhanced when the distraction task also includes greater demands for central cognitive processing.

Key words acute pain; children; cold pressor; distraction; virtual reality.

Introduction

Distraction is a pain management technique that has been shown to successfully reduce pain and behavioral distress in children undergoing invasive medical procedures. There are relatively limited data available regarding the specific characteristics of distraction tasks that will result in optimal pain management outcomes. As a result, there is little guidance for clinicians and other health care providers in selecting distraction tasks that will have the greatest potential to reduce children’s distress. Drawing on conceptual models of attention and pain, the current study examined the role of central cognitive processing in enhancing the effects of distraction for children experiencing acute pain.

Conceptual Models of Attention and Pain

Capacity Model of Attention

McCaul and Malott (1984) proposed two major principles behind the potential for distraction to reduce pain: (a) pain perception requires controlled processing such that one must actively attend to the painful stimulus in order for it to cause distress and (b) attention capacity is limited. A reduction in distress will occur if the distracting task takes away enough of one’s attention resources from the painful stimulus (McCaul & Malott, 1984). This premise is consistent with the capacity model of attention, which assumes that there is a limited, general supply of attention resources that can be allocated to one or more tasks at any given time; when the demands of two activities exceed the
Multiple Resource Model of Attention

According to the multiple resource model of attention proposed by Wickens (1984, 2007), there are relatively independent resources for the processing of sensory information, such that two tasks demanding the same sensory modality will result in a greater decrement in performance on one or both tasks compared to two tasks demanding different levels of that dimension (e.g., one visual perception task and one auditory perception task). Thus, distraction tasks that utilize the same sensory attentional resources as the pain stimulus should interrupt pain perception most effectively.

Cognitive-Affective and Neurocognitive Models of Attention and Pain

Eccleston (1995a) and Eccleston & Crombez (1999) argued that capacity and resource models alone do not adequately explain the powerful way in which pain interrupts behavior or the conditions under which attention can be directed away from pain. Eccleston and Crombez (1999) proposed that pain is part of a complex motivational system that affects human action. In their cognitive-affective model, pain is “evolutionarily disposed to interrupt attention,” emerge as the focus of attention, and become the most pressing motivation for action as it signals harm and motivates escape (p. 361). More recently, theorists have referred to this involuntary, unintentional capture of attention as “bottom up” selection (i.e., neurocognitive model; Legrain et al., 2009).

Because pain processing demands central attentional resources, Eccleston (1995a) argued that the process of deselecting or distracting from pain must also engage central cognitive resources—that is, the “supervisory central attentional system” (p. 401). Legrain et al. (2009) describe this voluntary redirection of attention as an intentional, goal-directed, “top down” process that is activated in working memory and modulates pain perception through the effortful direction of attention to primary goals (rather than pain) (p. 230).

Tasks that do not involve the intentional and effortful applications of attentional control, therefore, would not be expected to compete with the attentional resources used in pain processing. Furthermore, tasks that are more mundane or are repeated are likely to become increasingly automatic and ultimately require less central processing, thus making them less effective in competing with pain for limited central attentional resources (Eccleston, 1995a).

Finally, Eccleston and Crombez (1999) proposed that to be optimally effective, distraction should also take into account the affective nature of the pain experience. Tasks that elicit strong positive affect may compete with pain more effectively than neutral tasks (Eccleston & Crombez, 1999).

Implications for the Identification of Optimal Distraction Tasks

Many aspects of the cognitive-affective conceptual model of pain (Eccleston & Crombez, 1999) and neurocognitive, top-down models of attention to pain (e.g., Legrain et al., 2009) have significant implications for the identification of optimal distraction tasks for children. The notion that the distraction task should elicit affect that is incompatible with threat and fear, for example, is implicit in the pediatric distraction literature. The vast majority of studies employ distraction tasks that children would presumably find enjoyable, such as cartoons, videogames, and playing with developmentally appropriate toys (Powers, 1999), although the actual positive affect elicited by the various distraction tasks is rarely measured.

