The role of executive functioning in children's attentional pain control: An experimental analysis.

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INTRODUCTION

Distraction is an intuitive way of coping with pain and often used in children's pain management [55,65]. The existing reviews on the effectiveness of distraction in children generally report small to moderate positive effects in pain reduction [13,20,47,63,65,73]. However, results are heterogeneous and were collected using different pain measurement tools, research settings, and individuals delivering the distraction [13,63,73]. This may point to the role of moderating variables [24,47] in these effects. This study investigates the role of executive functioning as a moderator of distraction effectiveness in reducing pain.

Executive functioning refers to several cognitive functions (e.g., goal-shielding, attentional control, problem-solving, self-regulation) [41,42,45]. Research has identified three important executive functions: inhibition (i.e., the ability to inhibit dominant automatic or prepotent responses), task switching (i.e., the ability to shift between multiple tasks operations or mental sets), and working memory (i.e., updating and monitoring information on an ongoing basis) [28,42,54,60]. These functions share a small common variance but are generally considered unitary constructs [3,16,66,67,42,60].

Executive functioning involvement has been hypothesized as critical in distraction effectiveness [53,82]. It has been argued that distraction task engagement, and consequently, the effectiveness of distraction, increases in individuals with better task switching, inhibition and working memory skills. It is likely that these individuals have greater ability to (1) switch to the distraction task whenever pain interferes [22,23], (2) inhibit the predominant response of attending to the pain and resist distruption by pain

[30,61], and (3) maintain focus on distraction tasks and prioritize information in working memory relevant to ongoing tasks [17,18, 19,29]. Research investigating this hypothesis has mainly focused on the role of working memory [53], indicating that working memory minimizes the interference of goal-irrelevant distracters, and plays a role in visual, auditory and tactile attention [17,18,51]. Also, less pain is reported when distraction tasks requiring higher working memory engagement are used [8]. Research investigating the role of inhibition and task switching in attentional pain control is scarce. One preliminary study in university students has found a relationship between executive functioning and distraction task engagement, with particular support for the role of inhibition, but no relationship with distraction effectiveness was found [82]. As this was the only study using the current paradigm, we sought to explore this question in children. Research on the relationship between executive functioning and distraction effectiveness in children is, to our knowledge, non-existent. However, because of the large diversity in executive functioning at different ages [11,42], research in a pediatric population has the potential to facilitate the detection of effects of executive functioning on distraction task engagement and distraction effectiveness, and may therefore make an important contribution.

In this study, schoolchildren first performed general executive functioning tasks and subsequently performed a cold pressor test (CPT). Participants were randomly assigned to distraction or control groups. We hypothesized that executive functioning would moderate the relationship between group and distraction effectiveness, indicating that children with better executive functioning abilities would benefit more from distraction. Additionally, we explored the relationship between executive functioning and distraction task engagement.

METHOD

Participants

A total of 239 schoolchildren (9-19 years) from nine elementary and high schools in Ghent (Belgium) were invited to participate in a cold pressor experiment. Children were randomly recruited (by means of a computerized program) from a sample of 1015 schoolchildren, who participated in a large questionnaire study on pediatric pain, and consented to be re-contacted for experimental research [83]. Forty-eight declined to participate, mainly due to lack of interest or time. Eleven met one of the exclusion criteria, namely previous experience with the cold pressor task (N=2), heart conditions, cuts and sores on the hand to be immersed, chronic pain (N=3), epilepsy, developmental disorders (autism and ADHD) (N=2), color blindness (N=3), dyslexia or poor comprehension of the Dutch language (N=1). One hundred and eighty children remained (98% Caucasian), but due to scheduling problems and time constraints, only 174 actually participated (response rate 97%). Data from 12 children were excluded from further statistical analysis: Five participants did not endure the cold pressor task for 1 minute (control group: N=4, two girls, M_{age} =11.00 years, SD=0.82 years; distraction group: N=1 girl, 12 years), one participant made too many errors on the distraction task (3 SDs above the group error mean), two participants (both in the distraction group) reported not experiencing pain during the CPT, one participant reported having severe chronic pain at the time of testing despite previous screening, and three participants' trials were subject to technical problems. The remaining sample consisted of 162 children (control group: N=84, 40 girls, M_{age}=13.80, SD=2.68; distraction group: N=78, 42 girls, M_{age}=13.95, SD=2.55).

