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# Tactile and Visual Virtual Reality Attention Distraction From Pain in Cold Pressor Test

***Abstract:*** *The goal of this study was to test the efficacy of a tactile attention distraction from pain and compare its effectiveness with a virtual reality (VR) distraction on an analogous task. VR is considered to be the gold standard for attention distraction, but it cannot be used in certain clinical cases or for particular medical procedures. A repeated-measures experimental study was carried out with 42 participants using tactile and VR variants of an* n*-back task and a cold pressor test for pain. The independent variable was the distraction type (tactile, VR, or no-distraction) and the dependent variable was pain tolerance (i.e., time participants kept their hand in cold water). The results showed that both tactile and VR games effectively increased pain tolerance compared to the control condition. Effect sizes for both interventions were similar. However, the effect was observed only for female participants.*

***Keywords:*** *attention distraction, tactile interventions for pain, virtual reality, cold pressor test*

## 1. INTRODUCTION

The experience of pain is linked to attention, and there is a long history of research on how pain and attention are related (Legrain, Crombez, Verhoeven, & Mouraux, 2011; Sprenger et al., 2012; Torta, Legrain, Mouraux, & Valentini, 2017). Attention distraction is a commonly used method to alleviate experimental pain, or pain related to medical procedures. The proposed cognitive mechanism of distraction is limited attentional capacity, which suggests that more engaging and interactive methods of distraction should lead to greater pain alleviation effects (Birnie, Chambers, & Spellman, 2017). Virtual reality (VR) technology is becoming widely used to reduce experimental pain, with numerous studies confirming its effectiveness as a distractor (Kenney & Milling, 2016; Loreto-Quijada et al., 2014; Malloy & Milling, 2010; Keefe et al., 2012; Hoffman et al., 2011). VR technology was also effectively used with chronic pain patients (Matamala-Gomez et al.,2019a, 2019b; Pozeg et al., 2017; Solcà et al.,2018). While immersed in VR, patients wear head-mounted displays (HMDs) and use controllers so they can look around and interact with the 3D virtual environment. VR is considered to be an especially effective method of distraction because it is immersive, interactive, and engages multiple sensory modalities. Several studies have shown greater pain reduction effects with VR compared to other methods (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000).

This also makes VR a good benchmark for judging the effectiveness and usefulness of other novel types of distraction. If analgesic effect sizes of these novel distraction methods on pain are comparable to the effect sizes of VR, it can be assumed that the new methods meet the standard of a good distractor. Finding such novel methods is important because there are many cases or medical procedures where VR cannot be used. The most obvious examples are for individuals with visual impairments or for any medical procedure for which access to the facial area is needed.

A promising direction for research on novel distractors can be using tasks relying on a tactile sensory modality. Tactile distraction shares certain topological/spatial characteristics with visual modalities—making possible to substitute visual display for "tactile display"—as in research on sensory substitution, where visual pixels are translated into a pattern of vibrotactile units "displayed" on the skin (Bach-y-Rita & Kercel, 2003). Regarding experimental research design, it also means that an equivalent task/game can be programmed for either a tactile or visual (VR) modality so that both methods can be directly compared.

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There are also other theoretical reasons for using a tactile modality as a distractor. Multiple resources theory suggests that the effectiveness of a distractor is related to its ability to compete for the same resources utilized by pain perception (Johnson, 2005). Arguably, tactile attention distraction could be more effective than visual distraction because of the partly shared neural pathways for both tactile and pain communication (Vierck, Whitsel, Favorov, Brown, & Tommerdahl, 2013). Tactile stimuli can also influence pain perception by other means than attention distraction, as suggested by research on vibratory analgesia (Hollins, Corsi, & Sloan, 2017; Hollins, McDermott, & Harper, 2014; Staudl, Robinson, Goldman, & Price, 2011).

Additionally, prolonged pain may lead to reductions in tactile acuity (Maihöfner et al., 2006), and tactile discrimination training resulted in pain reduction in chronic limb pain patients (Moseley et al., 2008). Those results were interpreted by the authors in the context of cortical reorganization resulting from the training. Alternatively, the pain reduction effect observed in this study could be explained by either attention distraction, or exposure to threatening stimuli.