Passive versus Interactive Distraction

More importantly, the cognitive-affective and neurocognitive models would predict that distraction activities (such as playing a videogame) that require the child to actively engage with the distraction task and continuously utilize central attentional resources to selectively attend to the distraction stimulus in order to make some sort of non-routine cognitive decision should be much more effective than passive distraction activities that do not require the ongoing engagement of central attentional functions. Although a number of interactive distraction activities that could be argued to involve central attentional processes (Pillay, 2003) (e.g., videogames, interactive musical storybooks, interactive toy robots and educational electronic games) have been shown to be effective distractors for children in acute pain settings (Powers, 1999), only a few studies directly test the premise that such interactive distraction tasks are superior to passive distraction (e.g., Dahlquist et al., 2007; MacLaren & Cohen, 2005; Mason, Johnson, & Woolley, 1999). Moreover, the conclusions that can be drawn from some of the studies that compare interactive and passive distraction are limited by methodological confounds. For example, the passive distraction task of watching a cartoon has been compared to interactive distraction involving playing with an interactive musical story book (Mason et al., 1999) or handheld...
electronic toy (MacLaren & Cohen, 2005). However, these passive and interactive distraction tasks vary on many dimensions in addition to the dimension of interest—that is, whether the task was interactive.

Dahlquist et al. (2007) avoided such confounds in a study of passive and interactive distraction delivered via virtual reality (VR) technology. They provided elementary school-aged children identical visual and auditory stimuli (i.e., the same segment of a videogame) in two distraction trials and varied only whether or not the child was allowed to play the videogame (interactive distraction) versus watch the game. Both the passive and interactive distraction conditions resulted in significant increases in pain tolerance compared to a no-distraction control trial, but as the cognitive-affective and neurocognitive models would predict, interactive distraction was significantly more effective than passive distraction.

**Current Study**

Although the Dahlquist et al. (2007) findings are consistent with the cognitive-affective and neurocognitive models, it is also possible that the superior effect of their interactive distraction intervention was solely due to the fact that the interactive distraction condition involved the tactile and kinesthetic sensations involved in manipulating a joystick rather than the activation of central attentional processing. The current study attempted to rule out this alternate hypothesis and replicate the findings of Dahlquist et al. (2007) with an interactive distraction task that did not include a tactile/kinesthetic component, thus coming closer to isolating the relative benefits of engaging central cognitive attentional processes via interactive distraction for children experiencing acute pain. The primary aim of the present study was to compare the effectiveness of a passive distraction task with an interactive distraction task that involved identical visual and auditory stimuli but required greater attentional load—that is, ongoing utilization of central attentional resources.

We elected to use VR technology (i.e., a head mounted display helmet with integrated headphones) to deliver the distraction stimuli in a manner similar to the approach used by Dahlquist et al. (2007) for several reasons in addition to the desire to replicate and expand on their findings. First, children in past studies have expressed considerable interest and enjoyment when using the VR headset. Secondly, the VR helmet limits peripheral views of the experimental setting and muffles external sounds, thus helping attenuate unintended distractions extraneous to the experimental distraction tasks and establish a consistent experimental environment across subjects. Finally, VR technology has been used in a number of recent clinical interventions with a variety of pediatric populations including burn patients (e.g., Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000), children undergoing IV placement (e.g., Gold, Kim, Kant, Joseph, & Rizzo, 2006), and children with cancer undergoing portacatheter access (e.g., Gershon, Zimand, Pickering, Rothbaum, & Hodges, 2004) as well as with children undergoing the cold pressor task in a laboratory setting (Dahlquist et al., 2009, in press) (see reviews by Mahrer & Gold, 2009, and Wismeijer & Vingerhoets, 2005). We were interested in contributing to a better understanding of distraction applications that utilize this relatively new technology.

