Pain Medicine, 2025, **26**, 702–711
https://doi.org/10.1093/pm/pnaf120
Advance access publication 1 September 2025
Original Research Article

OXFORD

PSYCHOLOGY, PSYCHIATRY & BRAIN NEUROSCIENCE SECTION

The effects of companionship from strangers and companions on pain thresholds in immersive virtual reality: A randomized controlled trial

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Abstract

Objective: Virtual reality (VR) has been used to treat pain for decades, but improvements in the cost and accessibility of consumer devices open up new opportunities for increasing its efficacy; for example, by adding a social element to virtual experiences. Previous research on the effects of social interaction on pain thresholds in induced pain tasks indicates that even social interaction with a stranger has the potential to increase the effectiveness of VR for pain. In addition, interacting with friends or family members through media can offer social support, and conducting these interactions in immersive virtual reality may have an additive effect.

Design: Pre-registered, within-participants experiment examining effects of 4 conditions on pain threshold.

Setting: Academic research laboratory.

Methods: Participants ($N = 70$) completed a series of induced pain tasks under four conditions: (1) connecting with a companion (friend or family member) in VR, (2) connecting with a companion via Zoom, (3) connecting with a stranger in VR, and (4) alone in VR.

Results: Social interaction increased participants' pain thresholds in VR. Participants preferred interacting with their companions in social virtual reality to all other conditions. No statistically significant difference in pain thresholds was found between interacting with a stranger or a companion in VR.

Conclusions: These findings suggest that social interaction, especially in VR, can enhance pain thresholds, with a preference for interacting with companions and demonstrate the potential for social VR to improve pain management.

Keywords: virtual reality; pain threshold; social support; pain management.

Introduction

Hospitalized patients experience pain and social isolation, which can lead to overuse of medication.[1–3] The "buffering effect" theory posits that social support can lessen people's pain by reducing stress-related physiological responses.[4] Interacting with friends or family via media can offer social support, as shown by hospitalized patients using video conferencing during the coronavirus disease 2019 (COVID-19) pandemic,[5] and social interactions may also positively impact patients' pain thresholds and perceptions.[6–11] Virtual reality (VR) has been used to address pain in adults[12–18] and children[19–21] for decades[22] but to date, most virtual reality interventions for pain have been solo experiences. Social virtual reality (SVR) allows users to interact with another person while in virtual reality, which may enhance presence,[23] and encourage social participation.[24] Thus, recent work has investigated how adding a social component to therapeutic virtual reality experiences can enhance their efficacy.[25,26]

Existing research suggests the presence of a partner offering social support can improve patients' pain thresholds and perceptions.[6–8,27] However, some studies have shown participants reporting equal pain when interacting with friends and strangers,[28] or even using less pain medication when interacting with strangers compared to companions.[29] Thus, we compared interactions with companions in social virtual reality to interactions with strangers. Social virtual reality (SVR) may enhance social presence,[23] encourage participation,[24] and be more engaging than other media. However, it is currently more common for patients to connect with friends and family via videoconferencing. Thus, we also compared videoconferencing to immersive virtual reality when connecting with companions.

To understand which types of the above experiences might be useful for addressing pain, we conducted a preregistered,[30] within-participants clinical trial (NCT05335057) comparing participants' perceptions and experiences of pain in four conditions. Our comparator condition was experiencing virtual reality

Received: 24 September 2024. **Revised:** 14 March 2025. **Accepted:** 18 March 2025

alone. We compared this to an SVR experience with companions (friends or family members); an SVR experience with strangers; and video conferencing with companions. To our knowledge, this is the first study to compare these 4 conditions.

We hypothesized that participants would demonstrate a higher pain threshold in the social VR conditions compared to the alone condition. We also compared participants' preferences for—as well as the effect on pain thresholds of—interacting with companions or strangers in SVR. Finally, we compared participants' preferences and pain thresholds when interacting with companions in SVR to interacting with companions using videoconferencing (Zoom).

During stress, a person is more likely to have an increase in cortisol release and a decrease in pain threshold.[31] Cortisol levels may also be affected by the type and quality of human social relationships. For example, attachment level has been shown to be predictive of cortisol release in partners' social interactions.[32] Thus, we also sampled participants' cortisol levels to examine how these correlated with pain threshold and/or participants' reported social closeness with their partners.

Methods and materials

Setting

This study was conducted in a research lab at Cornell University.

Participants

We aimed to recruit 75 participants, following the power analysis from a previous study.[25] Inclusion criteria for participants were: Over 18; could bring a friend or family member to the appointment, normal or corrected to normal vision, and could communicate with the research assistants in English. Following the Meta health and safety guidelines, exclusion criteria included a history of "fainting or seizures," pregnancy, concussion, sensory impairments, susceptibility to "motion sickness," and balance or dizziness issues, as well as injury precluding the use of the non-dominant hand for the induced pain task. Post-enrollment, we also excluded participants who did not complete the study, had missing data, or whose pain thresholds reached 50 °C. In one case, we discovered halfway through the study that the participant had previously participated. All remaining participants ($N = 70$) were included in all analyses. All procedures were approved by Cornell University's IRB, and all participants signed informed consent. The study was registered at ClinicalTrials.gov (NCT05335057).

Study design

In this within-participants study, we recruited pairs of participants for each 2-hour session. Participants completed a series of induced thermal pain tasks, alone, or while conversing with "companions" (close friends or family members recruited by the participant) or research assistants (RAs). Participants experienced four conditions in randomized order: An *Alone VR* condition, in which participants experienced a VR environment solo; a *Companion VR* condition, where they spoke to their companion in VR; a *Zoom with companion* condition, where participants spoke to their companion by video conference; and a *Stranger VR* condition, where participants interacted with a "stranger" (a research assistant confederate) in VR. We did not create a condition in which participants interacted with a stranger via teleconference, as we did not feel this was realistic. To compare pain thresholds, we used a behavioral measure: The temperature at which participants removed their hand from a thermal device, and a subjective measure: Pain ratings on a scale of 1 to 10. We also tested salivary cortisol levels as a stress marker.[33–37] Each session was approximately 2 hours long. Participants were compensated with course credit or 30 US dollars.

