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Loudness Perceptions Influence Feelings of Interpersonal Closeness and Protect Against Detrimental Psychological Effects of Social Exclusion

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Abstract

We propose that perceptions of auditory loudness and interpersonal closeness are bidirectionally related. Across 12 experiments (total *N* = 2219; 10 preregistered; with Singaporean, British, U.S. American, Indian, and Australian participants), we demonstrated that louder audio made people feel physically (Study 1a) and socially (Study 1b) closer to others, presumably because of loudness activates interpersonal closeness-related concepts implicitly (Studies 1c, 1d). This loudness-interpersonal closeness effect was observed across diverse samples (Studies 2a, 3a, S1), for longer listening intervals (Study 2b), and in natural settings (Studies 3a, 3b). Conversely, individuals made to feel socially excluded rated their surroundings as quieter (Study 4). Furthermore, following social exclusion, individuals showed a preference for louder volume (Study 5). Finally, exposure to loud stimuli mitigated detrimental psychological effects of social exclusion (Study 6). Theoretical implications for the social cognition of loudness, social exclusion and compensatory strategies, and practical implications for ameliorating loneliness are discussed.

Keywords: auditory loudness, interpersonal closeness, physical proximity, social proximity, social exclusion

In everyday life, people generally seem to prefer for a certain level of background noise, or at the very least, a dislike of silence[1] (Gantz et al., 1978; Roe, 1985). This tendency is perplexing because people often seem to prefer background noise even when they do not intend to pay attention to it, such as leaving the television on while doing chores, or even when the noise may potentially interfere with the task at hand, such as listening to music while studying (Perham & Vizard, 2011). While people tend to instinctively avoid excessively loud sounds due to physical discomfort and potential noise-induced hearing loss (Kujawa & Liberman, 2009), it is less well understood why people also seem to gravitate away from excessively quiet environments. Even in everyday language, excessive quietness has often been referred to as the 'uncomfortable silence' or the 'deadly silence', which begs the question why silence would be construed in such negative light. Conventional wisdom suggests that the loudness of a sound source is simply a concrete sensory dimension that allows people to make judgements about their location and distance from the sound source. However, the aforementioned everyday observations seem to suggest that beyond concrete functions such as navigation and distance judgement, individuals sometimes rely on loudness cues to make additional inferences that are previously unrecognized.

Anecdotal evidence suggests that silence reminds people of loneliness and isolation, while loudness reminds people of interpersonal interactions and liveliness. In the present research, we aimed to investigate whether perceptions of loudness are mentally associated with feelings of interpersonal closeness. The present research is also motivated by the

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[1]In the present context, the word silence is used to refer to excessive quietness and not complete silence. This is because even in specialized booths designed to filter out all sounds, individuals would still be able hear sounds reflecting their bodily functions such as heartbeat and pulse.

intention to advance two distinct domains of social cognition research: (1) the social cognition of auditory loudness, and (2) interpersonal closeness, social exclusion, and social acceptance.

The Social Cognition of Auditory Loudness

Given the ubiquity of auditory stimuli, researchers in psychology have taken a keen interest in the study of auditory loudness from a broad range of perspectives. To date, there has been extensive research on the effects of loudness in music psychology (e.g., the effect of music volume on exercise exertion; Edworthy & Waring, 2006), clinical psychology (e.g., the relationship between loudness perceptions and annoyance levels in individuals with Tinnitus; Hiller & Goebel, 2007), biological psychology (e.g., effects of noise exposure on individuals' hormonal levels and cardiovascular activity; Evans et al., 1995), and cognitive psychology (e.g., effects of background noise loudness on individuals' ability to concentrate, and general cognitive performance; Hygge et al., 2002; Kou et al., 2018). There is also related research on the effects of auditory loudness on people's *preferences* for loudness levels in various contexts. Studies have shown, for instance, that people seem to *prefer* a louder volume when listening to music because it is often perceived as more pleasurable and associated with enjoyment (Manchaiah et al., 2018).

A common theme in psychological research on loudness perceptions and preferences is that loudness tends to be evaluated along a single evaluative dimension. Specifically, loudness may be desired when it is deemed "pleasant", such as in the case of music (Manchaiah et al., 2018), but disliked when it is deemed "unpleasant", such as in the case of traffic or other distracting background noises (Shepherd et al., 2010). It is possible that there is more nuance to the dimension of loudness beyond the 'pleasant' vs. 'unpleasant' distinction. That is, are there other aspects of loudness cues that can affect people and their loudness preferences? Given that humans are social organisms, and the fulfilment or thwarting of the need for sociality can have a paramount level of influence on people's psychological and physical well-being (Baumeister & Leary, 1995), it is surprising to see that loudness has rarely been investigated from a social cognition perspective. The present research therefore aims to fill this important knowledge gap by taking a social cognition perspective to study people's loudness perceptions and preferences.

Interpersonal Closeness, Social Exclusion, and Social Acceptance

The experience of physical and social closeness with other people is crucial to everyday life, and the 'need to belong' has been conceptualized as a fundamental human need (Baumeister & Leary, 1995). In support of the centrality of this need to belong is the temporal need-threat model of ostracism (Williams, 2009), which provides a comprehensive summary of the sequence of events associated with the thwarting or deprivation of the need to belong. The first line of defense seems to be hypersensitivity and overreactivity to cues reflecting social exclusion. An example of this is research showing that psychological distress accompanied social exclusion even when participants knew that they had been excluded by computers, rather than real people (Zadro et al., 2004).