All children were Belgian and reported good health and psychological functioning. A minority of the sample reported minor medical problems (20%), in most cases allergies and asthma. Seventy-four percent of the children's parents were married or cohabiting. Sixty-nine percent of the mothers and sixty-three percent of the fathers were educated beyond the age of 18 years. Children and parents participated voluntarily and received reimbursement to cover transport costs (25-35 euro). Both provided a written informed consent (and assent where applicable) and were fully debriefed after the experiment. The experiment was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University.

Materials and measures

Sample characteristics

Socio-demographic characteristics of the child and parents (e.g., child's sex, age, psychological and physical health (open questions), education level, parents' current profession, family situation, etc.) were obtained by means of an ad hoc questionnaire, which was completed by the parents.

Pain experience (PPQ)

Children's pain experience prior to the experiment was assessed with six items based on the Varni-Thompson Pediatric Pain Questionnaire (PPQ; [79]). Children were asked to indicate whether they had experienced pain during the past two weeks (yes/no). Overall pain intensity (4-point scale: 0="a little bit" to 3="very much") and frequency (4-point scale: 0="once" to 3="all the time") were also assessed. Using an adapted visual/numeric analogue scale (VAS/NRS), children indicated the worst pain they experienced during the last two weeks (0="no pain" to 100="very much pain"). Further, participants were asked to indicate all pain locations on a manikin figure. Finally, participants were asked to indicate on the VAS/NRS (0="no pain" to 100="very much pain") the pain they experienced at the moment of testing.

Cold pressor task (CPT)

Children participated in a pain-inducing cold pressor task (CPT) [86]. The cold pressor apparatus was a metallic water container (type Techne B-26 with TE-10D, size 53 x 32 x 17cm). Inside the apparatus, a circulating water pump (type Techne Dip Cooler RU-200) was used to prevent heat formation around the immersed hand [86]. We used a fixed immersion paradigm (i.e., immersion during a fixed time interval), in which children immersed their hand for 1 minute, rather than a tolerance paradigm (i.e., immersion until the pain can no longer be tolerated). Tolerance paradigms are less useful in experiments with youth participant groups that encompass a broad age range, as younger children tend to tolerate the cold pressor task for a shorter period of time than do older children [43], and the pain experience may be confounded by variance in immersion duration [23]. By using a fixed immersion interval, each participant experienced the same physical stimulation conditions. The water temperature was kept constant at 12°C. Previous research has revealed that this temperature and 1 minute immersion duration creates a painful stimulus of moderate pain intensity and is suitable for investigating distraction effects [81,82]. A highly intense pain stimulus was considered undesirable in this experiment as distraction is argued to fail for high intense pain [24].

To standardize the hand temperature, children were asked to immerse their hand in a container filled with water of room temperature (21°C) (type Julabo TW20, size 56 x 35 x 32cm) prior to cold water immersion.

Distraction task

The distraction task used was the Random Interval Repetition task (RIR; [76,77]). This well validated tone-detection task has been shown to be highly attention-demanding [76,77] and successfully used as a distraction task in previous research [32,74,82] in older populations. In the present study, children were instructed to respond as quickly as possible to tones (tone duration=150ms; tone pitch=750Hz, total task duration=1min) generated by a computer (ASUS L2000). Responses were given by means of a button pressing device. In this experiment, we used an adaptation of the original RIR-task. In the original task, tones are presented at stimulus-stimulus interval, with a randomly chosen inter-stimulus-interval of 900 or 1500ms. Younger children, however, may need more time to respond to the tones compared to older children, leaving them with less time to prepare cognitively for the next tone. Therefore, we presented the tones at stimulus-response interval (i.e., the next tone is presented at a random stimulus interval of 900 or 1500ms after responding to the previous one). By giving everyone an equal amount of time to prepare for the next tone, we made the task equally difficult for children of all ages. Tones were presented through headphones (Sony MDR-V150).

It has been argued that distraction tasks may only work when they are motivationally relevant [75]. Therefore, a financial reward was given to enhance the motivation to perform the distraction task [81]. Financial rewards are considered to be very influential and are often used to increase motivation in experimental research in adults and children [7,48]. Research has shown that the interest in and the understanding of money rapidly increases between the age of 5 and 7, and is fully established at the age of 8 [6,34]. In this study, participants could win 10 eurocents every time they pressed the button quickly and accurately. If the response was given too late or inaccurately, they could lose 10 eurocents. After the experiment, participants received 3, 4 or 5 euro for their task performance. This amount was randomly assigned and was unrelated to the actual task performance.