Procedure

Upon arrival, participants and companions were directed into different rooms. Each was assisted in customizing their *avatar* (a virtual human), which would represent their gestures and behaviors. Participants and companions had five minutes to customize their avatars' appearance however they wished.

After completing a baseline saliva sample, participants then underwent the first of 6 pain tasks. For the first pain task, participants looked at a spot on the wall with no other stimulus. Following avatar customization, participants completed a "baseline" pain task inside a solo VR environment (a different environment from the one shown during the "Alone" condition). The first 2 pain tasks were intended to be "practice" tasks that allowed the participants to get used to the thermal stimulation.

Participants then completed pain tasks in the four experimental conditions in a random order (Figure 1). Participants were allowed to talk to their companions about whatever they wanted in whatever language they chose. When speaking to the "stranger," the RA was instructed to maintain a neutral, calm conversation in English, starting with asking about how their previous VR experiences had gone but ultimately following the lead of the participant.

Virtual reality environment and hardware

For the virtual environment, we used the consumer virtual reality platform vTime XR.[38] vTime XR offered a variety of pre-existing, high-quality environments (Figure 2) designed to be experienced while seated. The platform's detailed but not photorealistic avatar customization allowed for a fairly diverse representation of gender, age, and body type (Figure 3). Due to technical errors, three participants navigated to different environments. We have included pictures of the two extraneous environments at the bottom of Figure 2 ("The Study" [2x] and "The Retreat" [1x]). Including or removing these participants did not make a statistically significant difference in any of our calculations; in the reported results below, we included them.

We used the Oculus Quest 1 and the Meta Quest 2 headsets, as the Quest 1 developed support issues during the time period the study was run. Both were stand-alone headsets with right and left-hand controllers.

Measures

All measures collected are listed in our preregistration. In this article, we discuss (1) pain threshold (2) self-report measures collected before, during, and after the experiment on pain, preference for condition, social presence, environmental presence, and social closeness; (3) cortisol measures derived from saliva swabs; and (4) the word count derived from transcripts of participants' conversations in each condition.

In addition to the measures described in this paper, we also collected data for future exploratory analysis. This included personality measures, feelings of satisfaction and identification with their avatar, and engagement and feelings of novelty in the virtual environment. At reviewer request, we have

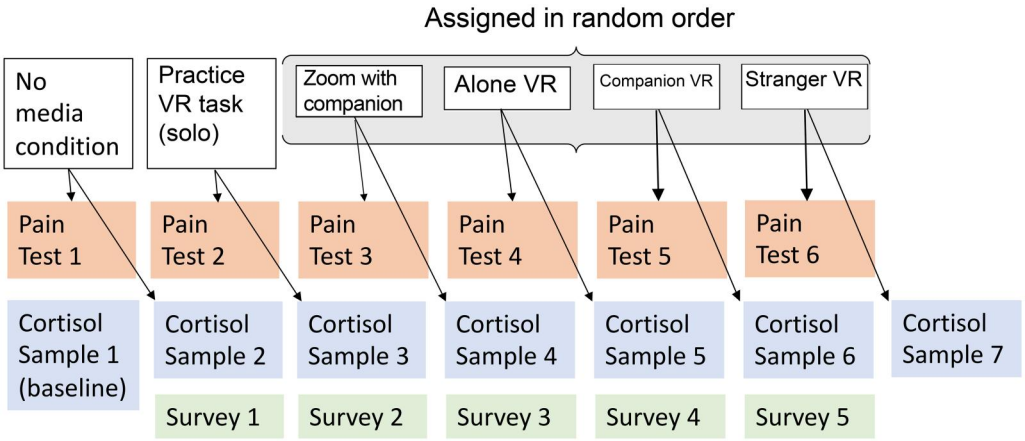

Figure 1. Flow chart illustrating the study design. Participants completed six pain tasks and seven cortisol samples. The first 2 conditions, "No Media" and "Baseline VR," were administered sequentially, each followed by a pain test and cortisol sample. The remaining 4 conditions (Zoom with companion, Alone VR, Companion VR, and Stranger VR) were assigned in random order. Arrows indicate the sequence and relationship between conditions, pain tests, and cortisol samples.

analyzed the relationship between these variables and pain measures, and we include the results of these analyses in Appendix B.

Finally, we transcribed the content of participants' conversations for future analysis to identify themes that might inform further development of virtual environments.

Behavioral pain measures

We used the Medoc Q-sense,[39] a validated measure of pain threshold.[25] The Q-sense is a small thermal device on which the participants placed their non-dominant hands. The baseline temperature started at 32 °C and increased in 0–2 °C/sec increments until it automatically shut off at 50 °C, a temperature that would not cause any lasting damage to participants' skin.[40] Participants were instructed to remove their hands when the sensation became painful or uncomfortable. We operationalized the behavioral pain measure as the temperature at which the participant removed their hand from the thermode.

Cortisol sampling

Each pain task was followed by a cortisol sample taken between 10 and 12 minutes after the pain task, to allow time for the cortisol to appear in the participant's saliva.[41,42] We collected 7 samples: A baseline, after the first pain practice task, one after the second practice pain task, and then one after each experimental condition. The participant would chew on the swab for 60 seconds, then deposit it into a tube. All saliva samples were kept in a −80° freezer until they were shipped to Salimetrics' SalivaLab (Carlsbad, California, USA) for analysis following the manufacturer's protocol.

Survey measures

All survey questions were administered via Qualtrics.

Subjective Level of Pain, Participants responded to this prompt: "On a scale of 1 to 10, where 1 is equivalent to no pain and 10 is the worst pain imaginable, how would you rate the peak pain you experienced just then? (Peak pain meaning the greatest pain that triggered you to remove your hand from the thermal plate.)."[43]

Social Closeness was measured by a scale (rating from 1 to 5) adapted from Won et al. 2020.[25] Participants rated their attitudes toward befriending or working with their partner, their feelings of understanding and connection, and rated their conversational partner on eight positive traits: (likability, interestingness, modesty, friendliness, trustworthiness, sincerity, warmth, and honesty).