Next, when social exclusion occurs, a number of potentially malign psychological and physiological consequences often ensue. For instance, social exclusion can threaten individuals' perceived levels of self-esteem, control, and meaningful existence (Zadro et al., 2004), worsen mood (Blackhart et al., 2009), engender physical pain (Eisenberger et al., 2003), increase cortisol levels (Beekman et al., 2016), and alter physical pain sensitivity (DeWall & Baumeister, 2006). These outcomes presumably serve as cues for excluded individuals to salvage at-risk social bonds. Subsequently, individuals often make swift behavioral changes in response to social exclusion, such as increased compliance (Carter-Sowell et al., 2008) or mimicry of others, presumably to fit in and establish new social affiliations (Lakin et al., 2008). If social exclusion persists however, such compensatory behaviors tend to diminish over time such that victims of chronic social exclusion feel a sense of numbness and hopelessness (Williams, 2009). Taken together, these findings appear consistent with the notion that interpersonal closeness and the need to belong are integral to well-being.

Events that foster or dampen a sense of interpersonal closeness, such as social acceptance and exclusion, can have social consequences, as outlined previously (Carter-Sowell et al., 2008). Understandably, researchers have taken a keen interest in examining social factors that could influence perceptions of interpersonal closeness, such as socio-economic status (Andersson, 2018) and perceived similarity (Muraru et al., 2017). However, given that events reflecting a loss of interpersonal connectedness have also been shown to engender physiological consequences (e.g., DeWall & Baumeister, 2006), research on *sensory* factors (with the exception of physical warmth; IJzerman & Semin, 2009; Schilder et al., 2014) associated with feelings of interpersonal closeness has been surprisingly scant. In the present research, we examine the relationship between one such factor, loudness, and feelings of interpersonal closeness.

Mental Associations and the Loudness-Interpersonal Closeness Link

Mental associations underlie a plethora of fascinating phenomena, such as nostalgic memories brought back by certain odors (Herz, 2016). Research has shown that mental associations are formed through a ‘co-activation’ mechanism – that physiological or mental experiences that are frequently co-experienced leads to concurrent neural activations of the brain regions involved, which, in turn, reinforces and strengthens these neural networks over time (Barsalou, 2016b). Mirroring this is the embodied perspective of cognition, which posits that psychological and sensory experiences are inextricably linked as a result of implicit mental associations formed between sensory and psychological perceptions that are usually co-experienced (Lakoff & Johnson, 2003). For instance, the experience of physical warmth has been shown to be associated with feelings of interpersonal warmth, presumably because physical warmth, in the form of emanating bodily heat, often accompanies gestures of interpersonal warmth, such as hugs and kisses, in everyday life (Fetterman et al., 2018). Similarly, in research on social schemas (Gocłowska et al., 2014), evaluations and contextual information that are co-experienced over time lead to mental models that link the evaluation and experienced stimuli together. Experience of the contextual information alone at a later time therefore leads to greater accessibility of the evaluation through ‘spreading activation’ (Wheeler et al., 2014). Taken together, theories from neural, cognitive, and embodied cognition perspectives converge in suggesting that experiential correlations engender mental associations over time.

While a case could be made for the *general* assumption that experiential co-occurrences foster mental associations, the question remains whether auditory loudness and feelings of interpersonal closeness, in particular, are frequently co-experienced. We believe that auditory loudness is often co-experienced with events that reflect interpersonal proximity, including both physical and social proximity. Specifically, physical proximity with others is often characterized by loudness because common experience suggests that in a given setting, if all other factors are held constant, loudness increases with crowdedness. In fact, the ability to perceive loudness serves as a sensory barometer that gauges the physical distance between the perceiver and the sound source (Kolarik et al., 2016), and in telecommunications, louder voices are often judged to be physically closer (Zhang et al. 2015). Similarly, social proximity with others seems to be associated with loudness because research suggests that people tend to be more verbal around their friends, and quieter around strangers (McCroskey & Richmond, 1990). Moreover, studies have demonstrated that people generally tend to be more expressive and uninhibited in front of those with whom they have a close relationship, and more shy and reserved in front of unfamiliar others (Cheek & Busch, 1981; Cheek & Buss, 1981). Over time, the repeated pairing of loudness with situations reflecting interpersonal closeness would likely lead to the formation of a robust mental association between the two.

In addition to experiential co-occurrences, ample language expressions support the association between loudness perceptions and interpersonal closeness mental concepts. For example ‘the lonely silence’, ‘the silent treatment’, and ‘loud and lively’ are a few English expressions that associate loudness with interpersonal closeness and quietness with interpersonal isolation. Researchers have theorized that such language expressions are not merely literary inventions, but reflections of how individuals tend to construe the world (Lakoff & Johnson, 2003). For instance, mental associations formed from the experiential co-occurrences of physical warmth and interpersonal warmth are reflected in metaphorical expressions such as ‘cold and lonely’ and ‘friendly and warm’.

Taken together, conventional wisdom, empirical research, and everyday language expressions converge in suggesting that ambient loudness frequently co-occur with events reflecting interpersonal closeness. This in turn allows us to make our primary prediction: feelings of interpersonal closeness and perceptions of loudness should share a common representational network such that the experience of one activates the other.