In this experimental study, we tested if tactile and VR distraction methods were comparable in their effect on pain reduction. We used a repeated measures design, programmed the same task (*n*-back) both in the VR and tactile versions, and we used a cold pressor test (CPT) as an experimental pain paradigm. The independent variable was the distraction type, which was comprised of three levels (tactile, VR, no-distraction). The dependent variable was pain tolerance (i.e., the time participants kept their hand in cold water).

## 2. MATERIALS AND METHODS

### 2.1 Participants

Forty-two participants were recruited for the study using social media (convenience sampling). The sample consisted of 23 females and 19 males ($M$ = 22.71, $SD$ = 2.68, min = 19, max = 30). The sample was large enough to detect moderate effect sizes (partial $\eta^2$ = .04). A power analysis was conducted using G*Power for a repeated measures ANOVA, assuming 1-beta power of .80. Additionally, a post-hoc sensitivity power analysis was conducted for male sample only. In this case, the sample size was large enough to detect only moderate to large effect sizes (partial $\eta^2$ = .09).

Participants with any circulatory system problems were excluded from the study. Participants were told that the purpose of the study was to examined the influence of temperature on performance for a range of cognitive tasks. Participants were told they could withdraw from the study at any time, without an explanation, and they provided written informed consent. This study was approved by the local ethics committee of Wroclaw University, Institute of Psychology.

### 2.2 Materials

**VR application.** The VR application was programmed in Unity3d, C#. The virtual scene consisted of an androgynous avatar, which could have been interpreted as either male or female. Participants were looking at the scene from the avatar's point of view. The avatar was sitting on a virtual bench, surrounded by a meadow and distant mountains (see Figure 1). On his right hand were four virtual lights flashing a sequence of *n*-back task patterns. The VR game was displayed on Oculus Dk2, an HMD (9,601 × 080 pixels per eye, 75 Hz refresh rate, 100 deg FOV, head tracking).

**Figure 1. Avatar on virtual beach.**

**Tactile distraction device.** A tactile distraction device (TDD) was constructed for the purposes of this study. The device had four vibrotactile motors, programmable microcontroller, four unipolar transistors, and an UART converter. The device could be programmed to switch on and off each motor separately, thus allowing vibratory patterns analogous to those used in visual *n*-back. Vibrotactile motors were mounted on an armband and positioned on the participant's arm (see Figure 2). Positioning reflected the positions of virtual lights on the avatar's arm in the VR condition. Motors were vibrating at a frequency of about 266 Hz.

***n*-back task.** The *n*-back task is an established paradigm in research on working memory (Owen, McMillan, Laird, & Bullmore, 2005). It has been demonstrated that thermal pain processing and the *n*-back task use overlapping cognitive resources. Moreover, Buhle and Wager (2010) found that participants reported lower pain intensity during three-back tasks than in a visually matched control condition. Results from Sprenger et al.'s (2012) neuroimaging study showed larger reductions in thermal pain with higher working memory load (two-back) compared to lower working memory load (one-back). The authors demonstrated that pain reduction was related to the inhibition of pain signals at the spinal cord level, which were mediated by the endogenous opioid system.

In this study, the *n*-back task was programmed in Unity3d, C# for both the VR and tactile version. The tactile *n*-back consisted of patterns of vibration changing every 5 seconds. Either one, two, three, or all four of the motors vibrated for 3 seconds; then, there was a 2-second break before the next trial. The total vibration time per trial was 3 seconds, but the vibration time of each motor was 3 seconds divided by the number of motors in each pattern. Thus, if a pattern consisted of one motor, that motor

