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Social Interaction and Pain Threshold in Virtual Reality

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Abstract

This experiment examined the effects of social presence and perceived location of a virtual environment on participants' pain thresholds in a preregistered, within-subjects experiment. First, we examined the effects of social interaction versus being alone in a virtual environment. Second, we compared a virtual environment representing a remote location to a replication of the laboratory environment. Social interaction predicted increased pain tolerance, but there was no effect of the ''location'' of the virtual environment. To our knowledge, this research project is the first to use real-time social interaction in virtual reality as a distractor for experimental thermal pain, and the first to examine the potential interaction between social interaction and transportation to different virtual locations. While this task is not directly analogous to the experience of pain in a medical setting, this preliminary study indicates future avenues for patient treatment. Clinical Trial Registration number: 1701006910

Keywords: virtual reality, pain, social presence, social closeness, transportation, induced pain

Introduction

This experiment examined the effects of social presence and perceived location of a virtual environment on participants' pain thresholds in a preregistered, within-subjects experiment. First, we examined the effects of social interaction versus being alone in a virtual environment. Second, we compared a virtual environment representing a remote location to a replication of the laboratory environment. While the ''location'' of the virtual environment did affect social presence, such that participants reported greater social presence with participants who were co-located, location did not predict pain threshold. However, social interaction did predict increased pain threshold in the induced experimental thermal pain task. In other words, participants kept their hand on the hot thermode longer when interacting socially with another person. To the best of our knowledge, this is the first use of real-time social interaction in virtual reality (VR) as a distractor for experimental thermal pain, as well as the first to examine the potential interaction between social interaction and transportation to different virtual locations. While this task is not directly analogous to the experience of pain in a medical setting, this preliminary study indicates future avenues for patient treatment.

Some of the earliest clinical applications of VR were interventions for acute pain.[1–3] Much existing research has examined the distractive qualities of VR for pain patients.[4–9] In particular, *presence*, or the ''illusion of going into the virtual world''[10] may aid in distraction. However, especially with the advent of consumer VR, there are now other ways to augment the effectiveness of VR, including adding social interaction.[11]

VR replaces sensory information from the physical world with sensations that create the illusion of a virtual environment and/or a body that can act in a virtual environment.[12,13] Previous work found that self-reported presence in virtual environments correlates with reduced pain.[14,15] When a person in pain subjectively feels that they are *not* present in the real-world location of the painful stimulus, their sense of actual or potential damage may be less, and therefore their pain tolerance may be greater.[12] Thus, one component of virtual environments that may affect pain perception is their ability to ''transport'' participants to locations other than the hospital, their home, or other places where they are experiencing pain.[16]

Today's virtual environments can also allow for social interaction. Social interaction in itself can be a distractor, and also increase presence.[17] Social interactions in VR may augment users' feeling of being transported to a virtual environment. This could reduce their sense of presence in their physical surroundings, which may be a hospital or location with negative associations.[18]

The sense of transportation could be augmented by social presence, or the sense of being with another person in a mediated environment.[19–21] In a study that found social interaction surpassed distraction only, participants who texted

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Table 1. Exclusion Criteria

Grounds for exclusion	*No. of participants excluded*
Did not complete the experiment or estimated distance of less than 1 mile	16
Failed the manipulation check by misidentifying one of the target cities described by their conversational partner	11
Participant could not see partner's avatar due to technical issues	1
Exceeded the maximum temperature on sensor	1
Excused for sickness	1
Stated in their free responses that they did not believe their conversational partner was another student	4
Stated that they were distracted or not paying attention during the chat	4

Reasons for exclusion of 38 participants (out of total of 105).

with a stranger while undergoing surgery required less analgesia than either those who texted with a loved one, or those who played a game on their phone.[22] While the authors suggest that the chats' contents may have affected pain levels, these patients may also have felt ''present'' with the people, with whom they were texting. When texting with strangers, they may have felt transported to the location of the strangers, who were outside the hospital. This could be more effective than feeling present with loved ones, who were located in the hospital waiting room. Thus, while this study supports the hypothesis that social interaction is a distractor in itself, it also leads us to ask whether a feeling of social presence could mentally transport participants to a virtual environment that is not associated with the painful stimulus.

However, feelings of transportation could also occur through feelings of social closeness with a participant's partner. Measures of social closeness have been associated with altered perceptions of distance.[23] Participants who report social closeness with conversational partners may underestimate distances to them. Thus, we also sought to investigate whether feeling socially close to someone far away could enhance a feeling of transportation away from a person's current location.

In a within-subjects experiment, we tested two different conditions for pain relief in an immersive virtual environment. First, we examined the effects of social interaction in an immersive virtual environment. We hypothesized that social interaction in a mediated environment would increase pain threshold compared to an environment without social interaction (H1). Second, we examined the effect of VR's ability to transport individuals. We hypothesized that participants experiencing a distant location would demonstrate a higher pain threshold (H2). Next, we examined the effect of distance on social presence. We hypothesized that interacting with a co-located partner, as opposed to someone in another city, would increase social presence (H3). We also hypothesized an interaction between social presence and location such that participants who reported higher social presence with a partner located in another city would demonstrate a higher pain threshold (H4).

Finally, we asked four research questions. Does social presence correlate with social closeness measures (RQ1)? Is social closeness affected by distance (RQ2)? Do social presence and social closeness affect pain threshold differently (RQ3)? Finally, since individual reactions to experimentally induced pain may differ by gender,[24] does gender modify these effects (RQ4)?

To our knowledge, this research project is the first to include real-time social interaction in VR as a distractor for experimental thermal pain, to examine the potential interaction between social interaction and transportation to different virtual locations, and to compare the effects of social closeness and social presence on pain threshold. We hope that this initial study can indicate future avenues for patient treatment.

Materials and Methods

This study was preregistered, and all study materials are in this repository: https://osf.io/tv7zx/?view_only=8cb85817340e4a798ae84a665f83daaf. It was approved by the Cornell IRB, and all participants signed informed consent.

Our 2×2 within-subjects design included five experimental pain stimulations. First was the ''Practice'' experimental pain stimulation, which served as a training task for the participants. Then, four more experimental pain stimulations were applied in a random order, in conditions crossing two factors.

Factor one, *Social*, included two conditions. In the ''Together'' condition, participants spoke with a research assistant confederate represented by an avatar. In the ''Alone'' condition, they were alone and were instructed to look around the virtual environment. Factor two, *Distance*, included two conditions. In the ''Near'' condition, participants experienced a virtual version of the actual laboratory room, and the conversational partner was in that physical room (although both wore head-mounted displays [HMDs]). In the ''Far'' condition, participants experienced a different virtual room, and believed their partner was connecting from another university.

Participants

Our power analysis was based on a between-subjects pilot study comparing near and far virtual environments, which suggested 48.5 participants for a power of 0.8.[25] However, to account for data loss, we preregistered a goal of 75

Table 2. Participant Demographic Information

Black American	*Multiracial*	*Black non-American*	*Caucasian*	*East Asian*	*Hispanic/Latinx*	*Pacific Islander*	*Southeast Asian*	*None of the above*
6	2	2	25	20	8	3	7	1

FIG. 1. Screenshot of the near condition.

participants. While running, we reviewed the survey responses and experimental notes on a rolling basis until we reached 75 participants who passed the exclusion criteria on this preliminary examination of the survey. Table 1 shows our exclusion criteria. This procedure resulted in 105 participants recruited from the community of a large U.S. university. All participants received course credit or a cash payment.

Thirty-eight participants were eliminated following preregistered exclusion criteria (8 after the study ended), leaving 67 participants (23 male, one nonreporting). Participants' self-reported race and ethnicity are reported in Table 2.

All procedures were approved by the Institutional Review Board, and all participants signed informed consent.

Experimental environments

Using the Oculus Rift system, participants experienced two virtual environments created using Unity3D. The ''Near'' virtual environment was a replication of the actual room in which the participant and their conversational partner were located (Fig. 1), while the ''Far'' condition represented another, similar laboratory room (Fig. 2). Participants and the research assistants who served as their conversational partners wore Oculus Rift headsets (oculus.com) and used Touch hand controllers to control the movements of their avatars. Participants conversed through the headset audio when their conversational partner was in the other room, and by voice when they were co-located. Figures 3–6 show the positions of the participants, research assistants, and research assistant confederates for each condition.