Social Exclusion, Ambient Loudness, and Mood Reparation

Following social exclusion, individuals typically exhibit a stronger desire for social reconnection to compensate for lost social affiliations (Maner et al., 2007). For instance, studies have shown that following social exclusion, individuals tend to exhibit more socially-oriented consumer behavior patterns (Mead et al., 2011), and are more drawn to people displaying genuine smiles over those displaying social smiles (Bernstein et al., 2010).

However, since social exclusion can also engender physiological consequences, surprisingly little attention has been devoted to examining compensatory strategies or behavior changes following social exclusion that relate to *sensory* parameters in the environment. While an exception to this is the sensory cue of ambient brightness (Pfundmair et al., 2019), the question still remains whether such sensory alterations are effective in ameliorating the detrimental effects of social exclusion. To address this important gap in the literature, the present study aims to test two auxiliary predictions: first, we propose that individuals who are made to feel socially excluded should display a preference for louder auditory stimuli, presumably as a way to restore feelings of social connection. Second, we predict that exposure to loud auditory stimuli can help ameliorate detrimental psychological effects of social exclusion. In addition to the applied value of establishing a novel mood reparation remedy following social exclusion, our findings would add insight to the loudness-interpersonal closeness link by elucidating whether it has a *compensatory* element. Specifically, whether feelings of social exclusion lead to a desire for greater levels of auditory loudness, and whether loudness can effectively compensate for feelings of social exclusion.

Overview of the Present Research

Taken together, examination of the loudness-interpersonal closeness link and its potential implications in settings involving social exclusion provides insight into the nature of the relationship between loudness perceptions and mental concepts of interpersonal closeness. To comprehensively examine our predictions and address the aforementioned gaps in the literature, we conducted a pretest followed by a series of 12 experiments (10 pre-registered). The pretest (presented in the Supplementary Online Materials; SOM) provided correlational evidence that people believe that everyday situations reflecting a higher level of physical and social closeness with others are generally louder. Studies 1a and 1b examined the basic effect, that is, the prediction that loudness induces a sense of interpersonal closeness. Studies 1c and 1d aimed to elucidate the mechanism underlying the basic effect by examining semantic associations through mediation and moderation respectively. Study 2a and 2b aimed to replicate the basic effect in a demographically different sample and using a longer auditory exposure window, respectively. Studies 3a and 3b (and Study S1; see SOM) aimed to test whether the basic effect could be replicated in natural settings. Study 4 examined the directional nature of the loudness-interpersonal closeness association, by testing whether people made to feel lonely rate their surroundings as quieter. Study 5 tested our auxiliary prediction that individuals who are made to feel socially excluded should prefer louder auditory stimuli. Finally, Study 6 tested our auxiliary prediction that exposure to loud auditory stimuli can help ameliorate detrimental psychological effects of social exclusion.

To establish the generalizability of our predictions, we aimed to replicate our effect in samples with diverse characteristics and in multiple contexts. Specifically, we sampled members of the public (mostly Caucasian; pretest, Study 2a), temple visitors at a Hindu temple (mostly Indian; Study 3a), and university students from Singapore (mostly ethnically Asian; Studies 1a-1d, 2b, 3b, 4, 5, 6) and Australia (Study S1). All experiments reported in the present manuscript received ethical approval from the first author’s institutional review board prior to commencement of data collection.

To ensure our studies were adequately powered, we used effect sizes from previous studies to calculate the a priori sample size (e.g., Studies 5 and 6). For the remaining studies, we adopted conservative rule-of-thumb sample sizes of 50 and 100 participants per condition for laboratory and non-laboratory experiments respectively (Simmons et al., 2013) and reported post-hoc sensitivity power analyses in the SOM. Regardless, all experiments (except Studies 1a and 1b) and their minimum target sample size were pre-registered via the Open Science Framework (OSF) and data were not analyzed before termination of data collection.

Finally, full details of data exclusions, manipulation checks, measures, and additional analyses can be found in the SOM. All study pre-registrations, materials, data, and output are archived online: https://osf.io/vm8h3/?view_only=8c46bdb495924594a9ee3b304c6ad029.

Note that since Studies 1a – 3b utilized similar procedures, to maximize brevity, only key information are reported below. Full methodological details and results can be found in the SOM.

Table 1

Overview and Results of Studies 1a to 3b

Study	Sample (total *N*)	Study Type[a]	Auditory Stimulus	Physical Proximity Statistics						Social Proximity Statistics					
				Loud Condition		Quiet Condition		*d*	*t*	Loud Condition		Quiet Condition		*d*	*t*
				M	*SD*	*M*	*SD*			*M*	*SD*	*M*	*SD*		
1a	Asian students (100)	Lab (overt)	Neutrally valanced audiobook	77.24	101.14	28.98	23.30	0.66	3.29**	–	–	–	–	–	–
1b	Asian students (100)	Lab (overt)	Neutrally valanced audiobook	–	–	–	–	–	–	4.22	1.73	3.40	1.58	0.50	2.48*
1c	Asian students (150)	Lab (overt)	Greek song compilation	85.94	76.59	46.86	41.54	0.63	3.17**	4.47	1.09	3.89	1.18	0.51	2.56*
1d	Asian students (100)	Lab (covert)	Noise of air conditioner	67.29	60.62	38.45	43.71	0.55	2.73**	4.59	1.61	3.79	1.56	0.51	2.55*
2a	Caucasian members of public (205)	Online (overt)	Greek song compilation	157.52	159.28	100.22	118.28	0.41	2.93**	5.54	1.03	5.11	1.23	0.38	2.71**
2b	Asian students (100)	Lab (overt)	Instrumental music	70.12	100.54	30.11	50.53	0.50	2.18*	4.09	1.33	3.49	1.30	0.46	2.26*