Distraction task engagement

Task performance served as a behavioural measurement of distraction task engagement. We calculated children's reaction time (RT) and response variation (SD), excluding anticipations (RTs<100ms) (2%), non-responses (1%) and outliers (RTs>3 SD above the individual mean) (2%) [32,74,81]. Errors were calculated by summing the number of anticipations and non-responses.

Self-reported distraction task engagement was examined with two items: children in the distraction group were asked to indicate how much "attention they paid to the task" and "how important it was for them to perform the task well". Task difficulty was also assessed. All items were scored on a 0 to 100mm scale, labelled at 0mm ('not at all'), 25mm ('a little bit'), 50mm ('quite a bit'), 75mm ('a lot') and 100mm ('very much'). While the use of these inter-anchor markers are not necessarily standard on rating scales, we chose to use them to reduce variance related to developmental trends where children may be biased in their responses toward the end anchors [31].

Self-reported attention to pain

Attention to pain was assessed with two items: children were asked to indicate how much attention they paid to the pain and the degree to which they were able to distract from the pain during the CPT, using a 0 to 100mm scale. The scale was labelled at 0mm (‘not at all’), 25mm (‘a little bit‘), 50mm (‘quite a bit‘), 75mm (‘a lot’) and 100mm (‘very much’). An “attention to pain” score (range -100 to +100) was calculated by subtracting the ability to distract from pain from the amount of attention paid to pain. The higher the score, the more attention was paid to pain during the CPT. We chose to use this composite measure of attention to pain given the possibility that the interaction between distraction and attention to pain could involve other processes including the ability of a person to switch attention toward and away from pain when completing a trial and between trials. Given such a possibility, we posit that this composite measure is important to employ rather than simply using a direct rating of attention to pain. This measure provides a more sophisticated indicator of potential processes engaged during the complex process of distraction from pain.

Self-reported pain during the cold pressor test (CPT)

Pain experience during the CPT was assessed through self-report. We assessed the pain after the CPT to avoid interference with the distraction process [22,23]. To avoid memory bias we assessed the pain immediately after the removal of the hand [50]. Pain intensity was assessed with two items (α=.92): children were asked to indicate the worst pain and the pain just before the end of the immersion on a 0 to 100mm scale, labeled at 0mm (‘no pain’), 25mm (‘low pain”), 50mm (‘moderate pain’), 75mm (‘most intense pain’) and 100 mm (‘enormous pain’). These two measures have proven to be valid indicators of the pain experience during the CPT [46] and have been used in previous distraction research [81,82]. A total pain intensity score was calculated by adding the two pain intensity items (range 0-200). Pain affect was assessed with two items (*α*=.52): children were asked to indicate how unpleasant the cold pressor experience was and how anxious/tense they were during immersion (-50=‘relaxed/pleasant’; +50=‘very anxious/unpleasant’). A total pain affect score was calculated by adding the two pain affect items (range -100 to +100).

Executive function tasks

Inhibition

Response inhibition and resistance to distractor inhibition are related, but resistance to proactive interference is not [30]. It can be expected that prepotent response inhibition and resistance to distractor intereference inhibition are related to the attentional control of pain. Response inhibition was assessed with the anti-saccade task, as used by Miyake et al. [60]. This task is a modification of the original anti-saccade task [25], as it uses manual key presses instead of eye-movements. Task completion took approximately 10 minutes. Each trial started with a white fixation cross that is presented against a black background in the middle of the computer screen (HP Compaq nc6120, 15 inch) with a variable duration (one of nine presentation times between 1500ms and 3500ms in 250ms intervals). Then a visual cue (white square, 1.5 x 1.5cm) is presented on one side of the screen for 225ms, followed by a target stimulus (arrow inside an open square, 6.7 x 6.7cm) on the opposite side for 150ms before being masked by white cross-hatching. Participants are asked to indicate the direction of the arrow by pressing the corresponding keyboard key (J=left, I=up, L=right). This task requires participants to inhibit the automatic response of looking at the cue because this hampers the identification of the direction of the target. Children were tested individually. They received on-screen written instructions and started with a short practice phase of 18 trials and subsequently performed 90 experimental trials. Error feedback was given on-screen. Reaction times were computed after removing anticipations (RT<100ms) and outliers (RT>3 SD above the individual mean) [81]. Reaction times served as the dependent variable. Lower reaction times refer to better inhibition abilities.