**Age Differences in Response to Distraction**

Emerging research suggests that age may predict children’s responses to pain management interventions (Dahlquist et al., 2009; Piira, Hayes, Goodenough, & von Baeyer, 2006; MacLaren & Cohen, 2005). In addition, research suggests that a fundamental reorganization of attentional and executive processes occurs between 1.5 and 5 years and then again between 5 and 10 years (e.g., Case, 1992). Anderson (2002) argues that attentional control (i.e., inhibition, selective attention, monitoring) develops rapidly during early childhood; cognitive flexibility (i.e., divided attention, working memory), goal setting (i.e., initiation, planning, organization), and information processing (i.e., efficiency, fluency, processing speed) improves greatly between 7 and 9 years and is relatively mature by 12 years. Therefore, secondary analyses were conducted to examine the relation between age and response to the distraction interventions used in this study.

**Materials and Methods**

**Participants**

**Recruitment**

Participants were recruited from a suburban community via flyers posted at local libraries and from a university summer day camp serving children of university and local community employees. Children for whom cold water exposure was contraindicated (e.g., sickle cell disease, Raynaud’s disease), had severe vision or hearing impairment, parent-reported mental retardation, or impaired receptive language ability on screening (i.e., Peabody Picture Vocabulary Test-III; Dunn & Dunn, 1997) that would have interfered with their ability to use the VR equipment, understand study instructions, and/or meet the verbal demands of the interactive distraction intervention were not eligible for study enrollment. However, none of the children who volunteered for this study met any of these exclusion criteria.
Informed Consent
This study was approved by the university institutional review board. During recruitment, parents and children were given information about the study, including procedures, risks, and benefits. Parents provided written consent prior to their child’s participation. The informed consent form was reviewed with all children, and written assent was obtained from children age 7 and older. All children were told that they could stop participating in the study at any time without any negative consequences, and a research assistant (RA) ensured each child understood this concept before proceeding with the study.

Sample Characteristics
Eighty-nine children and their parents agreed to participate. In total, ten children were excluded from study analyses. One child declined to participate prior to the first cold pressor trial. One child did not follow study directions (i.e., did not keep his hand submerged in the cold water). Two children were excluded because the VR equipment malfunctioned; three were excluded because they met the 4-min cold pressor pain tolerance ceiling at baseline; three children were excluded because they met the 4-min ceiling during both distraction trials, thereby making comparisons between the two treatments impossible.

Of the final sample of 79 children, 52% (n = 41) were male. Participants ranged in age from 6 to 15 years, with a mean age of 8.91 (SD = 2.04). Ethnic representation was as follows: 38 (48%) Caucasian, 25 (32%) African American, 1 (1%) Hispanic, 3 (4%) Asian/Pacific Islander, 7 (9%) biracial, and 1 (1%) “Other.” Ethnicity was not reported for 4 participants. PPVT-III scores were available for 78 participants, and ranged from 80 to 138 with a mean of 110 (SD = 12.34).

Design
All participants underwent a baseline cold pressor trial in which they wore the VR helmet but did not receive distraction, followed by the two intervention cold pressor trials presented in counter-balanced order: (a) passive distraction, in which participants used the VR helmet to watch pre-recorded footage of the sounds and images that are generated when the videogame is played, and (b) interactive distraction, in which participants used the VR helmet to view the same segments of the videogame and also interacted with the videogame by directing the avatar’s movements in order to achieve game objectives.

A subset of participants (n = 31) underwent a second baseline trial in which they wore the VR helmet but did not receive any distraction. The use of a two-trial baseline allowed for assessment of potential habituation to the cold pressor task secondary to repeated exposure.

The urn randomization method described by Wei and Lachin (1988) was used to counter-balance the order in which participants received the two distraction conditions. Participants were stratified by age (6–9 years and 10–15 years) and gender and then randomized to one of the following groups: (a) single trial baseline, passive distraction first, (b) single trial baseline, interactive distraction first, (c) two-trial baseline, passive distraction first, or (d) two-trial baseline, interactive distraction first. Cold pressor pain tolerance was the primary outcome measure, and was defined as the length of time that participants kept their hand in the cold water. This within-subjects design allowed comparison of each participant’s last baseline trial to his/her performance during the two experimental conditions. We did not assess pain intensity in the present study because of concerns raised by Eccleston (1995b) that the intensity rating procedure would have a reactive influence on participants by drawing the participant’s attention to pain and would also interfere with distraction.