3a	Hindu temple visitors (444)	Field (covert)	Hindu hymn	5.81	1.00	5.39	1.23	0.37	3.19^{**}	5.67	1.46	4.99	1.71	0.43	3.65^{***}
3b	Asian students (314)	Field (covert)	Instrumental music	5.23	1.15	4.98	1.23	0.21	1.88	4.81	1.16	4.16	1.19	0.55	4.91^{***}
S1	Caucasian students (200)	Online (overt)	Instrumental music	4.68	1.18	3.93	1.24	0.62	4.40^{***}	4.73	1.55	3.90	1.70	0.51	3.58^{***}
MA								0.45[b]						0.48[c]	

Note. [a]Participants were explicitly instructed to select either a loud or soft volume (overt), or were simply exposed to the audio stimulus without any explicit mention of its volume (covert); [b]N = 1413; [c]N = 1412. MA = Internal Meta-Analysis.

$^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$.

Studies 1a and 1b: Loudness Induces a Sense of Physical and Social Proximity

Method

In Studies 1a (*N* = 100; 49 female; M_{age} = 22.08 years, SD_{age} = 2.91) and 1b (*N* = 100; 52 female; M_{age} = 20.74 years, SD_{age} = 2.49), students at a University in Singapore were provided with headphones and told that they would be required to listen to a brief audio clip and answer a question on the computer screen. Participants were instructed to listen to an audiobook segment[2] at either the "loudest volume possible without it being uncomfortable" (loud condition) or "quietest volume possible without it being incomprehensible" (quiet condition), based on random allocation. After two minutes, participants in Study 1a were shown and answered the following question on the computer screen: "Pretend that you are the center of a sphere, if you had to make a quick guess, how many people do you think are there within a 30 meter radius in this very moment?" Unlike the measure of physical proximity in Study 1a, participants in Study 1b were required to rate their relationship closeness with a self-nominated individual using circles on a 7-point scale (1 = *two minimally overlapping circles* and 7 = *two maximally overlapping circles*) (Aron et al., 1992) as a measure of social proximity (IJzerman et al., 2018; IJzerman & Semin, 2009). All participants then completed some demographic information and were probed for suspicion, debriefed, and thanked. It is important to note that in all applicable studies, we took the dependent measures *during* the auditory exposure interval rather than after termination of the auditory stimulus. This was aimed at maximizing replicability of our hypothesized effects, since mental associations are

[2]Different audio stimuli were used throughout our experiments, all URLs are listed in the SOM.

more reliably activated *during*, not after, participants' exposure to cues responsible for the formation of such associations (Barsalou, 2016b).

Results and Discussion

Participants in the loud condition estimated significantly greater numbers of people within a 30 meter radius (M = 77.24, SD = 101.14) compared to participants in the quiet condition (M = 28.98, SD = 23.30), $t(54.19) = 3.29$, $p = .002$, Cohen's d = 0.66, 95% CI for the mean difference [18.84, 77.68]. Participants in the loud condition also reported that they were significantly more intimate with their self-nominated individual (M = 4.22, SD = 1.73) compared to participants in the quiet condition (M = 3.40, SD = 1.58), $t(98) = 2.48$, $p = .015$, Cohen's d = 0.50, 95% CI for the mean difference [0.16, 1.48]. These findings support our prediction and suggest that exposure to higher volume instills in people a greater sense of physical and social proximity such that they believe there are more people nearby, and are reminded of others with whom they share a closer relationship.

Study 1c: Mechanistic Elucidation through Mediation

Study 1c aimed to establish whether mental accessibility of closeness-related concepts mediates the basic effect. Furthermore, to eliminate the alternative possibility that exposure to low volume actually decreased perceptions of interpersonal closeness, rather than exposure to high volume increasing perceptions of interpersonal closeness, a no-exposure control condition was included.

Method

Measures

Perceived Physical Proximity

As with Study 1a, participants were asked to estimate the number of people within a given radius. To maximize the robustness of our results, however, instead of using a single item measure, participants were asked to make the same estimation for a 30m, 50m, and 20m radius. The mean of the three estimates constituted perceived physical proximity.

Perceived Social Proximity

As with Study 1b, participants were asked to rate their relationship closeness with a self-nominated individual. To maximize robustness of our results, instead of rating a single person, participants were asked to rate their relationship closeness with three self-nominated individuals. The mean of the three ratings constituted perceived social proximity.

Procedure

Students at a university in Singapore (N = 150; 92 female; M_{age} = 22.89 years, SD_{age} = 5.54) were invited to a computerized booth and those in the loud and quiet conditions were given headphones to listen to a Greek song compilation clip as background music during the experiment. Depending on the condition, participants were asked to listen to the clip at the “loudest volume possible without it being uncomfortable” or “quietest volume possible without it being inaudible”. Participants in a third no-exposure condition were not given any instructions. All participants were then administered a Lexical Decision task (LDT; see SOM) whereby their mental accessibility/sensitivity to closeness-related concepts were inferred using their reaction times to words semantically associated with closeness. Upon completion of the LDT, participants were handed a single handout with the measures of perceived physical and social proximity in random order, followed by some demographic questions. When this was completed, participants were probed, debriefed, and thanked.