Social Presence questions examined how present they felt with their partner in the virtual experience. The questions focused on how much the participant felt that their partner was really in the virtual environment with them, and how real the other person felt, on a scale from 1 to 5, with 5 being the highest level of social presence.[25]

Environmental Presence measures assessed how immersive the virtual environment felt to the participant. We asked them to rate how much the environment felt like the real world, how surrounded they felt, and if they felt like they had really visited the environment on a scale of 1 to 5, with 5 being the highest.[44]

Preference. Finally, participants wrote an open-ended response to the question: "Which experience did you feel was the most helpful during the pain task, and why?"

Word count

We transcribed the audio of all social conditions to collect the total number of spoken words during each conversation.

Data analysis

All analyses were conducted in R.[45] On publication, data and code will be archived on the Cornell Restricted Access Data Center with the final version of the paper.

Outcomes were assessed using the lme4[46] package in R for linear mixed effects models, which is robust to heterogeneity.[47] However, some of our measures were not normally distributed, so we examined the residual plots to verify that the results were usable (see Appendix A for histograms of distributions and residuals). As this was a within-participants experiment, all models used participant ID as a random effect unless otherwise stated.

Results

Baseline characteristics

Participants were primarily undergraduate and graduate students from the authors' affiliated institution (Table 1) and

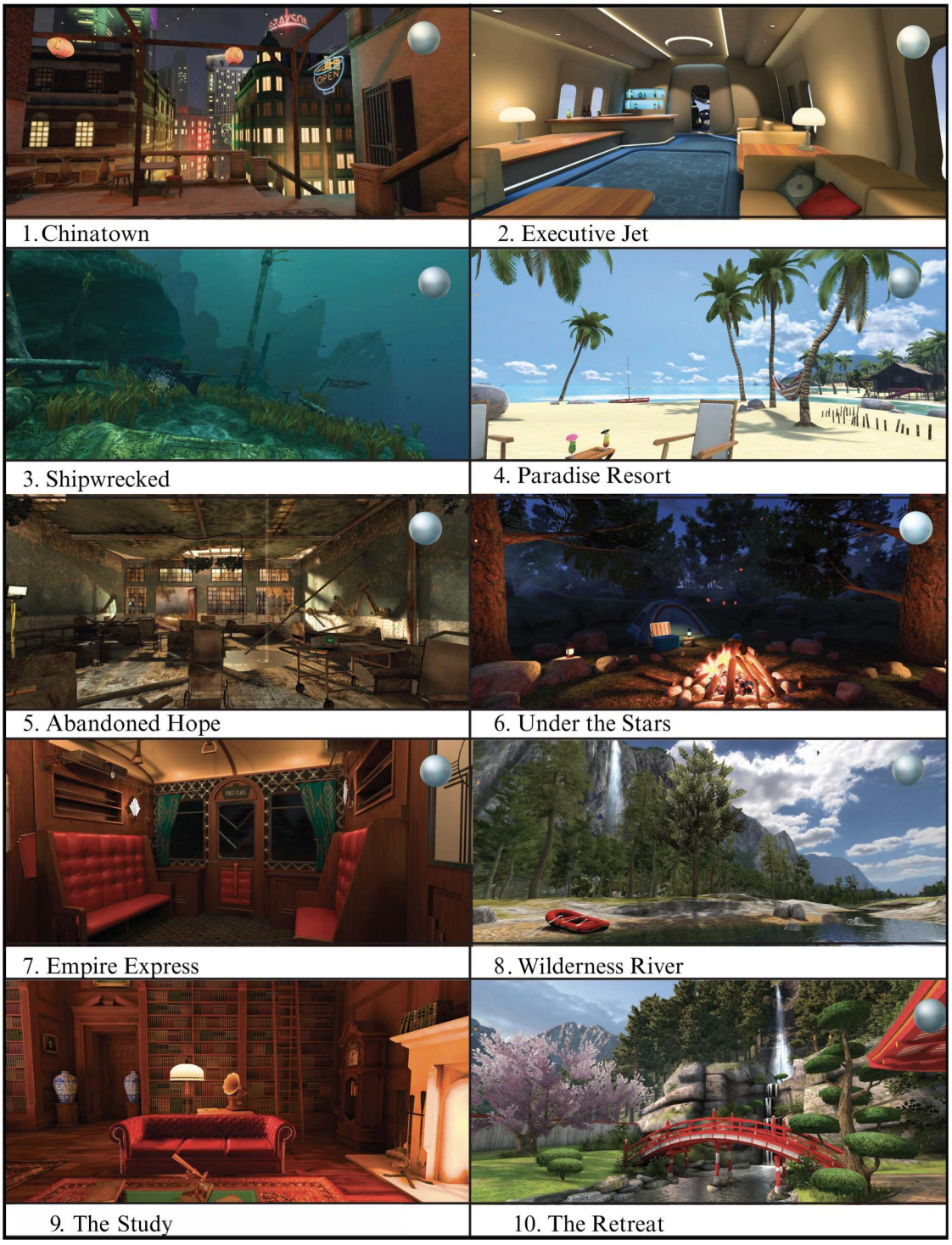

Figure 2. Visual examples of the 10 distinct virtual environments used from the commercial app vTime XR. Each environment offers a unique setting designed to immerse participants, ranging from urban scenes and serene natural landscapes to cozy indoor spaces and vintage interiors.

were enrolled and completed the study from October 19, 2021, to May 5, 2023. While we enrolled a total of 86 participants, 16 were excluded (Figure 4).