Participants controlled a generic avatar created in Mixamo (Fuse), which was selected by the research assistant to approximately match participants' skin tones. Avatar movements followed the tracked movements of the users' heads and hands. Their conversational partners were provided avatars of the same appearance. Figure 7 shows the avatars.

FIG. 2. Screenshot of the far condition.

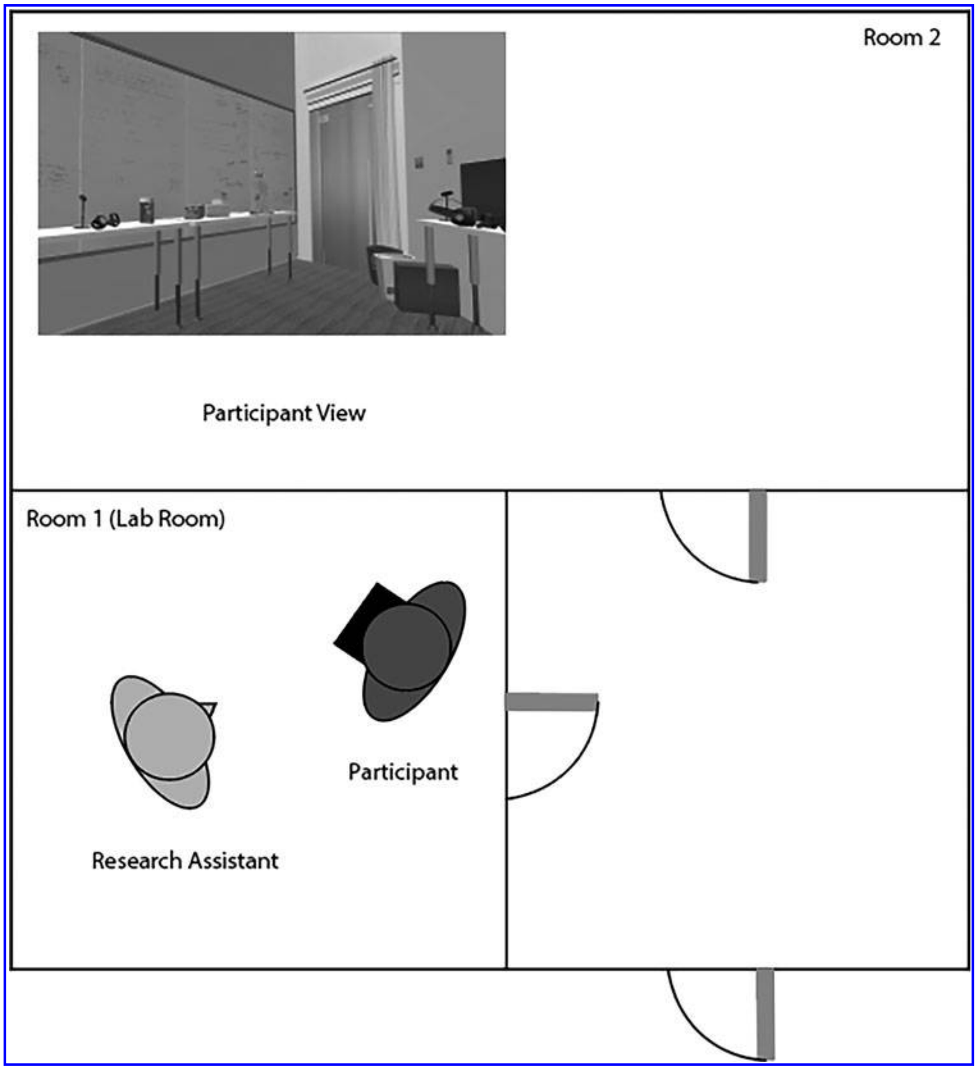

FIG. 3. Positions of the research assistant and participant in the near, alone condition, with a participant view of the condition.

Procedures

Participants were welcomed to the laboratory by a researcher, provided informed consent, and were then told they would later be chatting in VR with two other students, one from the same university and one from a collaborating university. The collaborating universities were identified as being in Saint Paul, Minnesota, or Tulsa, Oklahoma.

Participants were shown the Medoc thermode that was used to induce thermal pain, a TSA-II COVAS system.[26] A pain stimulus presented in a nonclinical environment must be extremely mild, especially in a within-subjects design where the task must be repeated. In our design, a thermode slowly increased in temperature from 32°C at a rate of 0.3°C/sec until the temperature reached a peak temperature of 50°C, at which point, it shut off and returned to baseline temperature.

In the first, baseline ''practice'' condition, and each subsequent condition, participants were instructed to stand, don the VR headset, and place their nondominant hand on the thermode. On experimenter keypress, the thermode slowly heated up. Participants were instructed to lift their hand as soon as the heat became painful. As soon as participants removed their hand from the thermode, the experimenter entered a second keypress and the temperature began to return to base level. This allowed the highest temperature reached for each trial to be retrieved after the experiment was over.

While this posed the risk of experimenter reaction time biasing the results, we note that when a participant removed their hand from the thermode, the tracked temperature would dip slightly if the button was not pressed promptly. Thus, if the experimenter was unsure of their keypress, the trace was inspected post-task for this divot.

After the first baseline ''practice'' experimental pain task, in which participants viewed a virtual laboratory room in the HMD without further instructions, participants filled out a brief survey that collected trait and state measures. Next, they completed the four experimental conditions. In each, they wore a VR headset and completed the same experimental pain task. After each condition, participants completed a brief survey. The experiment took 45–60 minutes for each participant.

Participants were randomly assigned to start with the Near or Far condition. They were then randomized again to start with the ''Alone'' or ''Social'' versions of the condition. This decision was made to more firmly connect the proposed