Results and Discussion

The basic effect of loudness on perceptions of interpersonal closeness was successfully replicated (p = .002; d = 0.63 and p = .012; d = 0.51 for perceived physical and social proximity respectively; additional statistics in Table 1). The present study also showed that participants in the quiet condition did not differ significantly from those in the no-exposure condition in our dependent measures, and that using either as the control condition yielded the same pattern of results (for both the basic effect and mediation; see SOM). This helps eliminate the alternative possibility that exposure to low volume decreased perceptions of interpersonal closeness.

We conducted mediation analyses using the PROCESS SPSS macro (Model 4; 5000 bootstraps; Hayes, 2013) and found significant indirect effects of loudness on perceived physical (*b* = 12.11, 95% CI = [2.41, 26.50]) and social (*b* = 0.16, 95% CI = [0.02, 0.35]) proximity via mental accessibility of closeness-related mental concepts. These results support our hypothesis and suggest that loudness increases perceived physical and social proximity by increasing mental accessibility of interpersonal closeness-related concepts (see Figure 1).

It follows then, that the effect of loudness on perceived interpersonal closeness should be more pronounce in individuals that tend to associate loudness with closeness more strongly. To investigate this, and to further corroborate the mechanistic process underlying the effect of loudness on perceived interpersonal closeness, Study 1d measured individuals' dispositional tendency to associate loudness with closeness using a modified version of the Implicit Association Task (IAT; see the SOM).

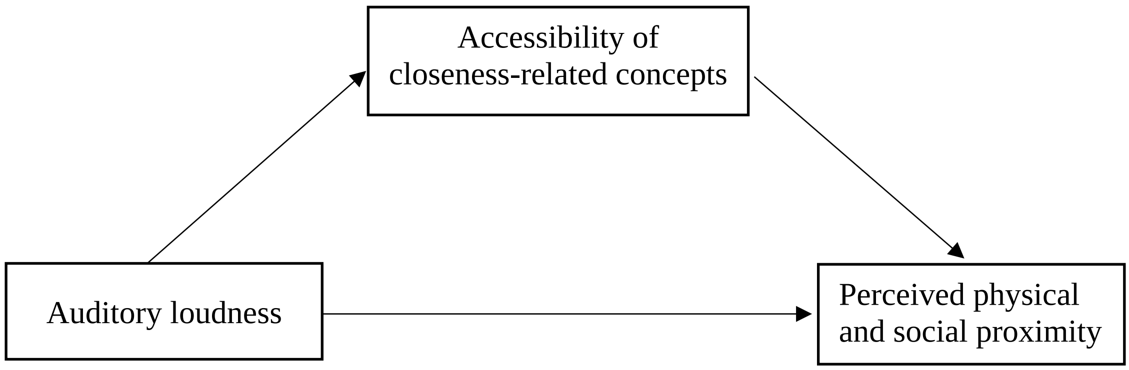

Figure. 1. Diagram representing mediation effects in Study 1c.

Study 1d: Mechanistic Elucidation through Moderation

Method

Study 1d (*N* = 100; 61 female; M_{age} = 22.56 years, SD_{age} = 2.44) replicated Study 1c with the following methodological exceptions. First, the Greek music clip was replaced with some "background noise" which participants were asked to bear with since the cover story was that they have been allocated to the control group of a music-related experiment. In actuality, this was an audio recording of an operating air-conditioner set at the desktop volume of either 1 (quiet condition) or 10 (loud condition) out of 100. Second, the LDT was replaced by an IAT administered after termination of the auditory stimuli and completion of the dependent measures. Finally, a no-exposure condition was not included.

Results and Discussion

The basic effect of loudness on perceptions of interpersonal closeness was successfully replicated ($p = .008$; $d = 0.55$ and $p = .012$; $d = 0.51$ for perceived physical and social proximity respectively; additional statistics in Table 1). We also conducted moderation analyses using the PROCESS SPSS macro (Model 1; 5000 bootstraps; Hayes, 2013) and obtained significant interaction effects (see SOM). Most critically, the effect of loudness on perceived physical proximity emerged only for participants with strong loudness-closeness implicit associations (loud: $M = 88.96$, quiet: $M = 35.54$), $b = 53.42$, $SE = 14.63$, $t(97) = 3.65$, $p < .001$, 95% CI = [24.38, 82.47], but evaporates for those with weak loudness-closeness implicit associations (loud: $M = 44.17$, quiet: $M = 41.12$), $b = 3.05$, $SE = 14.54$, $t(97) = 0.21$, $p = .834$, 95% CI = [-25.81, 31.91] (see Figure 2a). Likewise, the effect of loudness on perceived social proximity emerged only for participants with strong loudness-closeness implicit associations (loud: $M = 5.21$, quiet: $M = 3.63$), $b = 1.57$, $SE = 0.44$, $t(97) = 3.58$, $p < .001$, 95% CI = [0.70, 2.45], but not for those with weak loudness-closeness implicit associations (loud: $M = 3.94$, quiet: $M = 3.96$), $b = -0.02$, $SE = 0.44$, $t(97) = -0.05$, $p = .958$, 95% CI = [-0.89, 0.84] (see Figure 2b). These moderation effects corroborate results of Study 1c and suggest that implicit mental associations between loudness and closeness-related concepts are indeed the reason why loudness perceptions can influence feelings of interpersonal closeness.