Equipment
Videogame Equipment
The Nintendo Wii™ (Kyoto, Japan) is a home videogame console that is operated by a wireless controller. The “Aqua Garden” level of the Nintendo Wii™ “Nights: Journey of Dreams”™ videogame was used as the distraction stimulus. “Aqua Garden” provides a third-person perspective in which the user can see the avatar, a character named “Nights,” whom the user guides through an underwater environment to earn points by collecting coins, passing through hoops, and catching birds.

A pediatric neuropsychologist who is an expert in the evaluation of executive functioning in children evaluated the central cognitive processes involved in playing the “Aqua Garden” game. He identified the following executive control processes: working memory (e.g., holding game instructions and goals in mind; remembering a successful or unsuccessful strategy for future reference, updating the knowledge base as new information is gained); initiation and strategic planning (e.g., deciding which way the avatar should move, planning ahead to avoid pitfalls, gain more points, etc.); response inhibition and selection (e.g., deciding between two competing goals, shifting attention to relevant game aspects while inhibiting numerous salient but irrelevant game stimuli in pursuit of goals); emotional control (e.g., managing frustration in the face of obstacles) (G. A. Gioia, personal communication, April 1, 2010). This analysis is congruent with studies that have shown that children utilize problem-solving, working
memory, and planning while playing videogames (Pillay, 2003).

**Virtual Reality Equipment**
A 5DT HMD 800-26 adjustable head-mounted display (HMD) helmet (Fifth Dimension Technologies; Irvine, CA) with a 3D stereoscopic 480,000 pixel color display and integrated headphones was connected to the Nintendo Wii™ game system. The game was viewed through the HMD; auditory effects were delivered via integrated headphones.

**Cold Pressor**
A Neslab RTE17 refrigerated bath circulator (60.0 × 28.9 × 47.9 cm) manufactured by Thermo Electron Corporation (Newington, NH) was used as the cold pressor. The unit was set to maintain the water temperature at 7°C (±0.1°C). Previous studies have indicated that a water temperature of 7°C (±0.1°C) elicits a range of pain tolerance scores with minimal ceiling effects (e.g., Dahlquist et al., 2009).

**Thermal Feedback System**
A Bio-feedback Systems, Inc. (Boulder, CO) Thermal Biofeedback System (Model DT-100; Power ID-91) was used to measure finger temperature at baseline and between each trial.

**Measures**
**Pain Tolerance**
Cold pressor pain tolerance was defined as the amount of time (in seconds) that participants kept their hand in the cold water.

**Qualitative Post-Trial Probes**
After each cold pressor trial, participants were asked whether they heard or saw anything (other than the videogame) while wearing the VR helmet.

**Procedure**
The study took place in a 4.88 m × 3.66 m carpeted room in a university research laboratory. To minimize unintended visual distractions, the room was dimly lit by a standing lamp and small table lamp. Since the VR helmet was open at the bottom, participants wore a black smock to cover their arms and legs to further control for any potential visual distractions. A white noise generator was placed inside the room to control for unintended auditory distractions. Participants wore a hairnet under the helmet for sanitary purposes.

The experimenters were graduate students in child clinical psychology or undergraduate students majoring in psychology. Only the child and two RAs were present during cold pressor trials. One RA was responsible for taking data and the other was responsible for reading instructions and manipulating the game via a joystick based on the child’s verbal commands in the interactive distraction condition.

The child was seated next to the cold pressor tank such that his/her non-dominant hand could be comfortably submerged in the cold water up to the wrist.