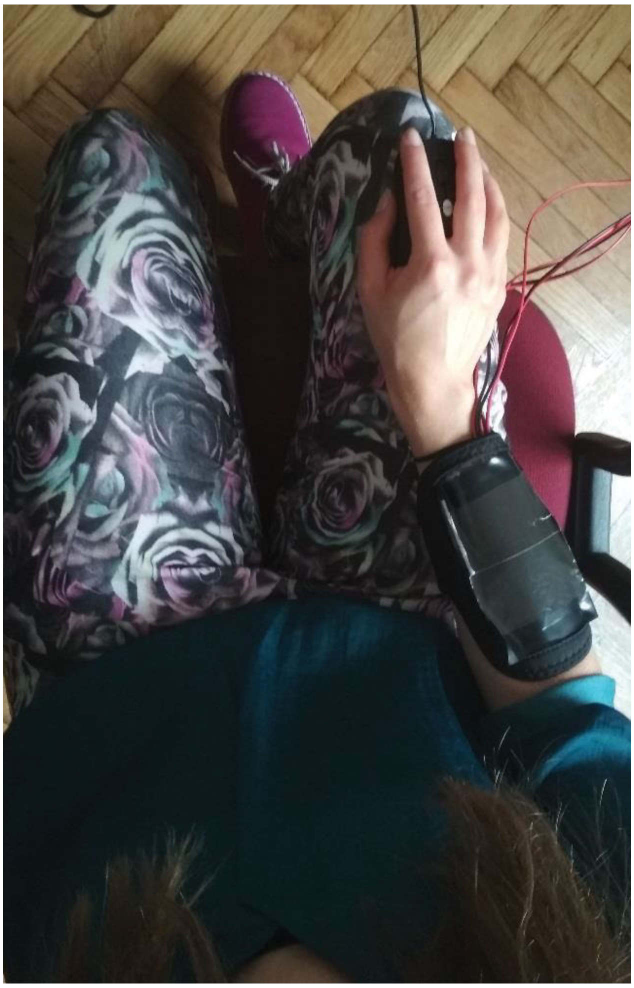

**Figure 2. Vibrotactile motors on armband.**

vibrated for the entire 3 seconds; if a pattern consisted of two motors, each motor vibrated for 1.5 seconds—one after another. For three-motor patterns, each motor vibrated for 1 second. The reason for this implementation was to increase the ability to discriminate among tactile patterns. In a pilot study conducted by our group, it was determined that when several motors vibrated concurrently, it was difficult for participants to discriminate among the different combinations of vibrations. However, the visual (VR) *n*-back implementation was slightly different: A constellation of four blue and white lights changed every 5 seconds. This implementation was chosen because in the visual modality, changing light patterns were easy enough to discriminate.

In both the tactile and visual version, participants provided responses using a mouse; they were instructed to left-click if the pattern was identical to the one presented *n* trials before. In a pilot study conducted by our group, $n = 2$ was determined as the optimal parameter for this task. Few researchers describe the details of constructing stimuli sequences in *n*-back tasks. The sequences used in this study were based on those described by Ralph (2014). One sequence consisted of 64 patterns, where 24 were targets, eight were lures, and 32 were non-lure distractions. *Lure trial* is a term that commonly refers to trials that match $n - 1$ or $n + 1$; so, in this experiment, $n = 1$ or $n = 3$. For example, during n=2 n-back task with a sequence: 1,3,2,2 – the last number "2" is a lure trial, because of preceding (n=1) value also being "2". In contrast a sequence 1,3,2,3 would be a target trial (participant should react, since "3" is the same value as n=2 values before). And 1,3,2,1 would be a non-lure distraction, since "1" does not match either n=2, or n=1 trial.

It was assumed that the correct rejection of lures required executive control (Ralph, 2014). Two analogous sequences were created: one sequence for VR condition and the other for the tactile condition (see the exact sequences in additional materials for this paper).

**Cold pressor test.** A CPT was used as an experimental pain paradigm. The CPT device consisted of a 25 × 35 cm container with cold water (2.8–3.8° Celsius). There was another smaller container inside, with ice cubes used to keep the temperature within the desired range. We also used an electric water circulator to avoid local temperature increases in some parts of the container (i.e., near the hand). The temperature was monitored continuously using a digital thermometer. This CPT device was used in a series of our previously published studies on VR analgesia, and similar devices have been used by other groups (Dahlquist et al., 2007; Forys & Dahlquist, 2007). Research suggests that CPT pain is mediated by unmyelinated C fibers (Walsh, Schoenfeld, Ramamurthy, & Hoffman, 1989). Additionally, CPT pain does not show spatial summation, meaning that small differences across conditions or participants in an area of skin immersed in cold water should not have influenced the results.