Order effects

Order ($(3207) = 5.135$, $P = 0.002$) was associated with participants' pain thresholds, with a statistically significant difference between the first and final pain threshold measures ($\beta = 0.536$, SE = 0.152, $t = 3.526$, $P < 0.001$). Order was also statistically significant when comparing participants' first and final subjective pain ratings ($\beta = 0.886$, SE = 0.134, $t = 6.637$, $(3207) = 16.154$, $P < 0.001$) such that pain thresholds were higher in the final task than in the first. Pain threshold temperatures and pain ratings correlated positively, meaning that people rated their pain higher when they kept their hand on the thermode to a higher temperature, regardless of whether we included order

Figure 3. Examples of avatars participants could customize in vTime XR. The top row shows the default stock avatars available as starting points. The bottom row displays examples of avatars after participants personalized features such as appearance and clothing.

Table 1. Participant demographic characteristics and average social closeness to partner by condition.

Variable	*n*	%
Gender distribution		
Female	48	68.6
Male	19	27.1
Preferred not to say	3	4.3
Race/Ethnicity distribution		
Black	3	4.3
Caucasian/White	12	17.1
East Asian	33	47.1
Hispanic/Latinx	4	5.7
Multiracial	2	2.9
South Asian	11	15.7
South East Asian	2	2.9
Unknown/Did not report	3	4.3
Age distribution		
18–22 years old	62	88.6
23 years old or more	5	7.1
I prefer not to answer	3	4.3
	M	
Social closeness by social condition		
Companion VR	4.16	
Stranger VR	3.72	
Zoom with companion	4.33	

Gender, race/ethnicity, and age distributions are presented as counts and percentages. The majority of participants identified as female (68.6%) and were between 18 and 22 years old (88.6%). Race/ethnicity data reflect a diverse sample, with the largest group identifying as East Asian (47.1%). Social closeness was assessed on a 5-point scale and averaged by each social condition: Companion VR ($M = 4.16$), Stranger VR ($M = 3.72$), and Zoom with companion ($M = 4.33$).

in the model ($\beta = 0.131$, SE $= 0.049$, $t = 2.668$, $(1267.13) = 7.116$, $P = 0.008$) or not ($\beta = 0.190$, SE $= 0.051$, $t = 3.731$, $(1266.850) = 13.918$, $P < 0.001$).

Virtual environments

Different virtual environments were marginally associated with pain threshold ($F(9132.64) = 1.919$, $P = 0.054$), while using condition as a fixed effect, with a statistically significant difference between the environments "Abandoned Hope" and "Under the Stars," such that pain threshold temperatures were lower in "Abandoned Hope" ($\beta = -1.187$, SE $= 0.313$, $t = -3.795$, $P = 0.008$). There was no significant interaction between pain rating and virtual environment $(9132.43) = 0.748$, $P = 0.664$).

Solo compared to social interaction

First, we examined the effects of solo versus social virtual reality experiences. Our model included order and environment as fixed effects and participant ID as a random effect. Experiencing a social VR condition (whether Stranger VR or Companion VR) was associated with higher pain thresholds compared to the Alone VR condition ($\beta = 0.288$, SE $= 0.135$, $t = 2.138$, $(1127.340) = 4.572$, $P = 0.034$) (on average 0.310 °C). However, there were no significant differences between conditions on pain ratings ($\beta = 0.072$, SE $= 0.133$, $t = 0.537$, $(1127.920) = 0.288$, $P = 0.592$). When we did not include environment in the model, the results for pain threshold ($\beta = 0.178$, SE $= 0.128$, $t = 1.396$, $(1136.010) = 1.950$, $P = 0.165$) and pain rating ($\beta = 0.019$, SE $= 0.124$, $t = 0.156$, $(1136.020) = 0.024$, $P = 0.877$) were not statistically significant.

Comparing companions and strangers

Using order and environment as fixed effects, we found no statistically significant difference between pain threshold temperatures in the Stranger VR condition compared to the

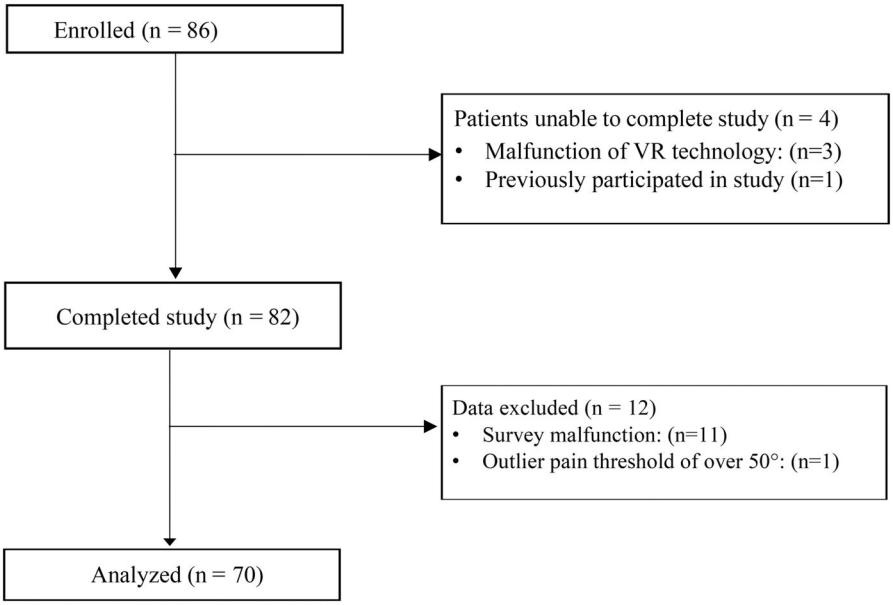

Figure 4. CONSORT chart depicting the total enrolled participant pairs (86), number who completed the study (82), and the number of usable datasets (70). Reasons for participant dropout or unusable data are also shown.

Companion VR condition ($\beta = -0.117$, SE = 0.145, $t = -0.807$, (1,58.195) = 0.651, $P = 0.423$). Nor was there a significant effect on subjective pain rating ($\beta = -0.153$, SE = 0.132, $t = -1.161$, (1,58.773) = 1.347, $P = 0.250$). Removing environment did not change these results for pain threshold temperatures ($\beta = -0.085$, SE = 0.146, $t = -0.586$, (1,66.219) = 0.344, $P = 0.560$) nor pain ratings ($\beta = -0.098$, SE = 0.128, $t = -0.760$, (1,66.202) = 0.577, $P = 0.450$).