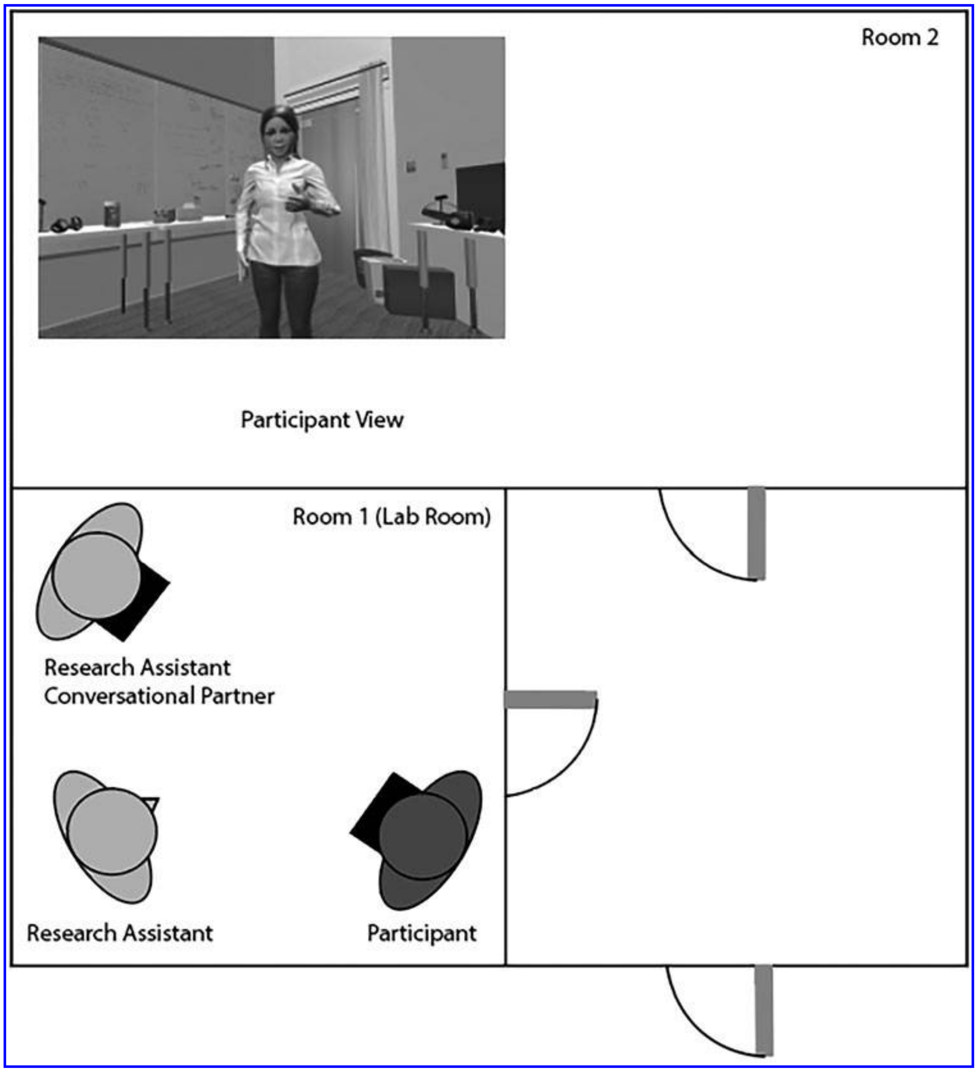

FIG. 4. Positions of the research assistants and participant in the near, social condition, with a participant view of the condition.

location to a real physical place, to augment any potential sense of transportation. When participants viewed the virtual environment representing another laboratory, they knew they had just been, or would shortly be, talking to someone in that same physical location, making the location less abstract. Table 3 shows the order in which conditions were experienced across all participants, and Figure 8 shows the experimental flow.

In the social conditions, participants saw their conversational partner's avatar as soon as they entered the virtual environment. After greeting each other, they had one minute to start the conversation, before the experimenter pressed the button that began to heat up the thermode. Timing started from this button press for each participant.

The research assistant confederates, both male and female, were blind to the study hypotheses, and instructed to be friendly. Their conversations were guided by a script (also posted in the Open Science Framework repository) to ensure that the descriptions of the target city under discussion would be as similar as possible across conditions and participants. However, to keep the conversation natural, their responses varied slightly depending on the participants' responses.

In the Far conditions, the researcher directing the experiment spoke with the research assistant confederate by phone to support the illusion that the second participant was remotely located. In the near conditions, the research assistant confederate was in the same room as the participant.

Measures

Our measures consisted of participants' pain threshold, or the temperature at which they removed their hand from the thermode of the Medoc pain machine, and self-report measures, which were collected by Qualtrics surveys after each experimental condition. Appendix A1 provides the complete text of the self-report measures. Table 4 provides brief descriptions of the measures, and Table 5 provides the mean and standard deviation for each measure, at each time and condition.

For future data exploration, and to give participants sufficient time to recover between the five experimental pain trials, we also collected other data on self-presence,[27] participants' perceptions of their experience and the locations depicted in the virtual environments, and environmental/spatial presence[27,28] after each trial. After the initial baseline task, we also asked participants to complete the ''Big Five'' personality trait questionnaire.[29] However, we do not analyze these measures in this article.

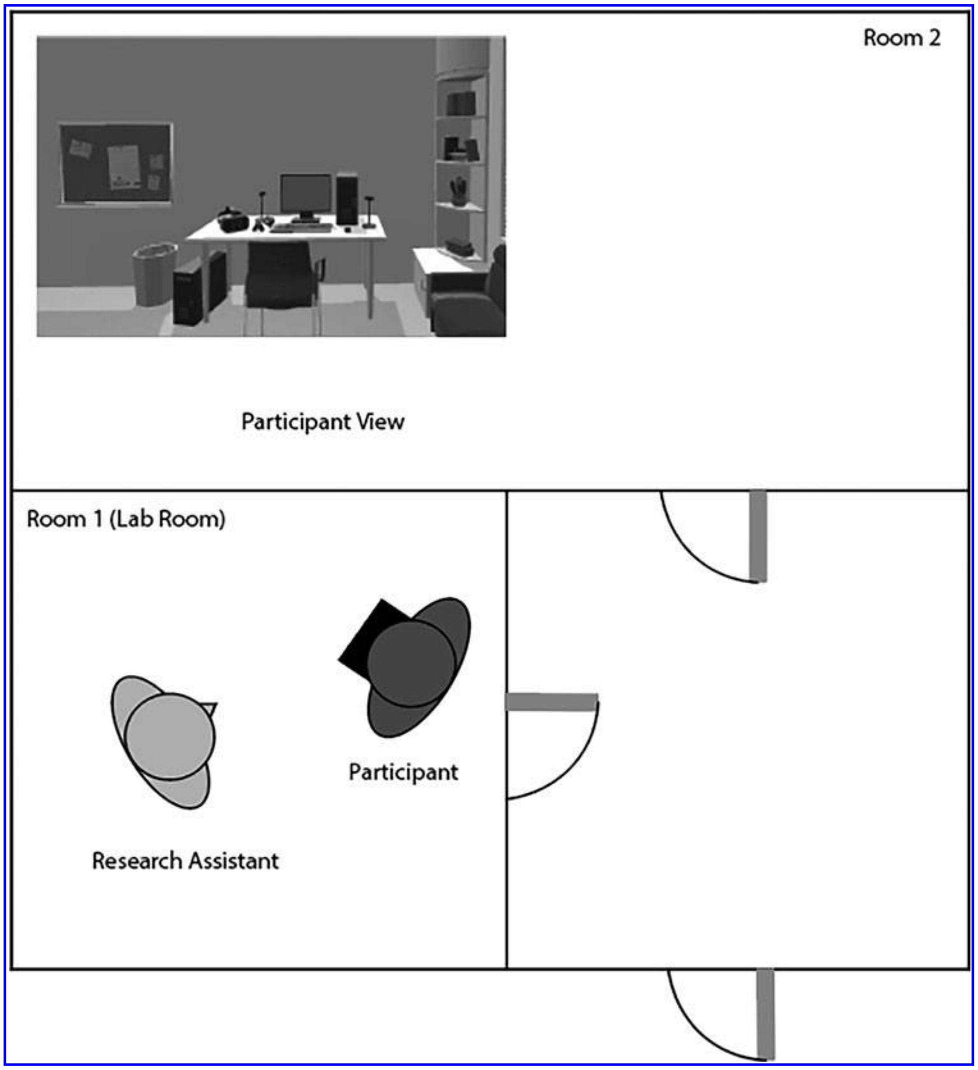

FIG. 5. Positions of the research assistants and participant in the far, alone condition, with a participant view of the condition.

Results

All analyses and descriptive statistics were calculated using R. The models we used, from the lme4 package in R, are robust to heterogeneity. However, because some of our measures were not normally distributed, we also checked the residual plots of these models to verify that results were usable. Appendix A2 shows these plots.

As this was a repeated-measures design, we included participant ID as a random effect.

We had expected that participants would remove their hands the most quickly when completing the baseline, ''practice'' task. However, when we examined the results, participants also removed their hand from the thermode at Time 1 more quickly than they did at Times 2, 3, and 4: (F[3, 198] = 5.09, p = 0.002). Thus, we included Time as a fixed effect to improve our models when pain tolerance (the temperature at which participants removed their hand from the thermode) was the dependent variable. While this was not a preregistered decision, the direction and statistical significance of the results remain the same.

H1 was supported—there was a main effect of social condition on pain tolerance. Participants in the social condition removed their hands later (M = 43.79°C, SD = 0.39°C), compared to the nonsocial condition (M = 43.32°C, SD = 0.39°C), (F[1, 197] = 15.65, p < 0.001) (Table 6). Figure 9 shows a plot of the pain threshold for each condition. H2 was not supported—there was no main effect of distance on pain tolerance, as shown in Table 7. H3 was supported—there was a main effect of distance on social presence, as shown in Table 8, such that participants who were co-located reported higher social presence (M = 3.58, SD = 0.12) than those who were not co-located (M = 3.00, SD = 0.12) (F[1, 66] = 22.30, p = 0.001). However, H4 was not supported (Table 9)—there was no interaction between distance and social presence on pain tolerance.