## 2.3 Procedure

Data collection was conducted in a lab room of the Psychology Institute of the University of Wroclaw. Data were collected at various hours during the day, from 9:00 a.m. to 8:00 p.m. The room temperature was approximately 22° Celsius. Data collection was conducted by the female experimenter, one of the authors (A.B.).

In this within-subject design study, each participant went through three experimental conditions: visual VR (Condition A), tactile (Condition B), and control (Condition C). The order of conditions was fully counterbalanced, which was done separately for males and females. Thus, before the beginning of the study, each participant was assigned to one of six groups: ABC, ACB, BAC, BCA, CAB, or CBA.

Upon arrival, participants were informed about their right to withdraw from the study at any moment, and they provided written informed consent. They were told that the purpose of the experiment was to investigate how cold temperature influences attention. The real purpose of the study was revealed after the completion of data collection. Participants were also reassured that CPT was a common research paradigm and did not have any significant health risks.

During each experimental condition, participants immersed their left hand (up to the wrist, palm down) in the cold water, and they were instructed to remove their hand when the pain became hard to tolerate. There was a ceiling time of 240 seconds, after which the experimenter removed the participant's hand. Participants did not know about this limit. There was a 5-minute break between conditions. During the break, participants kept their left hand under a blanket to warm it up.

In all three conditions participants were wearing noise canceling ear muffs (manufactured by 3M) to reduce any influence of auditory information, like background noises or sounds from the vibrating motors during the tactile condition. At the beginning of the experiment, a printed sheet with several examples of *n*-back sequences was presented to each participant. Their task was to point to patterns which were identical to $n = 2$ back. This was done to make sure the participants understood the task. In addition to that, participants were undergoing 12 test trials both before the VR and tactile condition.

In all three conditions participants were wearing HMDs and a TDD band with motors on their right hand. During the control condition, both devices were switched off; HMDs presented a blank screen and there were no vibrations from the TDD. During the VR condition, participants were playing a VR game, as described in the Materials section, responding with a click of the mouse with their right hand. The TDD band was switched off. During tactile condition, the HMDs were showing a blank screen, but the TDD motors were vibrating, and participants were responding with mouse clicks as in the VR condition. The entire experiment lasted between 20 and 30 minutes per participant.

## 3. RESULTS

Statistical analysis was conducted using R. Distributions were first tested for normality with the Shapiro-Wilk test; all of the distributions deviated from normality. Non-parametric tests were used for hypothesis testing (Friedman rank sum, Mann Whitney U test, Wilcoxon signed-rank test). A bootstrap method was used to compute effect sizes with 95% confidence intervals. This was done with the bootES package for R (Kirby & Gerlanc, 2013).

Descriptive statistics for pain tolerance data (time in cold water) are presented in Table 1. There was a great degree of variation in the data: Some participants were removing their hand after several seconds, others kept it in until the ceiling time of 240 seconds. Reaching the ceiling time means that the true pain tolerance level for these participants was unknown. Data from all participants was included in the analysis. The number of participants reaching the maximum time of 240 seconds is shown in Table 2, divided by sex and experimental condition.

The distribution of pain tolerance results can be seen in Figure 3. A visual inspection of the histograms suggests that there were differences in between males and females. A greater proportion of males reached the ceiling level. The distribution also appears bimodal, which is typical in CPT studies (Geisser, Robinson, & Pickren, 1992; Piskorz & Czub, 2014).

The distribution was also tested for normality using the Shapiro-Wilk statistic, separately for each experimental condition. In all conditions, the data deviated significantly from normal (VR: $W = .75$, $p < .001$; tactile: $W = .72$, $p < .001$; control: $W = .71$, $p < .001$). Consequently, nonparametric tests were used for hypothesis testing. The Friedman rank sum test was significant, $\chi^2 = 6.14$, $df = 2$, $p = .046$. However, subsequent pairwise comparisons using exact Wilcoxon signed-rank test were not significant, even before correcting for multiple comparisons.