**Baseline**
After the temperature of the index finger of the child’s nondominant hand was measured, the experimenter read the following script (adapted from Dahlquist et al., 2009):

> In a minute, you will be asked to put your hand in the cold water. After a while, you will notice that your hand will start to feel uncomfortable or hurt. I am going to time how long you can keep your hand in the water. I want you to try to keep your hand in the water as long as you can, even after it starts to hurt. But, when the water becomes too uncomfortable or hurts too much, you should remove your hand from the water.

The experimenter probed the child’s understanding of these procedures by asking the following questions: “What are you going to do during the cold water test?” and, “When should you take your hand out of the water?” The child’s responses were documented on a record sheet, and any confusion or misunderstanding was addressed before continuing with study procedures.

The child then put on the VR helmet and submerged his/her non-dominant hand in the cold water up to the wrist. The length of time that participants kept their hand immersed in the cold water was recorded (i.e., pain tolerance). Participants were not allowed to keep their hand in the water for more than 4 min (i.e., the recommended ceiling for pediatric cold pressor studies; von Baeyer, Piira, Chambers, Trapanotto, & Zeltzer, 2005). After participants removed their hand from the water, the temperature of the index finger of their non-dominant hand was measured. Participants then placed their nondominant hand in a warm (approximately 35°C) water bath. The experimenter asked the post-trial questions about unintended auditory and visual stimuli while the child re-warmed the hand. The next cold pressor trial began once the child’s hand reached baseline temperature (±1°C).
Subsequent trials followed similar procedures: the child’s pre-trial finger temperature was recorded, instructions for removing the hand from the water were repeated, pain tolerance was recorded, the child’s hand was re-warmed, and post-trial qualitative questions were administered.

Passive Distraction
Participants were told that they would watch a videotape of what the videogame looked and sounded like. The video output was displayed through the VR helmet and integrated headphones. The child was told that the purpose of the game was to explore the underwater environment and earn points by collecting bubbles, passing through hoops, and catching birds. To ensure that the two distraction conditions provided equivalent pre-cold pressor exposure to the videogame, the child then put on the VR helmet and watched a practice video approximately 2 min in length that featured pre-recorded footage from the “Aqua Garden” game. Then the experimental trial began, and a second segment of pre-recorded footage generated by the “Aqua Garden” videogame was presented through the VR helmet. In keeping with the Dahlquist et al. (2007, 2009) methodology, after 15 s of watching the video, the experimenter placed the child’s hand in the cold water.

Interactive Distraction
Participants were told that they would play the VR game in a special way by using their voice instead of the joystick to control the character. Visual and auditory distraction stimuli were identical to those used in the passive distraction condition, in that participants played the same “Aqua Garden” game segment that was presented in the video footage for the passive distraction condition. The videogame output was displayed through the VR helmet and integrated headphones. The child was told that the purpose of the game was to explore the underwater environment and earn points by collecting bubbles, passing through hoops, and catching birds. The experimenter read the following script:

You will tell (name of RA) where you want “Nights” to move in the game. Be specific about where you want “Nights” to go. (Name of RA) will move “Nights” where you tell him to go. Just like when you play a videogame with a joystick, “Nights” might not move exactly where you want him to go on the first try. If that happens, just tell (name of RA) where you want “Nights” to go. “Nights” will stop moving if you do not constantly tell him where to go, so keep telling “Nights” what to do even if you have to repeat yourself.

The RA demonstrated how to play the game using voice commands, and participants practiced playing the game for 2 min. Pilot testing indicated that 2 min was sufficient time for participants to reliably manipulate relevant aspects of the game via verbal commands. If the child’s rate of commands during game play was slower than one command per second, the RA manipulating the controller froze the avatar in place until the child gave the next command. The RA did not verbally prompt the child to issue commands after the game started.

After the training period, the RA restarted the game and the experimental trial began. After 15 s of game play, the RA placed the child’s hand in the cold water and recorded pain tolerance. The RA also recorded the incidence of each verbal command given by the child during the trial as a rough estimate of the child’s active involvement with the game. At the end of study procedures, participants received a $10.00 Target® gift certificate and a small prize valued at less than $3.00. Parents of children from the community received a $20.00 Target® gift certificate to compensate for their time and travel expenses.