Comparing virtual reality to teleconferencing

Zoom does not feature virtual environments, so order was the only fixed effect included in this model. There were no statistically significant differences between Zoom and Companion VR conditions in either pain threshold ($\beta = -0.141$, SE = 0.159, $t = -0.887$, (1,66.551) = 0.787, $P = 0.378$), or reported pain ($\beta = -0.089$, SE = 0.149, $t = -0.599$, (1,66.908) = 0.358, $P = 0.551$) (Table 2).

Participant preference for condition

The largest number of participants (16) specified Companion VR as their preference (Table 3), with 23 describing this condition without specifically naming it. Because the answers were open-ended, we classified participants' answers in 2 ways. Sometimes, participants mentioned a specific experimental condition. Other times, they described a particular virtual environment, like "a beach resort" which mapped to a condition they experienced. Others stated a more general preference, ie, for any social condition, or any virtual reality condition. Participant responses categorized by description, with representative quotes, are shown in Table 4.

Cortisol

We used cortisol as a predictor for pain threshold and included order as a fixed effect. In a second analysis, we added gender as an additional fixed effect. There were no statistically significant differences in cortisol means between conditions, gender, or time points (all P values > 0.050). The same was true of pain ratings and temperatures. There was a rise in cortisol levels between the first 3 samples (the initial sample and the samples following the 2 "practice" tasks) and experimental conditions ((1399) = 41.970, $P < 0.001$), but no significant differences between the experimental conditions themselves.

In addition, social closeness was not associated with cortisol levels when order and condition were included as fixed effects ($\beta = 0.003$, SE = 0.009, $t = 0.348$, (1183.01) = 0.121, $P = 0.729$).

Table 2. Average pain threshold temperatures and pain ratings in each condition.

Condition	Pain temp.	Pain rating
Stranger VR	44.981° (SD = 2.890)	5.800 (SD = 2.054)
Companion VR	44.950° (SD = 2.783)	5.757 (SD = 2.060)
Alone VR	44.722° (SD = 2.755)	5.686 (SD = 2.033)
Zoom with companion	44.830° (SD = 2.845)	5.829 (SD = 2.014)

Values represent means with standard deviations in parentheses. Pain threshold temperatures were measured in degrees Celsius, and pain ratings were collected using a 1 (no pain) to 10 (worst pain imaginable) numeric rating scale.

Presence

Previous studies have shown[48] that presence in a virtual environment can affect pain perception. To investigate this, we created models predicting pain with environmental and social presence using order, condition, and environment as fixed effects and individual ID as a random effect, for the virtual reality environments only.

However, the more environmental presence participants reported feeling in virtual reality, the *higher* their reported pain ($\beta = 0.412$, SE = 0.138, $t = 2.994$, (1157.240) = 8.964, $P = 0.003$), though the effect did not persist in pain threshold temperatures.

Social presence was similarly associated with pain rating, but not pain temperature thresholds. The more socially present the participant felt with their partner, the higher their

Table 3. Frequency at which each condition was chosen as the most helpful for handling the pain task.

Condition	Frequency by condition	Frequency by description
Companion in VR	16	23
Stranger in VR	8	11
Zoom with companion	5	5
Alone in VR	3	5
Any social	8	8
Any VR	2	2
Any with companion	7	7
Any social VR	2	2
Ambiguous Answer	4	4
Environment-specific answer	12	NA

Participants were asked to indicate what they found most helpful. Some responses named a specific experimental condition (eg, "Companion in VR"), while others referred to a particular virtual environment (eg, "a beach resort"), which was mapped to the condition they experienced. Additional responses reflected general preferences (eg, "any social" or "any VR" condition). Frequencies are reported both by original experimental condition and by participants' descriptive categorizations.

pain rating ($\beta = 0.207$, SE = 0.092, $t = 2.245$, (1145.360) = 5.039, $P = 0.026$).

Word count

At reviewer request, we tested a model that included condition and order as fixed effects. Word count did vary based on condition ((2,97.731) = 11.121, $P =< 0.001$), with Zoom featuring the highest word count and Companion VR the lowest (see Table 5). However, we found no significant relationship between word count and pain threshold temperature ($\beta =< 0.001$, SE =< 0.001, $t = 1.606$, (1109.484) = 2.580, $P = 0.111$) or pain rating ($\beta =< 0.001$, SE. =< 0.001, $t = -1.383$, (1116.403) = 1.913, $P = 0.169$).

Discussion

In this article, we examined the effects of social interactions with companions and strangers in virtual reality and Zoom on participants' pain thresholds, self-reported pain, and preferences for conditions. Participants reported a strong preference for interacting with their companions in social virtual reality as compared to other conditions (see Table 3). Somewhat replicating previous work,[44] we found that social interactions were significantly associated with higher pain thresholds, with higher thresholds in social VR compared to other conditions. However, removing environment from the model also removed the statistically significant difference between the solo and social VR conditions. While we recognize the impact environment can have on experience, and thus sampled multiple environments for stimuli to avoid unexpected confounds with the content of a specific environment, this was an unexpected finding. One explanation could be that different environments could include more content to discuss with partners or content that interacts with the type of pain participants experienced (for example, cool underwater or icy scenes).

While the largest number of participants preferred interacting with their companions in virtual reality, individual differences were notable. For example, one participant felt they could "tolerate the pain more if I'm alone as there are fewer distractions," while another preferred the Companion VR condition because "we were having an engaging conversation and I felt the most distracted from the pain."

Our most unexpected finding was the positive association between pain ratings and social and environmental presence. Other studies have shown that increased presence lowers pain ratings.[48–50] We believe this highlights the special nature of the induced pain task, where participants kept their hands on the thermode until they became uncomfortable. Thus, participants who experienced higher pain thresholds actually felt more heat and reported more pain.