In terms of our research questions, social presence and social closeness were indeed highly correlated (RQ1; Table 10), but social *presence* was significantly predicted by distance, while social *closeness* was not (RQ2; Table 11). However, neither self-reported social presence nor social closeness had a statistically significant effect on pain threshold (RQ3; Table 12).

None of the above results was significantly modified by adding participant gender into the models (RQ4, all p's greater than 0.25).

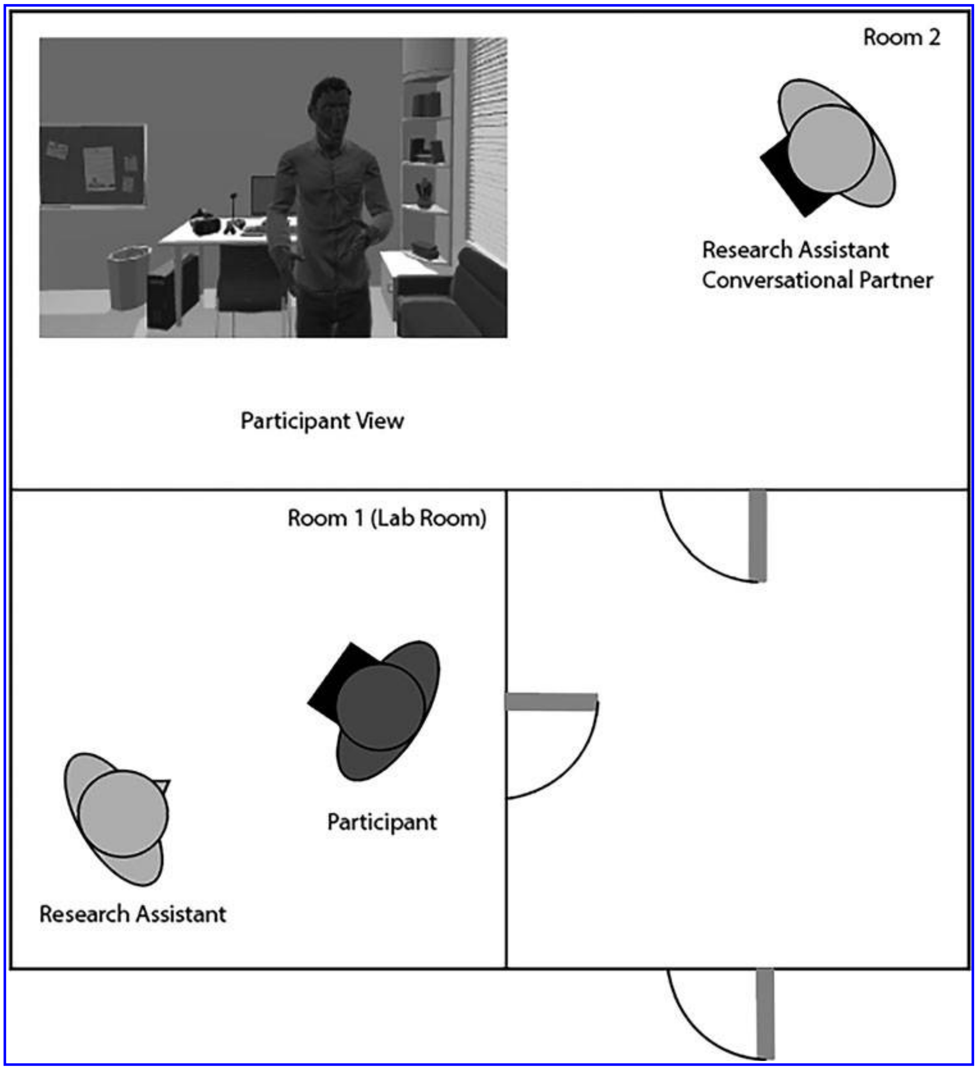

FIG. 6. Positions of the research assistants and participant in the far, social condition, with a participant view of the condition.

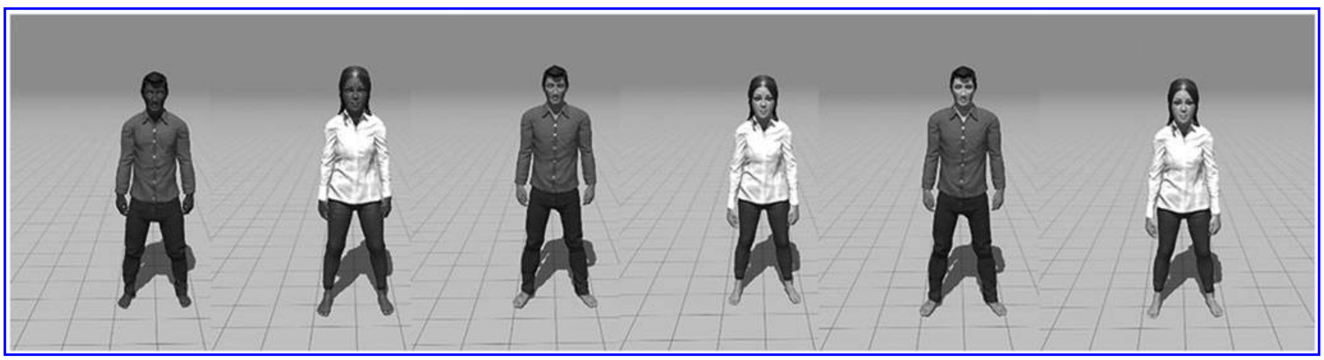

FIG. 7. Avatar options.

Discussion

In this study, we found a small, but consistent increased pain threshold in the social interaction conditions, such that participants removed their hand from a thermode at about 0.5°C higher temperature when with another person in VR, compared to being alone. However, the distance conditions had no effect—believing the conversational partner to be remotely located did not increase pain threshold. While

Table 3. The Order Participants Experienced Each Condition

	Far alone	*Far social*	*Here alone*	*Here social*
Time 1	14	18	16	19
Time 2	18	14	19	16
Time 3	16	19	19	13
Time 4	19	16	13	19

distance significantly reduced social presence, it did not significantly affect social closeness. In this experiment, neither measure significantly predicted pain threshold.

We found no effect of gender. However, in our study, we did not require participants to rate pain, but only to move their hands when the stimulus became uncomfortable. Male participants may have felt less motivated to downplay their pain than if they were providing ratings.

While the difference in pain threshold between social and nonsocial conditions was small, this is not surprising, considering the necessary mildness of the experimental pain task. Differences between baseline and condition pain threshold are