Interference inhibition was assessed with the Stroop colour-word test [41,70]. This test consists of three cards, each displaying 100 stimuli arranged in five columns of 20 items each. The first card ('words') displays colour names (blue, green, red and yellow) written in black ink. Children are instructed to read the words as fast as possible. The second card ('colour') displays colour bars (blue, green, red and yellow). Children are instructed to identify the colour as quickly as possible. The third card ('interference') displays colour words (blue, green, red and yellow) which are printed in a conflicting colour. Children are required to identify the ink colour and inhibit the automatic tendency to read the word. For each card the total reading time as well as the amount of errors is calculated. An interference score is calculated by subtracting the total time to read the second card from the third card. This score provided an inhibition measure and served as the dependent variable. Lower interference scores reflect better inhibition abilities.

Task switching

Task switching ability was assessed with a variant of the task switching paradigm developed by Meiran et al. [58], which is often used to measure switching ability [15,78]. Task completion took approximately 7 minutes. Children were instructed to switch as quickly as possible between two randomly presented reaction time computer tasks (50% colour identification task, 50% shape identification task). Each trial started with the presentation of the cue “colour/shape” on a computer screen (HP Compaq nc6120, 15 inch) for 400ms. After a cue-stimulus interval of 100ms, a target (blue or yellow triangle or circle) was presented for 500ms. Children were instructed to indicate whether the target was blue or yellow, when presented with the cue “colour” or whether the target was a circle or triangle when presented with the cue “shape” by pressing the corresponding keyboard key (F=yellow/triangle, J=blue/circle). Stimuli remained visible until response or until response time had elapsed (4000ms). The response-stimulus interval was 1500ms. Children performed a switch trial when the current task differed from the task on the previous trial (colour/shape task or shape/colour task) and a repetition trial when the current task was similar to the task on the previous trial (colour/colour task or shape/shape task). Generally, it takes longer to perform a switch trial than a repetition trial, creating a switch cost [58]. Reaction times were calculated after removing the first trial of each block as well as error trials (10%) and trials preceded by errors (8%) [58]. Anticipations ($RT<200$) as well as outliers ($RT>3$ SD above the individual mean) (2%) were also removed. Children were tested individually and received on-screen written instructions. The experiment started with a short practice phase of 16 trials which was followed by a test phase of 128 experimental trials, divided in two blocks. A short break was introduced after the first block. Only in practice trials error feedback was presented on-screen for 500ms. Switch cost was calculated by subtracting reaction times on repetition trials from reaction times on switching trials (RT_{switch} - $RT_{repitition}$) and served as a measure for task switching ability. The higher the switch cost, the lower the switching ability.

Memory capacity

Memory capacity was assessed with the 'digit span' subscale of the Dutch version of the Wechsler Intelligence Scale for Children (WISC-III NL). Research has shown that the WISC-III NL is reliable and valid [26,49]. Children are presented a sequence of numbers which they are instructed to repeat initially in the same direction (8x2 trials) and subsequently in the reverse direction (7x2 trials). Number sequence starts at two numbers. For each trial a number is added. The maximum sequence is 9 (forward) and 8 (backward). Children are given two chances to repeat each sequence length. When they missed both trials, the test was aborted. Total WISC-III scores for memory capacity were calculated by summing backwards and forward scores and served as dependent variable. On this test a higher the score represents better memory capacity.

Experimental manipulation

Children were randomly assigned to a distraction group, in which attention to pain during the CPT was manipulated using the attention-demanding RIR task, or a control group, in which no distraction task was performed.

Procedure

Parents were contacted by phone and received standardized information about the experiment. They were informed that their child would be asked to perform a cold pressor task, in which they should try to immerse their hand in cold water for one minute. They were told that their child would be asked to perform several other tasks, which would then be related to the child's pain experience. Parents were informed that their child could stop the experiment at any time and were told that they would receive a reimbursement to cover transport costs. When parents agreed to participate, exclusion criteria were discussed. When their child did not meet any of the exclusion criteria, an appointment was made. Parents received a confirmation to participate and a transportation map by mail.

Upon arrival, parents and the participating child received information about the experiment and provided informed consent. Children were told that "…*they would be asked to complete several questionnaires, perform several tasks, namely a 'colour task'* (Stroop*), two 'computer tasks'* (anti-saccade task and switching task)*, a 'memory task'* (digit span task)*, and a 'cold pressor task' (CPT), in which they should try to immerse the left hand in cold water for one minute…".* They were informed that *"…the cold pressor task, is generally experienced as unpleasant and painful, and is safe and often used in pain research…"*. Children were told that the aim of this experiment was to investigate 'pain experience' and were unaware that this experiment examined distraction from cold pressor pain. That way, potential placebo effects were kept at a minimum [5,80]. Parents were seated in a waiting room where they completed the socio-demographic questionnaire and were offered the possibility to participate in another study, which was of no relevance for the current study [83].