Limitations

A key limitation (shared with most induced pain studies) is that our participants were predominantly young and healthy volunteers who experienced mild, controlled, anticipated pain, not clinical pain. We also did not assess whether or not participants had pre-existing chronic pain conditions. Nonetheless, we believe these results are a valuable precursor, informing further investigation of social interactions in virtual reality for individuals experiencing real pain in non-experimental settings.

An unexpected factor that may have influenced our results is the social support that RAs provided to the participants. Despite being instructed to behave "neutrally," participants actually spoke more to RAs, who were, after all, their peers, in the social virtual reality conditions than they did with the companions they brought to the lab (Table 5). Although RAs were reassigned to prevent direct interactions with friends, at least one participant specifically told the RAs they appreciated their support. This resembles a comment left in the survey, "it was great when my questions could be answered in a second [by the RA]."

A potential limitation is the potential effects of human error arising from the fact that the time when the participant removes their hand from the thermode is manually recorded by the RA's button press. To address this, the RAs were blind to the study hypotheses and thoroughly trained on the machine. The fact that participants' self-report of their pain threshold was statistically significantly associated with the temperature at which they removed their hands from the thermode also reassures us about the reliability of these results.

One area in which we do not feel our results are reliable is, unfortunately, in the area of cortisol measurement. We feel that individual differences in the timing of cortisol release were likely not captured by our study design, meaning that our results do not provide useful information about the relationship between cortisol and induced pain.

Next steps

As described in our pre-registration, we aim to assess how pain threshold may be linked to the content of the conversation, for example, the number of words spoken, percentage of comfort words spoken, or topics of conversation (ie, pain vs no pain).

Another potential avenue of study could examine more engaging interactions, such as playing social games in VR rather than simply conversing.

In addition, the role of both participant and companion embodiment could be explored by asking both participants and companions about their perceptions of the resemblance of each other's avatars.

Table 4. Descriptions of and quotes from participants' preferred conditions.

Condition	Description of category	Representative quote
Alone VR	The participant experiences a VR environment solo	"I feel I could tolerate the pain more if I'm alone as there are fewer distractions and I could just focus on my sensations. But when I talk to my strangers, I couldn't tolerate the pain and conversation was distracting."
Companion in VR	The participant experiences VR with their companion	"i feel like in a virtual reality with my friend helps moderate the pain because i'm put into a new environment with new stuffs to explore, and the environment calms me. the presence of a friend definitely make the environment more engaging and approachable."
Stranger in VR	The participant experiences a VR environment with a "stranger" RA	"I also feel strangely that talking to the stranger actually distracts more from the pain. Maybe because with my friend, I know I am allowed to be a little distracted from our conversation, and thus the pain is felt more easily; while when talking with a stranger, I think there's a social norm of being focused and respect the other, and thus I'm focused on catching new information and respond promptly. So I feel more distracted from the pain."
Zoom with companion	The participant Zooms with their companion	"I think the experience C when talking to my partner over Zoom was most helpful with the pain task. I was able to engage and talk to my partner easily which helped distract me from the pain."
Any social	Participant stated a preference for any condition in which they were speaking to another person	"I think the experiences with other people helped distract me. Also the more stimulating environment I was in, I felt more distracted. I would say either the stranger or the friend experience I probably lasted longest in."
Any VR	Participant endorsed any condition where they were in VR, whether solo or social	"The Vr experience because it make me understand that I can connect with others or relax in virtual environment."
Any with companion	Participant preferred any condition where they were talking to their companion	"I thought when I was talking to my friend, because we were having an engaging conversation and I felt the most distracted from the pain."
Any social VR	Any condition where the participant speaks to another person in VR	"I thought that the VR experiences where I was speaking to someone else were the most helpful for distracting me from the heat sensation. I felt like I was more willing to wait for longer, because the heat wasn't the main thing I was focusing on."
Ambiguous answer	Answer mentions several things, or things irrelevant to the experimental condition	"calming VR environment, real life face contact with a familiar person."

This table summarizes each response category referenced in Table 3, provides a brief description, and includes a representative quote. These qualitative responses illustrate participants' reasoning and highlight the subjective nature of what made an experience "helpful" during the pain task.

Table 5. Average number of words spoken in each condition.

Condition	Average word count (SD)
Companion VR	323.38 (SD = 129.29)
Stranger	387.18 (SD = 131.70)
Zoom	426.72 (SD = 125.53)

Values represent means with standard deviations in parentheses. Conditions included Companion VR, Stranger VR, and Zoom with companion.

Finally, given the advent of generative AI, one obvious area to explore would be the use of embodied agents to provide social interaction in virtual environments when friends and family members are not available. However, this opportunity should not distract researchers from the value of providing people a new way to support loved ones who are undergoing a painful experience, as this can benefit both patients and those who love them.

Conclusion

In this study, we found that the greatest number of participants preferred interacting with companions in virtual reality during an induced pain task, compared to other conditions, although there were considerable individual differences. While participants' pain thresholds and ratings were not significantly different in Zoom than virtual reality, participants' strong preference for social virtual reality with companions suggests some useful avenues for future research. In addition, we partially replicate previous work demonstrating higher pain thresholds in induced pain tasks in social virtual reality experiences when compared with solo virtual reality experiences. However, participants also found value in interacting with strangers from their peer group. This adds context to previous findings pointing to social virtual reality as a promising opportunity to improve the therapeutic applications of virtual reality.

Acknowledgments

The authors would like to thank all of the Cornell research assistants who supported this project by assisting with data collection: Ph.D. Students Stephanie Belina, Julie Cannon, Ria J. Gualano, Yeonju Jang, Hyunju Kim, Swati Pandita, and Jonathan Segal; Masters students Eshaan Kaul, Lily Lin, Jhovanna Perez, Yejoon Yoo, Kexin Zhang; and Undergraduates Emily Chin, Stella Dong, Vera Gaddi, Anabella Maria Galang, James Huang, Krisha Jivani, Yohanes Kidane, Isabella LaHaye, Clara Lee, Josh Levine, Haotian Ma, Jessica Mandel, Marcus Posey, Noah Rebei, Samuel Rodriguez, Piero Salas-Allende, Krupa Sekhar, Stephanie Tan, Zixin "Coco" Xu, Ingrid Zhu, and Xinlu Zhou. They would also like to thank Stephen Parry for his

help with statistical analysis. This study was supported in part by the President's Council of Cornell Women.