Data Analytic Plan
Data were first examined to determine whether the distributions violated fundamental assumptions underlying analysis of variance (ANOVA) and multiple regression. Appropriate transformations were conducted as necessary according to the guidelines of Tabachnick & Fidell (2001). Paired t-tests were used to compare pain tolerance from the first baseline trial to the second baseline trial. Order effects were examined in two separate 2 × 2 (order by trial) ANOVAs in which the last baseline trial (Trial 1 for single-baseline participants, Trial 2 for double-baseline participants) was compared with the respective distraction trial. Since no significant order effects were obtained, the data were collapsed across order for the primary within-subjects one-way ANOVA comparing the last baseline trial with the passive distraction and the interactive distraction trials. Chi-square analyses were conducted to determine whether the proportion of children who reported seeing or hearing extraneous stimuli differed between the distraction and baseline trials. Secondary regression analyses were conducted on change scores to examine the degree to which age was related to response to distraction.
Results

Preliminary Analyses

A priori Power Analysis
For the one-way within-subjects ANOVA comparing each participant’s last baseline trial with his/her pain tolerance score during the passive and interactive distraction trials, a priori power analysis indicated the following: 74 participants were needed to detect a small effect size ($f = .10$), 28 participants were needed to detect a medium effect size ($f = .25$), and 12 participants were needed to detect a large effect size ($f = .40$).

Transformations
The distributions of the pain tolerance scores for the three conditions (control, passive distraction, interactive distraction) demonstrated substantial positive skew and kurtosis (i.e., $z$-score $>1.64$; Tabachnick & Fidell, 2001). LOG-10 transformation of pain tolerance scores reduced the skew and kurtosis values to acceptable levels (i.e., nearest to zero, Tabachnick & Fidell, 2001). Accordingly, all statistical analyses were conducted on the LOG-10 transformed pain tolerance scores. To facilitate interpretation of the results, Figure 1 presents a graph of the raw pain tolerance scores.

Relative Efficacy of Passive Distraction versus Interactive Distraction

Habituation
Participants who underwent two baseline cold pressor trials did not demonstrate a significant change in pain tolerance scores from baseline Trial 1 ($M = 1.17, SD = .25$) to baseline Trial 2 ($M = 1.21, SD = .23$), $t(30) = 1.41, p = .17$. The mean difference in raw pain tolerance scores from baseline Trial 1 ($M = 17.45, SD = 9.21$) to baseline Trial 2 ($M = 18.73, SD = 11.23$) was $1.28$ s (see Figure 1).

Order Effects
Two $2 \times 2$ (Order $\times$ Trial) repeated measures analyses of variance (ANOVAs) were conducted to evaluate order effects. The main effect of order and the order $\times$ trial interaction effect were not significant for the passive distraction condition and the interactive distraction condition (all $p$’s $>.25$). Therefore, the single and two-trial baseline conditions were collapsed across order of presentation.

Within-Subjects Analysis
A within-subjects one-way ANOVA was conducted to compare each participant’s last baseline pain tolerance score with his/her pain tolerance score during the passive and interactive distraction trials. A priori power analysis indicated the following: 74 participants were needed to detect a small effect size ($f = .10$), 28 participants were needed to detect a medium effect size ($f = .25$), and 12 participants were needed to detect a large effect size ($f = .40$).