We noticed that the lack of statistically significant differences between conditions was mainly caused by male participants, who were frequently reaching the ceiling level in all three conditions. There are several possible reasons why male participants may have been influenced by confounding factors (see the Discussion section). Thus,

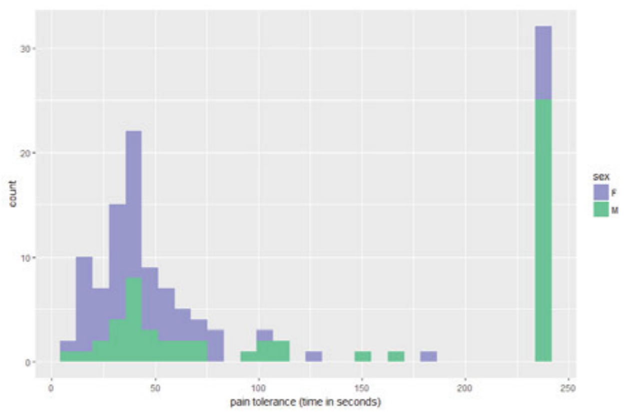


**Figure 3. Distribution of pain tolerance results by sex. Measurements from all conditions are plotted together.**

**Table 1. Pain Tolerance in Each Condition**

| | Visual VR distraction condition<br>*M ± SD* | Tactile distraction condition<br>*M ± SD* | Control condition<br>*M ± SD* |
|---|---|---|---|
| Male | 136.11 ± 94.43 | 131.74 ± 96.91 | 145.84 ± 99.07 |
| Female | 68.48 ± 60.14 | 67.70 ± 70.76 | 55.96 ± 67.38 |
| *n* | 99.07 ± 83.77 | 96.67 ± 88.60 | 96.62 ± 93.78 |

*Note*. VR = virtual reality.

**Table 2. Numbers of People Reaching the Maximum Time of 240 Seconds**

| | Visual VR distraction condition | Tactile distraction condition | Control condition |
|---|---|---|---|
| Male | 8 | 8 | 9 |
| Female | 2 | 3 | 2 |

we decided to test if pain tolerance results differed significantly between the sexes and to analyze data from female participants separately.

Between-sex differences were tested using Mann-Whitney tests. In all three conditions, male participants had significantly higher pain tolerance scores than females. For the VR condition: $U = 134$, $p = .03$; tactile: $U = 121$, $p = .01$, control: $U = 103$, $p < .01$. Data for female participants were more unimodal than for males, with only a few participants reaching the ceiling level (see Figure 4). The Friedman rank-sum test for female participants only was significant, $\chi^2 = 9.61$, $df = 2$, $p < .01$. Subsequently, pairwise comparisons were conducted using exact Wilcoxon signed-rank tests; $p$ values were then corrected for multiple comparisons using the Holm method. Both the VR and tactile conditions differed significantly from the control condition, but there was no significant difference between VR and tactile conditions (see Table 3).

Effect sizes, both raw and standardized (Hedges *g*), were computed with the bootES package for R. The same tool was used to obtain 95% confidence intervals for these effect sizes. Female participants were keeping their hand in cold water an average of 11.74 seconds, 95% CI [4.91, 20.08], longer in the tactile condition than in the control condition. In the VR condition compared to the control condition, females kept their hand in cold water an average of 12.52 seconds longer, 95% CI [1.7, 21.4]. This translates to an average effect size for the tactile versus the control condition of $g = 0.60$, 95% CI [0.23, 0.97], and for the VR versus the control condition of $g = 0.49$, 95% CI [-0.05, 0.97].

A Bayesian analysis was performed in order to assess the strength of evidence supporting the null hypothesis – which states that there is no difference in pain tolerance during VR and tactile conditions. Alternative hypothesis states that pain tolerance differs between VR and tactile conditions. Data from all participants (males and females) was used in the analysis.

**Table 3. Pairwise Comparisons (Females Only) Using Exact Wilcoxon Signed-Rank Test**

| Pair | *p* value (with Holm correction) | *z* value |
|---|---|---|
| Tactile distraction – control condition | 0.02 | 2.50 |
| Visual VR distraction – control condition | 0.02 | 2.63 |
| Tactile distraction – visual VR distraction | 0.48 | -0.73 |

*Note*. VR = virtual reality.