Supplementary material

Supplementary material is available at *Pain Medicine* online.

Funding

This study received $10 000 from the President's Council of Cornell Women's Affinito Stewart Award. It received no external funding.

Conflicts of interest: Co-author A.S.W. has previously received funding from Meta.

References

1. Wilson JM, Colebaugh CA, Flowers KM, Edwards RR, Schreiber KL. Profiles of risk and resilience in chronic pain: loneliness, social support, mindfulness, and optimism coming out of the first pandemic year. *Pain Med*. 2022;23(12):2010-2021. https://doi.org/10.1093/pm/pnac079.
2. Matthias MS, Hirsh AT, Ofner S, Daggy J. Exploring the relationships among social support, patient activation, and pain-related outcomes. *Pain Med*. 2022;23(4):676-685. https://doi.org/10.1093/pm/pnab306.
3. Yang Y, Grol-Prokopczyk H, Reid MC, Pillemer K. The relationship between pain and psychological distress during the COVID-19 pandemic: is social technology use protective? *Pain Med*. 2022;23(2):280-287. https://doi.org/10.1093/pm/pnab262.
4. Che X, Cash R, Ng SK, Fitzgerald P, Fitzgibbon BM. A systematic review of the processes underlying the main and the buffering effect of social support on the experience of pain. *Clin J Pain*. 2018;34(11):1061-1076. https://journals.lww.com/clinicalpain/fulltext/2018/11000/a_systematic_review_of_the_processes_underlying.10.aspx.
5. Kuntz JG, Kavalieratos D, Esper GJ, et al. Feasibility and acceptability of inpatient palliative care e-family meetings during COVID-19 pandemic. *J Pain Symptom Manage*. 2020;60(3):e28-32-e32.
6. Coan JA, Schaefer HS, Davidson RJ. Lending a hand. *Psychol Sci*. 2006;17(12):1032-1039. https://doi.org/10.1111/j.1467-9280.2006.01832.x.
7. Montoya P, Larbig W, Braun C, Preissl H, Birbaumer N. Influence of social support and emotional context on pain processing and magnetic brain responses in fibromyalgia. *Arthritis Rheum*. 2004;50(12):4035-4044. https://doi.org/10.1002/art.20660.
8. Roberts MH, Klatzkin RR, Mechlin B. Social support attenuates physiological stress responses and experimental pain sensitivity to cold pressor pain. *Ann Behav Med*. 2015;49(4):557-569. https://doi.org/10.1007/s12160-015-9686-3.
9. Floyd K, Ray CD, van Raalte LJ, Stein JB, Generous MA. Interpersonal touch buffers pain sensitivity in romantic relationships but heightens sensitivity between strangers and friends. *RPBS*. 2018;6(1):27-34. https://doi.org/10.12691/rpbs-6-1-4.
10. Chambers CT, Craig KD, Bennett SM. The impact of maternal behavior on childrens pain experiences: An experimental analysis. *J Pediatr Psychol*. 2002;27(3):293-301. https://doi.org/10.1093/jpepsy/27.3.293.
11. Master SL, Eisenberger NI, Taylor SE, Naliboff BD, Shirinyan D, Lieberman MD. A pictures worth. *Psychol Sci*. 2009;20(11):1316-1318. https://doi.org/10.1111/j.1467-9280.2009.02444.x.
12. Carrougher GJ, Hoffman HG, Nakamura D, et al. The effect of virtual reality on pain and range of motion in adults with burn injuries. *J Burn Care Res*. 2009;30(5):785-791.
13. JahaniShoorab N, Zagami SE, Nahvi A, et al. The effect of virtual reality on pain in primiparity women during episiotomy repair: a randomize clinical trial. *Iran J Med Sci*. 2015;40(3):219-224. https://api.semanticscholar.org/CorpusID : 14919641.
14. Indovina P, Barone D, Gallo L, Chirico A, De Pietro G, Giordano A. Virtual reality as a distraction intervention to relieve pain and distress during medical procedures. *Clin J Pain*. 2018;34(9):858-877.
15. Gupta A, Scott K, Dukewich M. Innovative technology using virtual reality in the treatment of pain: Does it reduce pain via distraction, or is there more to it? *Pain Med*. 2018;19(1):151-159.
16. Karaman D, Erol F, Yılmaz D, Dikmen Y. Investigation of the effect of the virtual reality application on experimental pain severity in healthy. *Rev Assoc Med Bras (1992)*. 2019;65(3):446-451.
17. Faraj MM, Lipanski NM, Morales A, et al. A virtual reality meditative intervention modulates pain and the pain neuromatrix in patients with opioid use disorder. *Pain Med*. 2021;22(11):2739-2753. https://doi.org/10.1093/pm/pnab162.
18. Sato K, Fukumori S, Matsusaki T, et al. Nonimmersive virtual reality mirror visual feedback therapy and its application for the treatment of complex regional pain syndrome: An open-label pilot study. *Pain Med*. 2010;11(4):622-629. https://api.semanticscholar.org/CorpusID : 6339807.
19. Schmitt YS, Hoffman HG, Blough DK, et al. A randomized, controlled trial of immersive virtual reality analgesia, during physical therapy for pediatric burns. *Burns*. 2011;37(1):61-68.
20. Brown NJ, Kimble RM, Rodger S, Ware RS, Cuttle L. Play and heal: randomized controlled trial of Ditto™ intervention efficacy on improving re-epithelialization in pediatric burns. *Burns*. 2014;40(2):204-213.
21. Olbrecht VA, O'Conor KT, Williams SE, et al. Transient reductions in postoperative pain and anxiety with the use of virtual reality in children. *Pain Med*. 2021;22(11):2426-2435. https://doi.org/10.1093/pm/pnab209.
22. Hoffman HG, Patterson DR, Carrougher GJ. Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: a controlled study. *Clin J Pain*. 2000;16(3):244-250. https://journals.lww.com/clinicalpain/fulltext/2000/09000/use_of_virtual_reality_for_adjunctive_treatment_of.10.aspx.
23. Campbell AG, Holz T, Cosgrove J, Harlick M, O'Sullivan T. Uses of virtual reality for communication in financial services: A case study on comparing different telepresence interfaces: Virtual reality compared to video conferencing. In: Adv. Inf. Commun. Proc. 2019 Future Inf. Commun. Conf. FICC Vol. 1. Springer; 2020. 463-481.
24. Speidel R, Felder E, Schneider A, Öchsner W. Virtual reality against Zoom fatigue? A field study on the teaching and learning experience in interactive video and VR conferencing. *GMS J Med Educ*. 2023;40(2):Doc19.
25. Won AS, Pandita S, Kruzan KP. Social interaction and pain threshold in virtual reality. *Cyberpsychol Behav Soc Netw*. 2020;23(12):829-845.
26. Neumann I, Käthner I, Gromer D, Pauli P. Impact of perceived social support on pain perception in virtual reality. *Comput Hum Behav*. 2023;139:107490.
27. Reddan MC, Young H, Falkner J, López-Solà M, Wager TD. Touch and social support influence interpersonal synchrony and pain. *Soc Cogn Affect Neurosci*. 2020;15(10):1064-1075. https://doi.org/10.1093/scan/nsaa048.
28. Brown JL, Sheffield D, Leary MR, Robinson ME. Social support and experimental pain. *Psychosom Med*. 2003;65(2):276-283.
29. Guillory JE, Hancock JT, Woodruff C, Keilman J. Text messaging reduces analgesic requirements during surgery. *Pain Med*. 2015;16(4):667-672.
30. Won AS. Preregistration for "the effects of companionship from strangers and companions on pain thresholds in immersive virtual reality: A randomized controlled trial." 2021. https://osf.io/32cqt/? view_only=19365ee6ff934a62946cd2dcf1a0c854.
31. Choi JC, Chung MI, Lee YD. Modulation of pain sensation by stress-related testosterone and cortisol. *Anaesthesia*. 2012;67(10):1146-1151.