Figure 1. Medians and interquartile ranges for untransformed pain tolerance scores across experimental conditions. Note: Baseline 1 and Baseline 2 represent the subset of participants who underwent two baseline trials ($n = 31$). Last baseline represents the last baseline trial of all participants ($n = 79$) (i.e., Baseline 1 for single-baseline participants, Baseline 2 for double-baseline participants). Passive Distraction and Interactive Distraction represent pain tolerance scores during these conditions for all participants ($n = 79$).
score (Trial 1 for single baseline participants, Trial 2 for double baseline participants) with his/her pain tolerance during the two distraction conditions. Results indicated a significant main effect for experimental condition, $F(2, 156) = 68.66, p = .001, f = .97$. According to Cohen’s (1988) guidelines, this is considered a large effect size. Post hoc paired samples t-tests with Bonferroni correction were conducted to probe this effect. Children demonstrated the lowest pain tolerance scores at baseline ($M = 1.23, SD = .23$) compared to passive distraction ($M = 1.34, SD = .26$), $t(78) = 6.42, p = .001$, and interactive distraction ($M = 1.46, SD = .31$), $t(78) = 9.75, p = .001$. As predicted, children demonstrated significantly greater improvement in pain tolerance during interactive distraction compared to passive distraction, $t(78) = 6.85, p = .001$ (see Figure 1).

**Descriptive Analyses**

The number of verbal commands issued by participants during interactive distraction ranged from 2 to 244, with a mean of 18 commands ($SD = 31.19$). Number of commands issued was highly correlated with the pain tolerance scores, $r = .76, p = .01$.

**Secondary Analyses**

To determine whether age was related to changes in pain tolerance, age was regressed on passive distraction pain tolerance change scores and interactive distraction pain tolerance change scores. Results indicated that age was not a significant predictor of the magnitude of response to passive distraction, $\beta = .16, t(77) = 1.26, p > .05$. However, age was a significant predictor of the magnitude of change in pain tolerance in response to interactive distraction, $\beta = .23, t(77) = 1.98, p = .04$. Older children demonstrated a greater response to interactive distraction than younger children.

**Qualitative Analysis**

During the passive distraction trial, the proportion of children who reported seeing or hearing something other than the distraction stimulus (0 and 17%, respectively) was significantly lower than baseline (11% and 29%, respectively), $\chi^2(1, N = 63) = 12.36, p = .001$, and $\chi^2(1, N = 63) = 6.99, p = .008$, respectively. Results for the interactive distraction trial were similar: the proportion of children who reported seeing or hearing something other than the distraction stimulus (1% and 7%, respectively) was significantly lower than baseline, $\chi^2(1, N = 67) = 10.22, p = .001$, and $\chi^2(1, N = 67) = 23.51, p = .001$, respectively. Fewer children reported hearing external sounds during the interactive distraction trial compared with the passive distraction trial, $\chi^2(1, N = 67) = 7.08, p = .008$.

**Discussion**

This study tested whether increasing the demand for central cognitive processing would enhance the pain-attenuating effects of VR technology-assisted distraction. As predicted, children demonstrated significant improvements in pain tolerance when they were provided either passive or interactive distraction. However, increasing attentional load by engaging the child in ongoing interaction with the distractor resulted in superior improvements in pain tolerance. These findings are consistent with the Dahlquist et al. (2007) findings that interactive distraction is superior to passive distraction for children experiencing acute cold pressor pain.

The study findings also are consistent with recent conceptual models of the role of attention and pain that propose that pain automatically engages central attention resources (i.e., through bottom–up capture of attention) and that engaging central cognitive resources in a competing task (i.e., top–down control of attention) interferes with pain processing (Eccleston & Crombez, 1999; Legrain et al., 2009). Attention to cold pressor pain appeared to be disrupted by the central cognitive processing involved in playing the game and directing the game avatar’s movements, resulting in greater improvements in pain tolerance during interactive distraction compared with passive distraction that used identical auditory and visual stimuli but required minimal central cognitive processing.

The methodological refinements that were incorporated into the study design enhance confidence in the findings. First, we used the same visual and auditory stimuli in both distraction conditions, varying only the presence/absence of the cognitive engagement component. In doing so, we avoided the confounds inherent in using different tasks for passive and interactive distraction (e.g., MacLaren & Cohen, 2005; Mason et al., 1999). In addition, the interactive distraction task used in the study allowed us to increase the central attentional demands of the distraction task without adding additional tactile/kinesthetic sensory stimuli. To our knowledge, this is the first study to attempt to isolate the cognitive engagement aspect of videogame distraction from the motor/kinesthetic/tactile aspects involved in manipulating the controllers used in traditional videogame and VR applications.