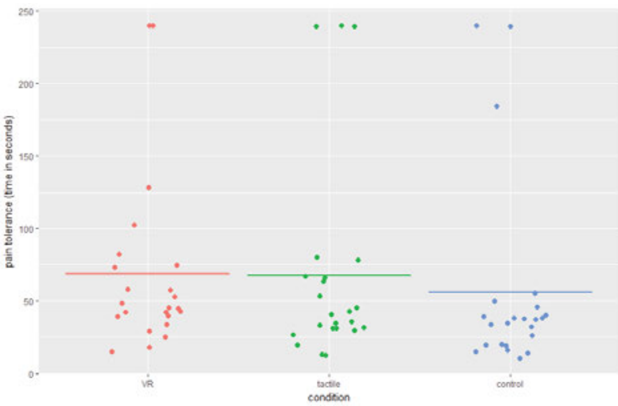


**Figure 4. Plot (with jitter) of pain tolerance data by condition, for females. Horizontal lines reflect mean values**

We applied the Bayesian paired samples t-test framework (Jeffreys, 1961, Rouder et al., 2009). Data was analysed with JASP (JASP Team, 2018).

Difference between conditions was assigned a Cauchy prior distribution (scale = 0.707). The resulting Bayes factor of $BF_{01} = 5.087$ indicates a moderate degree of evidence in support of the null hypothesis. This means that the data is about 5 times more likely to occur under null hypothesis than under an alternative hypothesis. The error percentage is <0.0001% which indicates very good stability of numerical algorithm which was used.

## 4. DISCUSSION

Results showed significant increases in pain tolerance for female participants in both experimental conditions compared to the control condition. The effect sizes for both the VR and tactile distraction were comparable. The results suggest that tactile distraction may have similar effectiveness as VR. This is important from an applied perspective, given that VR is considered to be a very effective distraction method, but it cannot be used in certain situations.

First, we will discuss this main result, and then we will examine possible reasons for why it was obtained only for female participants. The effect size between the control and tactile conditions (Hedges $g = .60$) means that 73% of tactile condition pain tolerance scores were above the mean of the control condition scores. Respectively, 69% of VR condition scores were above the mean of control condition scores (the effect size between the control and VR was $g = 0.49$).

Similar effect sizes were obtained in other studies on VR analgesia using the CPT paradigm with adults. In a study by Loreto-Quijada et al. (2014), corrected effect size (Hedges *g*) was 0.76, 95% CI [0.17, 1.34], while in a study by Sil et al. (2014), the effect size was $g = 0.31$, 95% CI [-0.34, 0.96]. Also, in previous experiments on VR analgesia conducted by our group, we obtained similar effect sizes.

As indicated by a recent meta-analysis of 14 studies, the mean effect size for a VR intervention on pain was slightly higher, $g = 0.90$ 95% CI [0.72, 1.08] (Kenney & Milling, 2016). This may be partly explained by the fact that many of these studies used highly engaging and dynamic commercial VR games as distractors, while we used a simple and mostly static VR scene. We were unable to find any studies combining a CPT paradigm with vibratory analgesia. Studies using other pain paradigms or clinical groups reported pain reductions ranging from large to small and statistically insignificant (Staudl et al., 2011; Watanabe, Svensson, & Arendt-Nielsen, 1999).

The effect size for tactile condition in our study was a bit smaller than the one obtained from the meta-analysis on VR analgesia studies. However, in the future, some improvements could be made to the tactile *n*-back game that we used, which could lead to an increase in its effectiveness. We set $n = 2$ as a parameter for the *n*-back task by pilot testing both VR and tactile games before the study. Participants in the pilot tests assessed $n = 2$ as an optimal difficulty level. However, the pilot tests were done without the CPT. In the main study, several participants commented that the tactile task was too difficult for them, especially while experiencing pain. One participant admitted that after failing (in his opinion) to do the task well, he gave up focusing on it. Some participants reported that they had difficulty differentiating between the vibrotactile constellations. It is very likely that participants differed regarding their tactile sensitivity as well as their working memory, which would have ultimately impacted their ability to attend to the task. Therefore, some version of an adaptive *n*-back task could be better suited for participant engagement—increasing *n*-value when participants perform well and decreasing it when they make mistakes. Furthermore, vibrotactile stimuli constellations could be chosen more carefully, possibly by testing in advance which constellations are easier to discriminate.