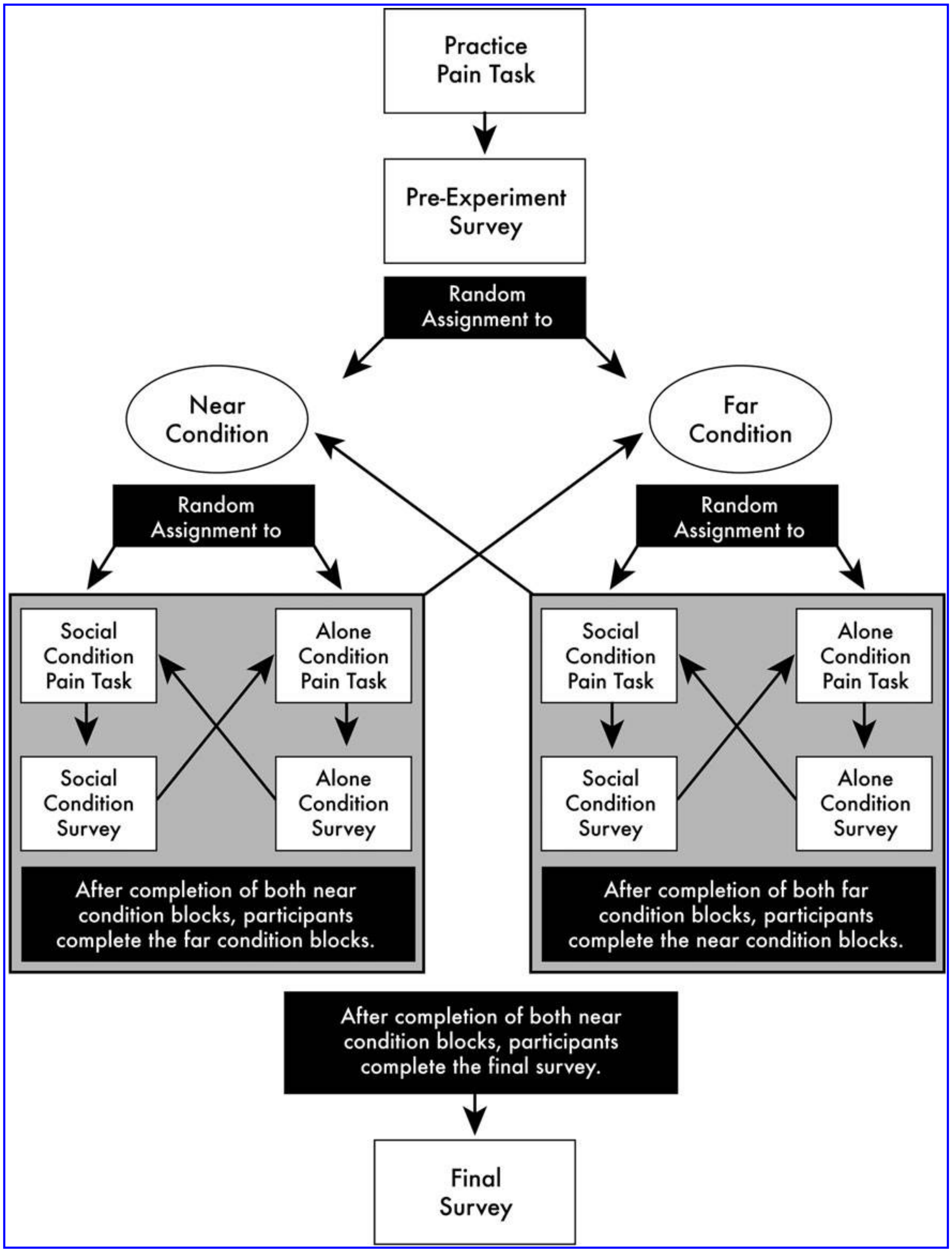

FIG. 8. Experimental flow of the conditions. In each pain task, participant was experiencing a virtual environment. For the baseline pain task, they saw a virtual version of the laboratory room, but received no instructions.

Table 4. Description of Measures Used for the Hypotheses and Research Questions

Measure	*How measures were derived*	*Descriptive statistics*
Pain threshold	The temperature at which participants removed their hand from the thermode of the Medoc pain machine.	These measures were not normally distributed ($M = 43.56°C$, $SD = 3.29°C$).
Social closeness	To capture participants' sense of social closeness, which has been shown to correlate with estimated distance, we used a measure from Won [25] that took the mean of 20 questions on a Likert scale from 1 "not at all" to 5 "very strongly." Appendix A1 lists all questions.	These questions were normally distributed. $\alpha = 0.93$, $M = 3.39$, $SD = 0.57$
Social presence	We created a measure of Social Presence by taking the mean of four questions on a Likert scale from 1 "not at all" to 5 "very strongly." These questions were: I felt like my partner was present with me. I felt like I was in the same room as the other participant. I felt like my partner was aware of my presence. I felt like my partner was real.	This response was *not* normally distributed according to the Shapiro-Wilk test ($W = 0.97$, $p = 0.003$). $\alpha = 0.87$, $M = 3.29$, $SD = 1.00$. We thus examined the residual plots for these models, shown in Appendix A2.

Table 5. Mean and Standard Deviation for Each Measure, for Each Condition, and for Each Time

Time	*Condition*	*Mean pain threshold (°C)*	*SD pain threshold (°C)*	*Mean self-report social presence (average of four questions on 1–5 Likert scale)*	*SD self-report social presence (average of four questions on 1–5 Likert scale)*	*Mean self-report Social distance (average of 20 questions on 1–5 Likert scale)*	*SD self-report social distance (average of 20 questions on 1–5 Likert scale)*
1	Far alone	43.13	3.59	NA	NA	NA	NA
	Far social	43.72	3.36	3.13	0.90	3.42	0.50
	Near alone	42.93	3.25	NA	NA	NA	NA
	Near social	42.82	3.89	3.43	0.96	3.44	0.53
2	Far alone	43.98	2.92	NA	NA	NA	NA
	Far social	44.14	3.08	3.04	1.20	3.40	0.71
	Near alone	42.70	3.66	NA	NA	NA	NA
	Near social	43.92	2.91	3.23	0.96	3.24	0.46
3	Far alone	44.00	3.34	NA	NA	NA	NA
	Far social	42.90	3.68	2.93	0.82	3.32	0.57
	Near alone	43.53	2.75	NA	NA	NA	NA
	Near social	44.53	3.38	3.65	0.92	3.44	0.60
4	Far alone	42.58	3.67	NA	NA	NA	NA
	Far social	44.68	2.87	2.89	1.06	3.20	0.65
	Near alone	44.08	3.61	NA	NA	NA	NA
	Near social	44.04	2.85	3.97	0.91	3.62	0.51

NA, not applicable.

Table 6. Statistical Results of Hypothesis 1

Hypothesis	**H1. Social interaction in a mediated environment increases pain threshold (temperature in degrees Celsius at which hand is removed from the thermode) compared to an environment with no social interaction.**						
Statistical test	*Linear mixed-effects model predicting temperature, fixed effects of social condition and time, and a random effect of participant ID*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	SE	F-*score*	*Confidence interval*	p[a]
Social (no)	43.32	0.39		0.12	(1, 197) = 15.65	42.54–44.11	
Social (yes)	43.80	0.39	0.47			43.01–44.58	0.0001064[a]
Time 1	43.13	0.40			(3, 197) = 5.98	42.33–43.93	0.0006369[a]
Time 2	43.66	0.40	0.53	0.17		42.86–44.46	
Time 3	43.67	0.40	0.54	0.17		42.87–44.47	
Time 4	43.78	0.40	0.65	0.17		42.97–44.58	

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

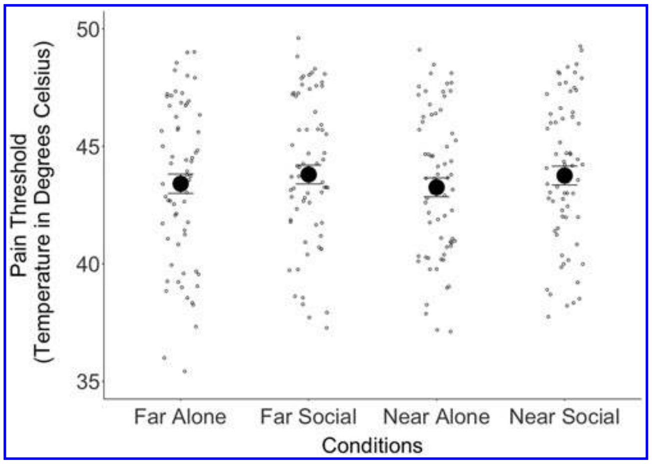

FIG. 9. Plots representing individual pain thresholds for each condition, and the mean and standard error for each condition superimposed on the plots. These are not adjusted for the effects of time.

shown in Appendix Figure A1. Thus, we believe these findings offer useful information for future work. There are at least three reasons that social interaction might increase pain tolerance. First, social support may mitigate pain. Participants may have felt supported by the presence of the warm, friendly conversational partners. In addition, or alternatively, the cognitive load of conversing with another person might increase distraction. Finally, social presence may increase participants' sense of presence in the virtual environment.

Limitations

Although the research assistants who conversed with the participants were blind to the hypotheses of the study, they were not blind to condition. The researchers who supervised the study were aware of the study hypotheses. The VR environments were designed and presented using consumer VR equipment, which is still in a relatively early stage of development, and avatar customization was also limited. Although we provided repeated exposures, there could still be an effect of novelty.