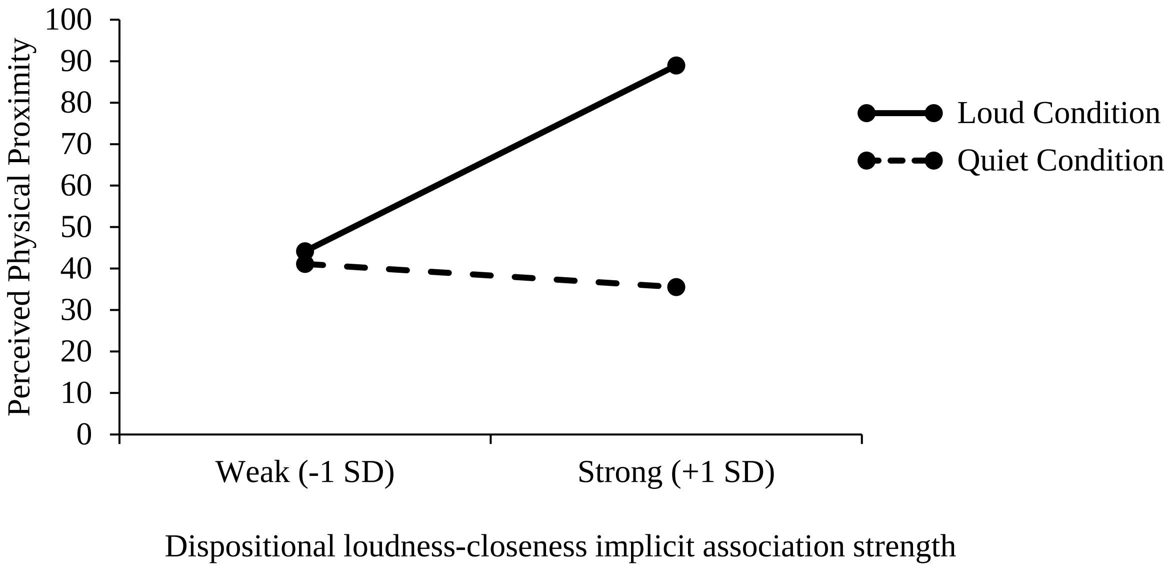

Figure. 2a. The interactive effect of participants' loudness condition and dispositional loudness-closeness implicit association strength on perceived physical proximity (Study 1d).

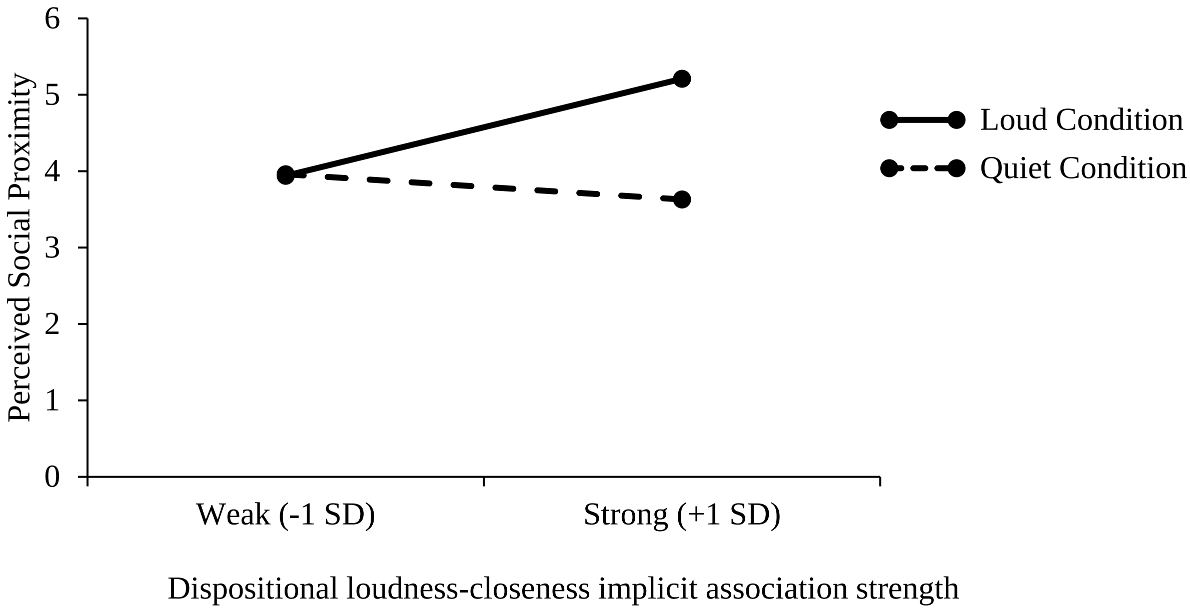

Figure. 2b. The interactive effect of participants' loudness condition and dispositional loudness-closeness implicit association strength on perceived social proximity (Study 1d).

Study 2a: Cross-Cultural Replication

Study 2a sought to replicate the basic effect on Caucasian members of the public via Prolific. A secondary aim of Study 2a was to explore whether the basic effect is moderated by explicit general beliefs about the association between loudness and interpersonal closeness. These moderation analyses are an exploratory component of the present study, and are therefore presented in the SOM.

Method

Study 2a (N = 205; 96 female; M_{age} = 28.44 years, SD_{age} = 9.41) replicated Study 1c (without the no-exposure condition) in an online format such that the instructions were presented via Qualtrics, and participants were mostly Caucasian members of the public. Participants also completed a general beliefs questions (for moderation analyses; see SOM) instead of the IAT.