While using tactile n-back task as a distractor, observed pain reduction could result from either tactile discrimination or working memory load. In this study working memory load was present both in visual n-back, and tactile n-back tasks. However, with the current design we were not able to separate effects of memory load and tactile discrimination during tactile distraction experimental condition.

Another possible way for increasing the effect size of the vibrotactile intervention would be to place vibrating motors on the same arm as the pain stimulus. Results of a study by Staud et al. (2011) suggested that ipsilateral stimulation can be more effective than contralateral stimulation. We decided to place the vibrotactile motors on a contralateral arm because of safety reasons related to electricity and water. However, other types of pain stimuli can be used in further studies or better safety measures could be enacted with CPT to allow placing the vibrotactile motors on the ipsilateral arm. Such positioning close to the body region affected by pain could also be possible while using tactile *n*-back to alleviate various forms of clinical pain.

Another potential improvement would be to manipulate the frequency and amplitude of motor vibrations. Recent research suggests using a Pacinian system in vibratory analgesia (Hollins et al., 2017). Certain combinations of frequency and amplitude may lead to larger analgesic effects. Because of the limits of the technology available to us for this study, we were unable to benefit from Hollins et al.'s (2017) suggestions in designing our tactile game.

We believe that the findings from this study are of clinical importance, even without the hypothetical increases in effect size after the improvements mentioned above. VR distraction, despite its effectiveness, cannot always be used. There are many groups or conditions for which this technology is unavailable; individuals with visual disabilities are one obvious example. Using VR applications necessitates that users look around in virtual environments, thus excluding patients and medical procedures for which such movements are not possible or not advisable.

Lastly, if vibrotactile interventions alleviate pain through other mechanisms than attention distraction, these two interventions could potentially be combined, creating a synergistic effect.

There is an ongoing debate regarding mechanisms of vibratory analgesia. One explanation is that pain-touch interactions occur in the primary somatosensory cortex, modulated by Pacinian afferents (Hollins et al., 2014; Hollins et al., 2017); the other explanation is attention distraction. While the evidence seems to weigh in favor of the former, we believe distraction cannot yet be ruled out. Hollins et al. (2014) study used Cognitive Failures Questionnaire (CFQ-D) to measure distractibility and found only a weak correlation with pain reduction. But, this is a self-report measure, reflecting participants' opinions about their general trait, not a direct test for the influence of distraction. Stronger arguments against the role of distraction are related to the fact that participants in both Hollins et al.'s (2014) and Hollins et al.'s (2017) study were asked to monitor their pain and give a continuous measure of its intensity. Also, as the authors concluded that distraction could not produce change from hypoalgesia to hyperalgesia, which was observed in the latter study.

While we agree with Hollins et al. (2014) and Hollins et al.'s (2017) conclusions, we think they are limited to simple cases of vibrotactile interventions. While the focus of these studies was on mechanisms of vibratory analgesia, we focused on testing a vibrotactile task against a VR approach. Our goal was to test if research on vibrotactile games led to clinically useful interventions.

We consider the tactile n-back task to be a tactile discrimination task, rather than tactile stimulation – vibrotactile stimuli were weak, and the task consisted in perceiving and remembering stimulation patterns. The task however also involved a working memory load, and further studies should aim to separate the effects of tactile discrimination, and memory load on pain.

One can easily imagine utilizing a range of vibrotactile tasks, employing several different mechanisms—from simply experiencing vibration to more attentionally demanding tasks like the one used in this experiment. The interactions of these mechanisms remains to be studied, especially given that they may have synergistic effects.

## 5. LIMITATIONS

The main limitation of this study was the fact that only pain tolerance, and not pain intensity (subjective ratings of pain level given by participants) was measured. Pain tolerance results might have been confounded by pain intensity. Also, clinically (and statistically) significant effects were obtained for only female participants.

Lack of a statistically significant effect in male participants may have resulted from the low statistical power of this study. Sample size for male participants was sufficient to detect only moderate to large effect sizes. It is possible, that an effect size smaller than $\eta^2 = .09$ exists in the male sample. Therefore, any further discussion of this study findings regarding the efficacy of tactile and VR distraction on pain in males is relevant only for large effect sizes. A replication with greater number of male participants is required to extend such discussion to include small or moderate effect sizes.