After performing the executive functioning tasks that were approximately 30 minutes in duration, the children received standard information about the cold pressor procedure, and immersed their left hand for 1 minute in the room temperature tank to standardize hand temperature [86]. Before the cold water immersion, children in the distraction group received information about the distraction task. They were instructed to *"… focus on the task during immersion…"* and were informed that *"…it was important to perform the task well…".* They were instructed that they *"…could earn 10 eurocent every time they pressed the button fast and accurately and lose 10 eurocent every time they pressed the button too late or inaccurately, with the possibility to earn a maximum of 6 euro, which they would receive at the end of the experiment…".* Children in the control group were instructed to *"…keep their mind on the cold water and the pain they experienced…"* [56]. Finally, children in both groups were instructed to "…*immerse their hand and wrist, not to form a fist and not to move their fingers…*" [86]. After instructions, children immersed their left hand in the cold water container for one minute. Immediately following the cold water immersion, participants answered questions about the pain experience [50]. Children in the distraction group also completed the distraction task questions. The cold pressor procedure ended with hand submersion for 1 minute in the room temperature tank to recover [86]. During the cold pressor test, the researcher stayed in the room, and sat behind a screen to minimize contact with the child. After the cold pressor test parents and children were fully debriefed.

Data-analysis

Data were analyzed by using SPSS 15.0. First, descriptive analyses were used to investigate distraction task engagement and its relationship with executive functioning abilities. Second, we examined overall differences in attention to pain, pain intensity, and pain affect between the distraction and control group by means of ANOVA analyses. Effect sizes were calculated by using Cohen's *d* (0.20 'small', 0.50 'medium' or 0.80 'large' effects) [14]. Third, we examined the role of executive functioning in the effectiveness of distraction with a series of moderator-analyses [40]. All variables entered in these analyses were centred [1].

RESULTS

Descriptive statistics

Sample characteristics

The majority of the sample (77%) experienced pain during the two weeks prior to the study, which was mostly described as low (30%) or moderately intense (58%). Leg pain (42%), stomach ache (18%) and pain in other parts of the body (e.g., hands, feet) (33%) were the most frequently reported. The majority of the sample reported having experienced pain once (24%) or a few times (61%) during the past two weeks. At the moment of testing, 48% reported being pain free, the other half reported some type of pain (also pain from bumps and bruises), which was of low intensity (M=15.20, SD=16.39, range 0-100). The distraction and control group did not differ in the pain experienced before the experiment (occurrence: χ2(1)=.46, p>.10; intensity: all t<1, p>.10), the current experienced pain (t(160)=1.01, p>.10, d=.16), age (t(160)=-.37, p>.10, d=.06) and sex ($\chi^2(1)$=.63, p>.10).

Executive functioning abilities

Descriptive analyses (Pearson) showed a significant relationship between interference inhibition and response inhibition (r=.25, p<.01), suggesting that these constructs overlap conceptually but generally measure different constructs of inhibition, as previously discussed. Interference inhibition was related to working memory (r=-.23, p<.01) whereas all other executive functioning measurements were not interrelated (all r<.14, p>.05).

Furthermore, Pearson correlations showed an association between executive functioning abilities and age, indicating that response inhibition (r=-.39, p<.001), interference inhibition (r=-.50, p<.001) and working memory abilities (r=.28, p<.001) improved with age. Subsequent analyses were therefore conducted controlling for age statistically. Independent sample *t*-tests showed no overall differences in executive functioning between boys and girls (all t<1.83, p>.05, d<.30).

Finally, independent sample *t*-tests showed no differences between the distraction group and the control group in response inhibition (M_{contr}=443 ms, SD=130, 99% correct; $M_{distrac}$=435 ms, SD=127, 98% correct), interference inhibition (M_{contr}=31.27, SD=14.55; $M_{distrac}$=31.44, SD=15.75), switching ability (M_{contr}=226 ms, SD=188, 89% correct; $M_{distrac}$=219 ms, SD=186, 91% correct) and working memory (M_{contr}=15.10, SD=3.36; $M_{distrac}$=14.85, SD=3.43) (all t<1, p>.10, d<0.08).