We found no effect of the distance manipulation on participants' pain threshold, perhaps because they were designed to be very similar to one another. Previous differences between participants exposed to hospital and nonhospital environments[16] may have been due to different associations with these environments and unrelated to the perceived location of the virtual space.

Another limitation was that participants chose the cities to discuss. These associations could potentially also elicit some sense of transportation. Future studies could include the location of cities participants chose to discuss as an additional random effect.

Most importantly for generalizability, we used an experimental pain threshold task on healthy participants, many of whom were not frequent users of VR. This very mild pain stimulus is very different from pain experienced as a patient in a clinical setting. However, this population of convenience is a necessary first step to refine our hypotheses.

In the preregistration, we did not specify using time as a covariate. In addition, our criteria for ''failing the

Table 7. Statistical Results of Hypothesis 2

Hypothesis	**H2. There will be a main effect of location, such that participants who experience a remote location will demonstrate a higher pain threshold.**						
Statistical test	*Linear mixed-effects model predicting Temperature with Distance condition and Time as fixed effects and participant ID as a random effect.*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	SE	F-*score*	*Confidence interval*	p[a]
Distance (no)	43.52	0.39				42.73–44.30	
Distance (yes)	43.60	0.39	0.08	0.12	(1, 197) = 0.46	42.82–44.39	n.s.
Time 1	43.15	0.40			(3, 197) = 5.02	42.35–43.96	0.002253
Time 2	43.64	0.40	0.48	0.17		42.83–44.44	
Time 3	43.66	0.40	0.50	0.17		42.85–44.46	
Time 4	43.78	0.40	0.63	0.17		42.98–44.59	

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

Table 8. Statistical Results of Hypothesis 3

Hypothesis	**H3. Belief that a conversational partner is co-located, as opposed to located in another city, will increase the social presence between two participants.**						
Statistical test	*Linear mixed-effects model predicting Social Presence with Distance Condition*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	*SE*	F-*score*	*Confidence interval*	p[a]
Distance (no)	3.58	0.12				3.35–3.82	
Distance (yes)	3.00	0.12	–0.59	0.12	(1, 66) = 22.30	2.76–3.23	0.0001263[a]

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

Table 9. Statistical Results of Hypothesis 4

Hypothesis	**H4. There will be an interaction between location and social presence, such that participants who report higher social presence with a remote other will demonstrate a higher pain threshold.**						
Statistical test	*Linear mixed-effects model predicting Temperature with measure of Social Presence, Distance condition, and Time as fixed effects, participant ID as a random effect, and the interaction of Social Presence and Distance condition*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	*SE*	F-*score*	*Confidence interval*	p[a]
Social presence	43.74	0.39	–0.08	0.20	(1, 72.70) = 1.41	42.96–44.53	n.s.
Distance (no)	43.76	0.40					
Distance (yes)	43.73	0.40	0.82	0.73	(1, 62.46) = 1.27	42.93–44.54	n.s.
Social presence[a] Distance			–0.26	0.21	(1, 62.19) = 1.47		n.s.
Time 1	43.53	0.43			(3, 64.29) = 1.76	42.68–44.38	n.s.
Time 2	43.63	0.44	0.11	0.34		42.76–44.51	
Time 3	43.73	0.44	0.21	0.30		42.86–44.60	
Time 4	44.09	0.43	0.56	0.27		43.22–44.95	

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

Table 10. Statistical Results of Research Question 1

Research question 1	***Is there a distinction between social presence as commonly defined in virtual reality (VR Social Presence), and social presence as defined in other media?***						
Statistical test	*Linear mixed-effects model predicting Social Distance from Social Presence as a fixed effect and participant ID as a random effect.*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	SE	F-*score*	*Confidence interval*	p*
Social Presence	3.29	0.05	.25	0.04	(1, 126.86) 40.55	3.29–3.49	0.000000003216

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

Table 11. Statistical Results of Research Question 2

Research question 2	***If there is such a distinction, does location affect these two measurements of social presence differentially? (in other words, does distance also affect social closeness?***						
Statistical test	*Linear mixed-effects model predicting social closeness with distance condition*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	SE	F-*score*	*Confidence interval*	p
Distance (no)	3.44	0.07				3.31–3.58	
Distance (yes)	3.34	0.07	–0.11	0.07	(1, 66) = 2.69	3.20–3.47	0.1059

Not statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

Table 12. Statistical Results of Research Question 3

Research question 3	***Do social presence and social closeness differentially affect pain threshold?***						
Statistical tests	*Linear mixed-effects model predicting Temperature, fixed effects of Social Presence and Time, and a random effect of participant ID* *Linear mixed-effects model predicting Temperature, fixed effects of Social Closeness and Time, and a random effect of participant ID*						
Predictors	*Adjusted mean*	*Adjusted standard error*	*β*	SE	F-*score*	*Confidence interval*	*p*[a]
Social presence			–0.12	0.14	(1, 74.07) = 0.75		n.s.
Time 1	43.58	0.43			(3, 66.76) = 2.22	42.73–44.43	.094
Time 2	43.61	0.44	0.03	0.33		42.73–44.48	
Time 3	43.78	0.44	0.20	0.30		42.91–44.65	
Time 4	44.15	0.43	0.58	0.26		43.30–45.01	
Social closeness			0.18	0.29	(1, 83.23) = 0.38		n.s.
Time 1	43.57	0.43			(3, 67.18) = 2.08	42.72–44.41	.111
Time 2	43.64	0.44	0.08	0.34		42.77–44.52	
Time 3	43.76	0.44	0.19	0.30		42.89–44.62	
Time 4	44.15	0.43	0.59	0.26		43.30–45.01	

[a]Statistically significant at alpha of 0.01, using the Bonferroni correction for five comparisons, dividing the alpha of 0.05 by 5.

manipulation check'' did not specify removing participants who merely did not mention the city. However, whether or not time is used as a covariate, and whether or not these participants are included, our results are consistent.

Future research

Following these findings, researchers may consider how to add social elements to make virtual environments more effective for pain patients, either by providing social support through companionship or by additional distraction arising from social interaction. Since research suggests that people are capable of feeling empathy toward virtual humans,[30] and other work finds positive effects of artificial conversation partners,[31] investigating the effects of both human-agent and human-human conversation may be useful.

We aim to extend this work following recent guidelines on the design of VR experiences for clinical interventions.[32] Can simulated social interactions be integrated into distracting interventions such as games?[33,34] Can companionship be integrated into clinical applications? In pursuing these questions, we will pay particular attention to real patients' opinions of such interventions,[35] and how individual differences may affect effectiveness.[36]

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Appendix

Appendix A1

Social Presence Questions:

Q23 I felt like my partner was present with me.
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q24 I felt like I was in the same room as the other participant.
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q25 I felt like my partner was aware of my presence.
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q26 I felt like my partner was real.
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Social Closeness Questions:

Q28 How would you feel about working in a company alongside the person you interacted with?
- ○ Very displeased (1)
- ○ Slightly displeased (2)
- ○ Neither pleased nor displeased (3)
- ○ Somewhat pleased (4)
- ○ Very pleased (5)

Q29 How would you feel about befriending the person you interacted with?
- ○ Very displeased (1)
- ○ Slightly displeased (2)
- ○ Neither pleased nor displeased (3)
- ○ Somewhat pleased (4)
- ○ Very pleased (5)

(*Appendix continues* →)

Q30 How coordinated did you feel with your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q31 To what extent did you feel that you and your conversational partner felt the same way?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q32 How well did you feel that you understood your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q33 To what extent did you feel a sense of mutual agreement with your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q34 To what extent did you feel that you and your partner were a unit?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q35 To what extent did you feel a sense of connection with your partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q36 How competent was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q37 How confident was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q38 How honest was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q39 How likable was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q40 How informed was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q41 How interesting was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q42 How modest was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q43 How friendly was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q44 How credible was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q45 How sincere was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q46 How warm was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