Finally, secondary findings provide support for the study’s internal validity. The qualitative data collected after each trial suggest that the distraction tasks reduced...
children’s attention to other stimuli in the expected manner. Children reported seeing and hearing external stimuli when they wore the VR helmet but did not receive distraction. However, children reported noticing far fewer extraneous stimuli during distraction trials compared to baseline, and reported hearing the fewest external sounds during interactive distraction.

Moreover, pain tolerance scores during distraction showed greater improvement than resulted from simply being exposed to two cold pressor trials without any intervention. Therefore, it is unlikely that the beneficial effects of the two distraction interventions are due to simple habituation to the cold pressor task.

Developmental differences were evident in children’s responses to interactive distraction. Both older and younger children in this study demonstrated a significant improvement in pain tolerance scores during the two distraction conditions and experienced the greatest benefit from interactive distraction relative to passive distraction. However, older children demonstrated a greater magnitude of response to interactive distraction than the younger children. Further research is needed to determine whether age differences in response to distraction reflect developmental differences in the supervisory attentional system or other aspects of executive functioning that enhanced their ability to selectively attend to the goals of the videogame. On the other hand, it is possible that older children obtained greater benefit from the interactive distraction condition due to their more mature expressive language skills. Further research is needed to determine whether the effectiveness of the interactive distraction intervention evaluated in the present study is attenuated for younger children and children with expressive language impairments.

Limitations

Perhaps the greatest limitation of the present study is the lack of direct assessment of the specific cognitive processes involved in the interactive distraction task. Although detailed analysis of the videogame employed in this study suggests that a number of central executive control processes were involved in playing the game, we did not evaluate whether children actually engaged in any of these cognitive processes during the interactive distraction task. Future research that includes more direct assessment of the cognitive processes involved during interactive VR distraction tasks is needed. For example, it may be useful to replicate adult pain studies (e.g., Buhle & Wager, 2010) in which they employ distraction tasks that are known to require certain executive functions. In addition, although we measured involvement with the interactive distraction task in terms of the amount of verbalization made by the child in order to make sure that the children were actively involved in the task, we did not measure actual videogame performance (i.e., success with the task). Including children’s scores on the game in future studies may allow for possible evaluation of decrements in performance due to unsuccessful efforts to direct attention away from pain.

Finally, it is impossible to rule out the competing hypothesis that the efficacy of the interactive distraction task was due to the fact that children were required to speak, rather than the increased demands on central attentional processes. Future research should test whether the requirement of any speech at all impacts pain responses, or if speech must reflect central cognitive processes involved in interacting with the distraction task.

This is the first study, to our knowledge, to evaluate an interactive VR distraction intervention that did not involve joystick manipulation. Thus, comparisons that can be drawn between this study and existing research on VR distraction may be limited. However, the extent to which joystick manipulation is essential to the effectiveness of VR distraction is unknown. Current theory (e.g., Eccleston, 1995a; Eccleston & Crombez, 1999; Legrain et al., 2009) would suggest that the engagement of central attentional processes is more important than the engagement of tactile and kinesthetic senses, but that question remains to be tested empirically.

Finally, the degree to which the results of this laboratory pain paradigm will generalize to painful medical procedures in clinical settings is not known. More research is needed to determine the relative importance of engagement of central attentional processes in distraction interventions for children undergoing painful medical procedures in clinical settings. For example, future research could examine the feasibility and effectiveness of the hands-free interactive distraction intervention used in the present study for children who are not able to use traditional videogame controls (e.g., children with motor impairments, children undergoing burn wound care in a hydrotank, etc.).

Implications and Future Directions

Despite these limitations, this study adds to the relatively limited body of work attempting to identify the specific components of distraction tasks that enhance the efficacy of acute pain interventions for children. Ultimately, results from this line of research should aide clinicians and other health care providers in selecting distraction tasks with the greatest potential to ease or prevent children’s suffering during painful medical procedures.
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