Results and Discussion

The basic effect of loudness on perceptions of interpersonal closeness was successfully replicated (p = .004; d = 0.41 and p = .007; d = 0.38 for perceived physical and social proximity respectively; additional statistics in Table 1). This speaks to the cross-cultural generalizability of the effect of loudness on feelings of interpersonal closeness.

Study 2b: Replication Using a Longer Auditory Exposure Period

Method

Study 2b (N = 100; 36 female; M_{age} = 21.30 years, SD_{age} = 3.47) replicated Study 1d with two methodological differences. First, the audio stimulus was an instrumental piece of music played on a loop. Second, the listening period before participants completed the dependent measures was extended to 30 minutes under the cover story that the study aimed to explore the effect of background noise on concentration. Participants were therefore instructed by the blind experimenter to self-study for 30 minutes while the audio clip was played in the background at the desktop volume of either 3 (quiet condition) or 13 (loud condition) out of 100.

Results

The basic effect of loudness on perceptions of interpersonal closeness was successfully replicated (p = .033; d = 0.50 and p = .026; d = 0.46 for perceived physical and social proximity respectively; additional statistics in Table 1) even when individuals have been exposed to the auditory stimuli continuously for 30 minutes.

Study 3a: Field Replication – Temple Setting

To test whether the effect of loudness on perceived interpersonal closeness can be observed in a non-laboratory setting, a field study was conducted at a Hindu temple.

Method

Study 3a was disguised as a "temple experience survey" where visitors at a Hindu temple in Singapore (N = 444; 197 female; M_{age} = 44.62 years, SD_{age} = 13.53) completed the dependent measures using a clipboard while a blind experimenter played a context congruent hymn using a mobile device at either 90% (loud condition), 50% (quiet condition), or 0% (no-exposure condition) of full volume. We operationalized perceived physical proximity as participants' perceptions of how lively and crowded the temple is. Perceived social proximity was operationalized as the extent to which participants' felt a sense of companionship, and closeness, with their 'temple friends'.

Results

The basic effect of loudness on perceptions of interpersonal closeness was successfully replicated (p = .002; d = 0.37 and p < .001; d = 0.43 for perceived physical and social proximity respectively; additional statistics in Table 1) in natural settings using ecologically valid measures of perceived physical and social proximity. Note that as with Study 1c, the no-exposure condition yielded results that were not significantly different from that of the quiet condition, and using either condition as the reference group produced the same pattern of results (see SOM).

Study 3b: Field Replication - Classroom Setting

A second field study was conducted in a University classroom setting. We operationalized perceived physical proximity as participants' perceptions of how lively and crowded the University campus is. Perceived social proximity was operationalized as the extent to which participants' felt a sense of companionship, and closeness, with their University friends. Please note that given the difficulties of conducting field studies, a pilot study for Studies 3a and 3b was conducted - see Study S1 in the SOM.

Method

Administrative staff of the University approached tutorial classes in the final weeks of semester to obtain students' evaluations of their tutors as part of routine practice. To minimize suspicion, the experimenter accompanied the staff during these sessions to collect data. Following instructions to students relating to the tutor evaluation questionnaire, the experimenter distributed the information sheet of the present study and a handout containing the dependent measures in random order. As a cover story, students were told that the university wished to obtain some additional non-mandatory anonymous feedback. The experimenter then played an instrumental music clip on a mobile device at either 90% (loud condition) or 50% (quiet condition) of maximum volume as "background music while the evaluations are being completed". Upon completion, students were verbally debriefed and thanked. A total of 314 students (159 female; M_{age} = 20.68 years, SD_{age} = 2.88) participated in the present study.

Results

The present study's results were similar to that of the previous field study (p = .061; d = 0.21 and p < .001; d = 0.55 for perceived physical and social proximity respectively;

additional statistics in Table 1), although the effect of loudness on perceived physical proximity was only marginally significant.

Study 4: Individuals Made to Feel Socially Excluded Rate their Surroundings as Quieter

Establishing the bidirectional nature of the loudness-interpersonal connection relationship is fundamental not only for the completeness of our prediction, but also because a change in perceptual sensitivity following social exclusion would act as a precursor to a change in sensory preferences since the latter may serve as a form of compensation for the former. For example, socially excluded individuals show an increased preference for brighter lighting, however, this does not manifest independently, but rather, in conjunction with their perception that the surroundings are darker compared to those who were not socially excluded (Pfundmair et al., 2019). This suggests that changes in sensory preferences are not independent manifestations, but may serve as a compensatory mechanism for the perceptual changes experienced following social exclusion. By the same token, it is important to first establish whether individuals do perceive the environment as quieter following social exclusion, before testing whether they show a preference for louder auditory stimuli. This was the goal of Study 4.

Method

Students from a university in Singapore (N = 100; 53 female, M_{age} = 21.86 years, SD_{age} = 3.23) sat in a laboratory booth and were asked to reflect on either a social acceptance or a social rejection-related memory (DeWall & Baumeister, 2006). Two minutes later, participants were told: “before we proceed to the next task, the maintenance staff have requested laboratory users to provide some quick feedback on their experience of the laboratory environment for decisions on future renovations and laboratory architecture”. Participants were then provided with the ostensible laboratory experience survey containing the measure of perceived ambient quietness (“How quiet is this lab booth?” answered using a 9-point scale from 1 (*too quiet*) to 9 (*too loud*)) and some filler items to minimize suspicion. On completion of the form, participants were probed for suspicion and asked to complete some demographic information before being debriefed and thanked.