Eight male participants (40%) reached the ceiling level. Higher pain tolerance in male participants was reported in previously published studies (Hellström & Lundberg, 2000; Kowalczyk, Evans, Bisaga, Sullivan, & Comer, 2006; Riley, Robinson, Wise, Myers, & Fillingim, 1998). However, the difference in pain tolerance between male and female participants in this experiment was larger than those reported in the literature. It is therefore likely that factors other than sex influenced the results.

Setting a maximum time of 5 or more minutes could potentially cause more participants to remove their hand before reaching the ceiling time. However, in CPT studies, unpleasant or painful cold sensations peak after about 1 minute, stay at that level for another 2 minutes, and diminish after 3 minutes; thus, individuals can keep their hand in cold water for a longer period of time (Hilgard, 1973). It is likely that those participants who reached a ceiling at 4 minutes would do the same at 5 or more minutes.

Water temperature could have been another factor responsible for the high ceiling rate among males in this study. In this experiment, the temperature was 2.8 to 3.8° Celsius; colder water—around 0.5 to 1.0° Celsius—could have possibly made more participants remove their hand before 4 minutes. However, studies testing how cold temperature is related to pain tolerance have not found a significant difference between 1 and 3° Celsius (Mitchell, MacDonald, & Brodie, 2004), or between 4 and 6° Celsius (Koenig et al., 2014). However if cold induced numbness is responsible for ceiling effects in CPT, lowering the temperature may not diminish the ceiling rate.

Another possible explanation for the large difference in pain tolerance between males and females in this experiment could be the inclusion of a female experimenter. Levine and De Simone (1991) found that male participants assessed CPT pain to be significantly lower when the experiment was conducted by a female researcher. Similar results were obtained by Levine and De Simone for female participants reporting pain in experiments conducted by male experimenters. In another study, participants of both sexes assessed pain as lower when the male researcher conducted the experiment than when the female researcher conducted the experiment (Vigil, Rowell, Alcock, & Maestes, 2014). Despite these results, experimenter sex is often not reported in CPT studies. Ignoring this variable can create problems with the replicability of pain studies (Chapman, Benedict, & Schiöth, 2018). Additionally, differences on pain perception between males and females were demonstrated before (Feine et al.,1991) and future studies design and statistical analysis plan should account for those sex differences.

Another possible limitation of this study was immersing the right hand of all participants, despite their handedness. Some published results suggest that pain tolerance may be different in CPT trials based on hand dominance. In a study by Pud, Golan, and Pesta (2009), right-handed participants showed higher pain tolerance for their dominant hand compared to their non-dominant hand.

The two experimental conditions differed slightly – not only in sensory modality used to convey n-back task. In tactile condition stimuli for any given pattern were delivered in sequence, and in visual condition they were displayed all at once. Also, the time interval between trials was different in visual and tactile versions – and this could have affected task difficulty. This was done to balance the difficulty level of both tasks – however in future studies more similar n-back implementations may be used, and data from the tasks recorded and analyzed in order to test how much participants engaged in the distraction task.

Published research on pain perception and tactile discrimination suggests several possible confounding factors – which could have influenced results of this study, and which should be controlled for in future replications. Results of this study could have been influenced by the distance between the tactile and pain stimuli. Research by Mancini et al. (2014) show that pain relief by touch decreases linearly with the increase of the distance between tactile and pain stimulation sites. Also, disturbances in body perception may influence both pain, and tactile acuity, as shown by Lewis et al. (2012). Therefore, the extent of body perception disturbance should be assessed in future studies.

Lastly, it is important to understand if pain reduction effect observed in this study was related to tactile discrimination activity, or other mechanisms, for example observing a virtual limb during cold pressor test. (Osumi et al. 2012; Moseley et al. 2009)

Lastly, virtual reality environment used in this study was relatively static, and interactions were limited – thus not fully exploiting the potential of this medium as a distractor.

Despite the limitations, the results from this study showed that tactile-based interventions could be effectively used to alleviate pain, and further research in this area is warranted.

## AUTHORS CONTRIBUTIONS:

Study design: M.C., A.B.
Data collection: A.B.
Data analysis: M.C.
Manuscript preparation: M.C., A.B.
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