Q47 How trustworthy was your conversational partner?
- ○ Not at all (1)
- ○ Slightly (2)
- ○ Moderately (3)
- ○ Strongly (4)
- ○ Very strongly (5)

(*Appendix continues* →)

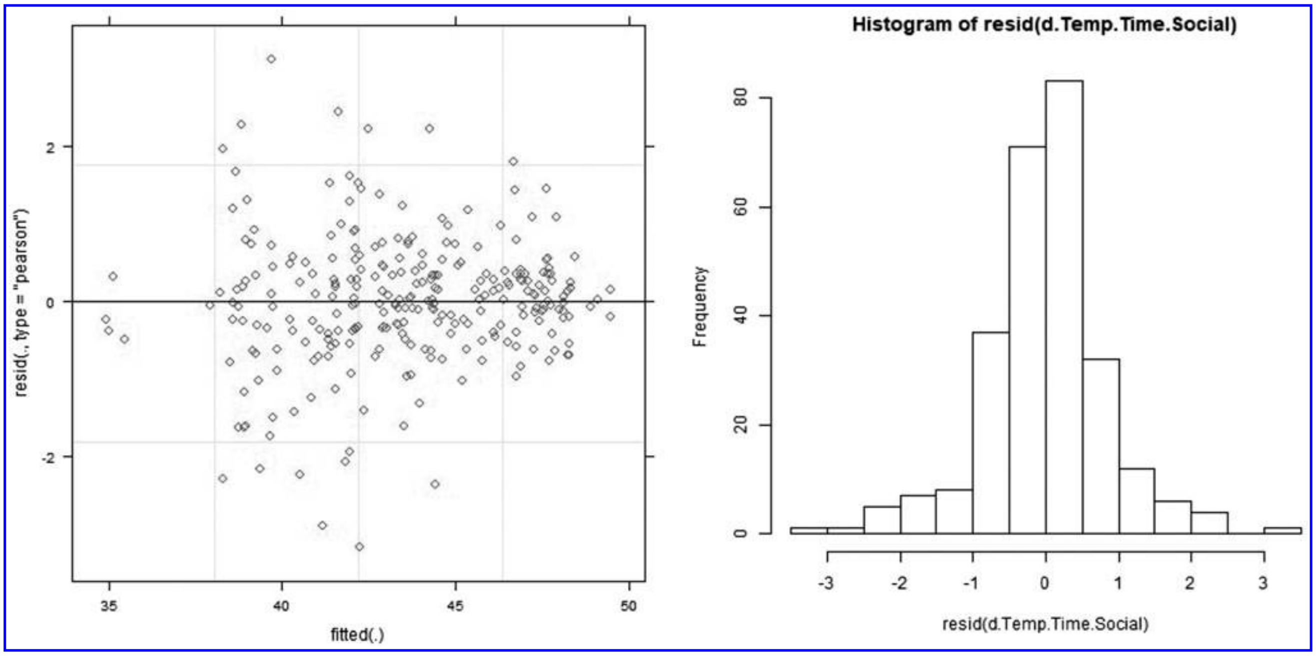
Appendix A2

We present the residual plots for statistically significant results below.

H1. Social interaction in a mediated environment increases pain threshold compared to an environment with no social interaction.

(F[197, 1] = 15.65, p < 0.001)**

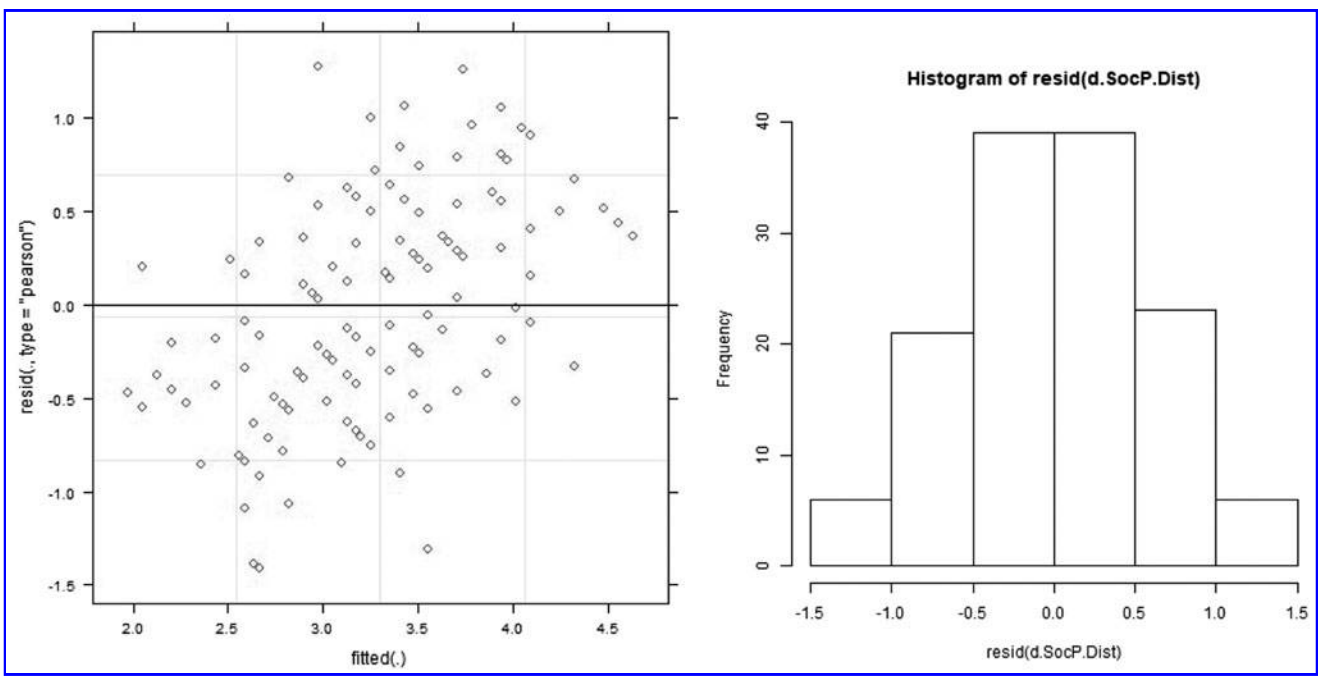
Participants in the social condition removed their hand from the thermode at a higher temperature (43.80°C) than participants in the nonsocial condition (43.32°C).



H3. Belief that a conversational partner is co-located, as opposed to located in another city, will increase the social presence between two participants.

(F[66, 1] = 22.30, p < 0.001)**

Social presence was rated significantly higher (M = 3.58, SD = 0.12) when the research assistant confederate was in the room than when they were only virtually connected (M = 3.00, SD = 0.12).