Distraction task measures

Descriptive statistics indicated that age was not related to task difficulty (r=-.12, p>.10), attention toward distraction task (r=.05, p>.10) and attention toward pain (r=-.004, p>.10), suggesting that task difficulty and level of distraction related to the task were not significantly different across children of all ages.

Descriptive analyses were conducted to investigate distraction task engagement (see Table 1). Results showed that children in the distraction group completed the distraction task quickly (*RT*:M=254, SD=69) and accurately (*Errors*:M=3%, SD=3%), with little variation in response time (*SD:* M=69, SD=30). Furthermore, children on average reported to have paid much attention to the task (M=77, SD=25). They reported finding the task moderately important to perform well (M=57, SD=24). Pearson correlations showed a relationship between distraction task performance and response and interference inhibition. More precisely, results showed that with better response inhibition abilities the distraction task was performed faster (r=-.29, p>.05). Further, with better interference inhibition abilities, distraction task performance was higher (r=.32, p>.01). Furthermore, task performance was related to working memory, indicating a decrease in the number of errors made on the distraction task for those with better working memory skills (r=-.38, p<.01). Self-reported distraction task engagement was associated with switching abilities, indicating that with better switching abilities more attention to the distraction task was reported (r=-.26, p<.05).

- INSERT TABLE 1 –

Overall effects of distraction on attention to pain, pain intensity and pain affect

ANOVAs were conducted to examine overall differences in attention to pain, pain intensity and pain affect between the distraction and control groups. Attention to pain composite scores were not significantly different from simple ratings of attention paid to pain. Results indicated that children in the distraction group reported significantly less attention to pain (M=-34, SD=36, min=-100, max=25) than controls (M=23, SD=38, min= -69, max=100) (F(1,160)=96.17, p<.001, d=1.54), indicating that our distraction manipulation was indeed successful. However, no overall differences were found in pain intensity (M_{contr}=96, SD=47, min=17, max =200; M_{distr}=89, SD=46, min=5, max= 200) and pain affect (M_{contr}=9, SD=42, min= -100, max=90; M_{distr}=9, SD=36, min= -85, max=85) between the distraction and control group (all F<1, p>.10, d<.16).

Impact of executive functioning on distraction effectiveness

To examine the impact of influencing factors on the effectiveness of distraction, a series of moderator analyses were carried out. In these analyses, attention to pain, pain intensity and pain affect served as dependent variables. In the first step, we controlled for age and sex. Group allocation and executive functioning measurements were included in the second step. In the third step, we entered the interaction terms of group with executive functioning measurements. Results showed a main effect of group on attention to pain (β=-.61, *t*=, p<.001). Furthermore, an interaction effect of group by working memory was found on attention to pain (β=-.14, t=-2.16, p<.05), indicating that with better working memory skills, there was more attention toward pain in the control group than in the distraction group. No main or interaction effects were found on pain intensity (all β<.14, p>.10). Finally, results showed main effects of working memory (β=-.19, t=-2.31, p<.05) and response inhibition (β= .17, t=1.99, p<.05) on pain affect, indicating that with better working memory and inhibition abilities, pain affect decreased during the CPT.

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DISCUSSION

This study investigated the role of executive functioning as a moderating factor of distraction effectiveness in children. Our distraction manipulation was successful in that children in the distraction group reported paying significantly less attention to pain than controls. However, distraction was ineffective in reducing pain intensity and pain affect during the CPT. Executive functioning was associated with engagement on the distraction task, but did not moderate distraction effectiveness.

Although children in the distraction group were engaged in the distraction task and reported less attention to pain than controls, distraction was found to be ineffective in reducing pain intensity and affect during the CPT. This finding contradicts studies that have found beneficial effects of distraction [47,73,84], but corresponds to other studies that have not found any effect of distraction [4,9,10,43,57]. However, these studies have all been in pediatric populations. Heterogeneous findings may point to the role of other moderating factors not measured in this study.

Of additional interest is the finding that executive functioning was related to the overall experience of pain. More precisely, results indicated that children with good inhibition and working memory abilities overall experienced less pain *affect* during the CPT. This implies that executive functioning abilities might be involved in complex ways in the experience of pain. This hypothesis finds support in neuroimaging studies. For instance, the dorsal anterior cingulate cortex and the dorsolateral prefrontal cortex, considered important structures of executive functioning [45,59], are involved in the attentional control of pain [2,72]. Other support is found in a behavioral study [62] that showed a relationship between inhibition and pain tolerance. Future research should explore the relationship between executive functioning and aspects of pain experience.