32. Ketay S, Beck LA. Attachment predicts cortisol response and closeness in dyadic social interaction. *Psychoneuroendocrinology*. 2017;80:114-121.
33. Bozovic D, Racic M, Ivkovic N. Salivary cortisol levels as a biological marker of stress reaction. *Med Arch*. 2013;67(5):374-377.
34. Hannibal KE, Bishop MD. Chronic stress, cortisol dysfunction, and pain: a psychoneuroendocrine rationale for stress management in pain rehabilitation. *Phys Ther*. 2014;94(12):1816-1825.
35. Van Eck MM, Nicolson NA. Perceived stress and salivary cortisol in daily life. *Ann Behav Med*. 1994;16(3):221-227.
36. Muhtz C, Rodriguez-Raecke R, Hinkelmann K, et al. Cortisol response to experimental pain in patients with chronic low back pain and patients with major depression. *Pain Med*. 2013;14(4):498-503.
37. Evans KD, Douglas B, Bruce N, Drummond PD. An exploratory study of changes in salivary cortisol, depression, and pain intensity after treatment for chronic pain. *Pain Med*. 2008;9(6):752-758.
38. Kenwright M. vTime XR. vTime Holdings Limited; 2021.
39. Granot M, Sprecher E, Yarnitsky D. Psychophysics of phasic and tonic heat pain stimuli by quantitative sensory testing in healthy subjects. *Eur J Pain*. 2003;7(2):139-143. https://www.sciencedirect.com/science/article/pii/S1090380102000873.
40. Ltd M. Q-sense technical reference service manual. 6th ed.; 2018.
41. Petrowski K, Wintermann GB, Siepmann M. Cortisol response to repeated psychosocial stress. *Appl Psychophysiol Biofeedback*. 2012;37(2):103-107. https://doi.org/10.1007/s10484-012-9183-4.
42. Smyth N, Hucklebridge F, Thorn L, Evans P, Clow A. Salivary cortisol as a biomarker in social science research. *Soc Pers Psych*. 2013;7(9):605-625. https://doi.org/10.1111/spc3.12057.
43. Breivik H, Borchgrevink PC, Allen SM, et al. Assessment of pain. *Br J Anaesth*. 2008;101(1):17-24. https://doi.org/10.1093/bja/aen103.
44. Won A, Perone B, Friend M, Bailenson J. Identifying anxiety through tracked head movements in a virtual classroom. *Cyberpsychology Behav Soc Netw*. 2016;19(6):380-387.
45. R Core Team. R: A language and environment for statistical computing. Vienna, Austria; 2019. R Foundation for Statistical Computing. https://www.R-project.org/.
46. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw*. 2015;67(1):1-48.
47. Knief U, Forstmeier W. Violating the normality assumption may be the lesser of two evils. *Behav Res Methods*. 2021;53(6):2576-2590.
48. Hoffman H, Sharar S, Coda B, et al. Manipulating presence influences the magnitude of virtual reality analgesia. *Pain*. 2004;111(1-2):162-168.
49. Gutierrez-Martinez O, Gutierrez-Maldonado J, Cabas-Hoyos K, Loreto D. The illusion of presence influences VR distraction: effects on cold-pressor pain. *Stud Health Technol Inform*. 2010;154:155-159.
50. Brown P, Powell W, Dansey N, Al-Abbadey M, Stevens B, Powell V. Virtual reality as a pain distraction modality for experimentally induced pain in a chronic pain population: an exploratory study. *Cyberpsychol Behav Soc Netw*. 2022;25(1):66-71. https://doi.org/10.1089/cyber.2020.0823

Pain Medicine, 2025, 26, 702–711
https://doi.org/10.1093/pm/pnaf120
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