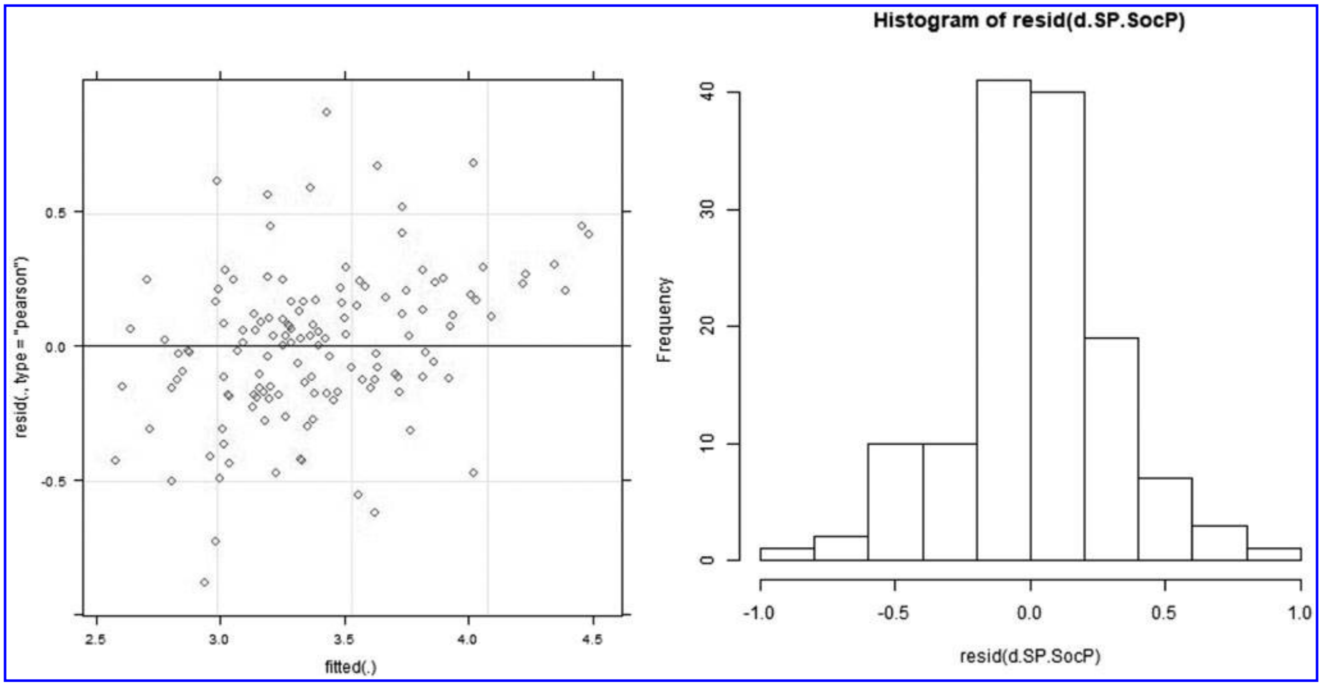


(*Appendix continues* →)

RQ1. Is there a distinction between social presence as commonly defined in virtual reality (VR Social Presence), and social presence as defined in other media? (social closeness)

(F[126.86, 1] = 40.55, p < 0.001).

Social closeness and social presence are closely related.

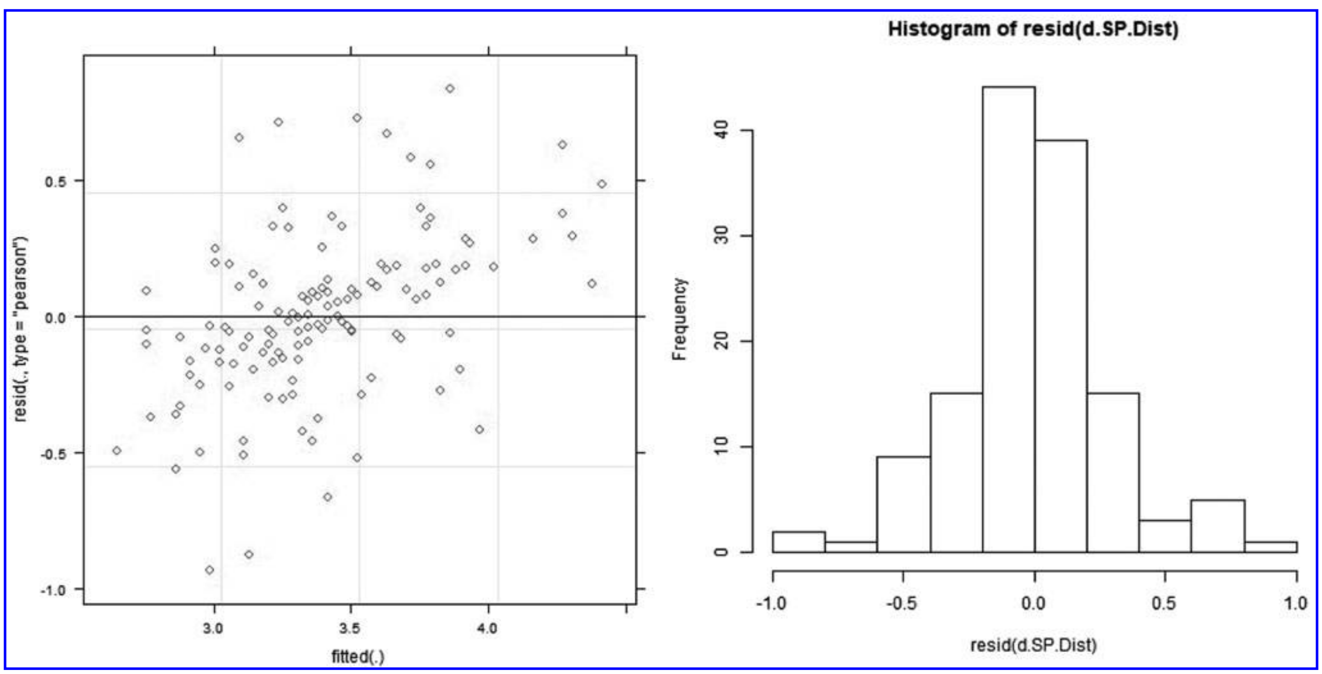


RQ2: If there is such a distinction, does location affect these two measurements of social presence differentially?

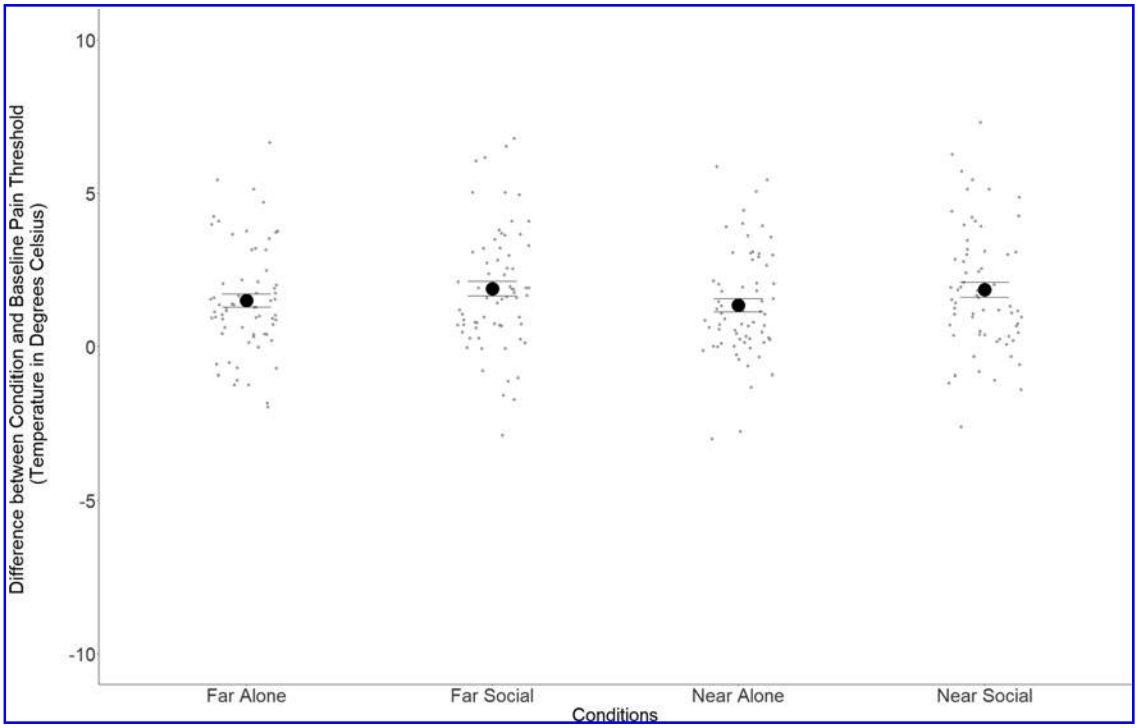
Results and residual plots for RQ2A are shown under Hypothesis 3.

RQ2B: Speaking to someone in the same room (M = 3.44, SD = 0.07) compared to someone remotely located (M = 3.34, SD = 0.07) had only a marginally statistically significant positive effect on social closeness. (F[66, 1] = 2.69, p = 0.1059)

(F[66, 1] = 2.69, p = 0.1059)



(*Appendix continues* →)



APPENDIX FIG. A1. Plot of differences between baseline and condition pain threshold.