Results showed that executive functioning did not moderate the effectiveness of distraction, suggesting that neither high nor low executive functioning benefitted from distraction. These results are in line with a preliminary study in young adult university students that also did not find a relationship between executive functioning and distraction effectiveness [82]. It is however premature to conclude that executive functioning does not influence distraction effectiveness, as a relationship was found between executive functioning and distraction task engagement. More precisely, our results indicated that while the distraction task did not reduce pain intensity, our findings are consistent with existing cognitive models of executive function in that: (1) with better response inhibition abilities, the distraction task was performed faster with less response variation; with better interference inhibition abilities, the distraction task was performed with less response variation and fewer errors, (2) with better working memory abilities, the number of errors made on the distraction task decreased and (3) with better switching abilities, more attention to the distraction task was reported. Results concerning the relationship between inhibition abilities and distraction task performance replicate preliminary findings in a university student population which showed a relationship between response inhibition and distraction task performance and extend those findings to the role of interference inhibition. Although this relationship is not strong (r<.33), it appears to be consistent and indicates that inhibition abilities could be important in focussing on a task despite pain. Future research should further investigate the relationship between inhibition and distraction effectiveness, including measures of interference and response inhibition.

Further, it has been assumed that distraction would be more effective in individuals with stronger task switching abilities as they are likely better able to switch their attention back to the distraction task whenever pain interferes. Results of this study provide support for this hypothesis as schoolchildren with better switching abilities reported more attention to the distraction task. Results however contradict the results in a preliminary study, which indicated that young adult students with better switching abilities reported less attention to the distraction task [82]. This discrepancy suggests that the relationship between task switching and distraction effectiveness might be determined by other factors, such as motivation. Good task switching capacities might also allow individuals to pay attention to the distraction task and pain at the same time, if one is motivated to pay attention to the pain.

This study has a strong methodological design as it has taken into account the most common methodological problems raised in distraction research (see [23] for a review; [63]). For instance, we used a stimulus of moderate pain intensity to optimize the chance of finding a standard distraction effect before testing our hypothesis about the modulation of distraction effectiveness by executive functioning abilities [24]. We assessed pain after, rather than during the CPT to avoid interference with the distraction process, and used different items to measure pain intensity and affect. The use of the CPT was standardized in terms of instructions, immersion duration and exclusion criteria [86]. We used a control group, which was instructed to avoid the use of spontaneous distraction techniques, and concealed the true purpose of the study to control for bias from participant belief in the putative effectiveness of distraction [55]. Finally, we used a distraction task that had all the necessary qualities to be effective in reducing pain as it was attention-demanding [76,77], directed attention to an external cue [44], involved another perceptual modality [85], was made motivationally relevant [75] and has been proven successful in previous research [32,74,81]. We also investigated the engagement with the distraction task [23].

Despite the strengths, there were some limitations associated with this study. First, participants in this study were generally healthy schoolchildren and the painful stimulation was created and delivered in the laboratory. Further research is needed to demonstrate whether our results can be replicated in a sample of children experiencing clinically relevant pain. Second, pain was induced with the CPT. Although this is a well validated pain inducing method often used in distraction research in children [86], the pain experience may however fluctuate during immersion, with the pain increasing rapidly in the beginning of the immersion (as a result of vasoconstriction), and the pain leveling off after two to four minutes [23,35,86,87]. We have therefore used a fixed immersion paradigm of one minute instead of a pain tolerance paradigm to ensure that all children would experience the same nociceptive stimulation and our self-report measure of pain was not confounded by immersion duration. Third, other factors in addition to executive functioning might influence distraction effectiveness (e.g. pain related affect, preferred coping style, temperament, self-efficacy) and may explain why distraction did not impact the pain experience in this study [47,63,64,81]. Fourth, we wanted to increase the possibility of finding a standard distraction effect before examining the moderating role of executive functioning and therefore increased the motivation to perform the distraction task [75]. The relationship between executive functioning and distraction effectiveness might be influenced by motivation, but the current research design does not allow this hypothesis to be tested. An additional consideration to be addressed in future research is the possibility that the lack of effect on pain in this study could have occurred if participants were able to switch attention briefly to pain during the time gaps between trials. Alternatively, a similar problem could occur if pain continued in the affected hand after being removed from the water when the distracting task ended. This could have resulted in a similar experience to the non-distracted participants. As well, our choice to use a developmental sample may have increased the variance on one or more of the above mentioned factors. While this broad sample strengthens our generalizability to a community sample, it may have made it more difficult ascertain how distraction specifically affects the pain experience at a given developmental stage. Finally, although the RIR-task is a valid task for investigating effectiveness of distraction in a fundamental way, it differs from the usual distracting tasks used in everyday life. Future research should demonstrate whether results are generalizable using other distraction tasks. Such research should also explore whether tasks that have a higher attentional demand may have a stronger effect on pain intensity and pain affect. It may also be that the effects of distraction will be seen most strongly when the distraction task is highly demanding and when the pain being experienced is high [22,23]. Finally, the fact that this distraction task was successful in adults but not in this pediatric sample suggests that further research is required to examine factors associated with this difference.

Despite these limitations, the present study clearly shows an association between executive functioning and the engagement with a concurrent task during pain, with strong support for the role of inhibition. Importantly, participants with increased inhibition and working memory abilities had improved distraction task performance. These skills that will be useful to target in future research and highlight that these individuals may be more likely to effectively deal with affective components of painful stimuli. An important relationship was also noted between executive functioning and pain affect, suggesting that those with stronger inhibition and working memory abilities had less stressful and unpleasant pain experiences. This suggests that executive functioning abilities may not necessarily be involved in directing attention away from pain, but might instead be involved in the overall experience of pain.

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TABLES

Table 1: Cognitive performance data

	M(SD)	1	2	3	4	5	6	7	8	9	10	11	12
Executive functioning													
1. Response inhibition	435 (127)	-	.10	.21	-.10	.22 [(a)]	.28*	-.003	.06	-.004		.14	.15
2. Interference inhibition	31.44 (15.75)		-	-.09	-.24*	-.02	.31**	.32**	-.01	-.13		.09	-.18
3. Switching	219 (186)			-	-.14	.08	.01	-.02	-.26*	.18		-.07	.03
4. Working memory	14.85 (3.43)				-	.04	-.17	-.38**	.16	-.19		-.04	-.14
Distraction task performance													
5. Reaction times	254 (69)					-	.58**	-.22 [(a)]	-.001	.05		.11	.09
6. Response variation	69 (30)						-	.13	-.23*	.19		.11	.18
7. Errors	1.28 (1.60)							-	-.15	-.01		.02	-.01
Self-reported distraction task engagement													
8. Attention to RIR	77 (25)								-	-.46**		-.12	-.27*
9. Importance to perform RIR													
Self-reported attention to pain and pain experience													
10. Attention to pain	-34 (36)									-		.17	.42**
11. Pain intensity	89 (46)											-	.55**
12. Pain affect	9 (36)												-

Note: Reaction times (RT) are presented in ms, self-report measurements in mm; (a) p=.06, *p<.05; *p<.01

Means, standard deviations and Pearson correlations of executive functions, distraction task (RIR) performance measures, self-reported distraction task engagement, self-reported attention to pain and pain experience in the distraction group

Table 2: Regression results.

Criterion variables	Step	Predictor	β	ΔR²	Adj R^2
Attention to pain	**1**	Age	.04	.01	.001
		Sex	.11		
	2	Group	-.61***	.40***	.39***
		Response inhibition	-.03		
		Interference inhibition	-.12		
		Switching	.05		
		Working memory	-.01		
	3	Group x Response inhibition	-.01	.02	.39***
		Group x Interference inhibition	.03		
		Group x Switching	.04		
		Group x Working memory	-.14*		
Pain intensity	**1**	Age	-.03	.01	-.001
		Sex	.04		
	2	Group	-.08	.03	-.003
		Response inhibition	.13		
		Interference inhibition	.06		
		Switching	-.09		
		Working memory	-.001		
	3	Group x Response inhibition	.003	.00	-.03
		Group x Interference inhibition	.01		
		Group x Switching	-.01		
		Group x Working memory	.01		
Pain affect	**1**	Age	.20 [(a)]	.03	.02
		Sex	.12		
	2	Group	.002	.06	.04[(a)]
		Response inhibition	.17*		
		Interference inhibition	-.01		
		Switching	.07		
		Working memory	-.19*		
	3	Group x Response inhibition	.01	.02	.04
		Group x Interference inhibition	-.06		
		Group x Switching	-.09		
		Group x Working memory	.06		

Note: Standardized betas of the last step are displayed, (a) p=.05, *p< 05, **p<.01,***p<.001

Hierarchical regression analyses with group, inhibition, switching and memory capacity as predictors and attention to pain, pain intensity and pain affect as criterion variables.