Results and Discussion

Participants in the social exclusion condition (M = 3.32, SD = 1.69) perceived the laboratory booth to be quieter compared to participants in the social inclusion condition (M = 4.48, SD = 2.09), $t(98) = -3.05$, $p = .003$, $d = -0.61$, 95% CI for the mean difference [-1.91, -0.41]. Participants in the social exclusion condition did not differ from participants in the social inclusion condition on filler items such as perceived spaciousness of the booth, all ps > .457. These findings suggest that individuals feeling a sense of social exclusion actually perceive the immediate surroundings to be quieter compared to individuals feeling a sense of social inclusion.

Study 5: Social Exclusion Increases Individuals’ Preferred Volume

Thus far, our studies have focused on our primary prediction relating to the basic loudness-interpersonal closeness link, and its underlying mechanism, generalizability, and bidirectionality. In Studies 5 and 6, we sought to test the auxiliary predictions relating to the interplay between loudness and feelings of social exclusion.

Research has demonstrated that relative to the socially included, socially excluded individuals tend to display an increased desire to socially reconnect (Maner et al., 2007). Importing this social reconnection theory to our findings thus far gives rise to a bold but intriguing follow-up question: if individuals seek to reconnect with others following social exclusion, and loudness confers a sense of interpersonal closeness, would individuals display a preference for higher volume following social exclusion compared to social inclusion? We tested this hypothesis in Study 5.

Method

Students from a university in Singapore (N = 80; 52 female, M_{age} = 22.01 years, SD_{age} = 3.03) arrived at a quiet laboratory in same-sex groups of four, and were asked to write their names on a name tag placed on the table in front of them and to try and remember each other's names while proceeding with the first task. As a cover story, participants were told that the study explores individuals' evaluations of peer personalities during communication. Participants were told that for the first 10 minutes, they should get to know each other by asking each other some ice-breaker questions (Sedikides et al., 1999). Following this get-acquainted task, participants were led to separate booths and were told that there will be an upcoming task that involves the group members working in pairs. Participants were shown a slip with the following message "We are interested in forming pairs in which the members like and respect each other. Below, please write your own name followed by the names of two people (out of the three that you met today) you would most like to work with for the next task" (Zhou et al., 2009). Upon collection of their preference slips, participants were asked to wait while the experimenter ostensibly collated their preferences and allocated them to pairs. By random assignment, the experimenter then returned to each participant and told them that either everyone (inclusion condition) or no one (exclusion condition) had written their name as a preferred partner, and that therefore they will be randomly allocated to one of their elected members for the next task. Following this, participants were told that prior to the dyad task, they are required to listen to an audio segment until they are told to stop. Participants were then provided with headphones and asked to click 'play'. They were also shown the volume bar which was preset at zero, and asked to adjust the volume to their preference. Two minutes later, participants were stopped, probed for suspicion, debriefed, and thanked. Their volume preference was measured by simply recording their desktop volume (0 to 100).

Results and Discussion

Participants in the social exclusion condition (*M* volume = 43.43, *SD* = 19.82) selected louder volume levels compared to participants in the social inclusion condition (*M* = 32.90, *SD* = 15.42), $t(78) = 2.65$, $p = .010$, $d = 0.59$, 95% CI for the mean difference [2.62, 18.43]. This finding supports our prediction and suggests that following social exclusion, individuals' social reconnection propensity manifests through a preference for ambient loudness, presumably because loudness provides a false sense of companionship. Coupled with the findings of Study 4, the present findings also provide a further insight into the mechanism behind the loudness-interpersonal closeness link by demonstrating how feelings of social exclusion affect people's perceptual experiences. It seems that when people are made to feel socially excluded, they perceived the surroundings to be quieter *and* show a preference for louder auditory stimuli. Given that the change in loudness preference was not the sole outcome following social exclusion, and that a change in loudness perceptions was also observed, these findings suggest that loudness may possess compensatory properties when the need for sociality is thwarted.

Study 6: Loud Auditory Stimuli Protect Against Detrimental Psychological Effects of Social Exclusion

Having determined that the loudness-interpersonal closeness link entails a compensatory component, it is important to investigate whether this preference for louder volume is effective in ameliorating the negative effects of social exclusion. We reasoned that since loudness has been shown to induce a sense of interpersonal closeness, exposure to loudness should be effective in partially countering the detrimental psychological effects of social exclusion. We tested this hypothesis in Study 6.

Method

Students from a university in Singapore (*N* = 128; 84 female, M_{age} = 22.98 years, SD_{age} = 5.21) were randomly allocated to one of four conditions in a 2 (social exclusion: inclusion vs exclusion) x 2 (volume: loud vs quiet) design.

Participants were asked to enter a quiet individual cubicle to play an online ball-throwing game with three other student players from other local Universities. Unbeknownst to them, there were no other players as it was actually a preset software used to manipulate social exclusion (Williams et al., 2000). Specifically, while participants in the social inclusion condition received an equal number of throws as the other ‘players’, participants in the social exclusion condition only received two throws (30 throws in total). In order to minimize participant suspicion that the ‘other players’ were not real, participants were led to believe that the experimenter’s colleagues from other local Universities were also involved in the present task. Specifically, a sham phone call from an ostensible colleague took place at the beginning of the experiment in the presence of the participants and participants were led to believe that the caller was calling to check if the experiment could be started on time. An additional cover story included the in-built instructions page of the ball throwing software (Williams et al., 2000) which informed participants that the task aims to investigate individuals’ mental visualization skills.

Before playing the game, participants were also shown an online audio clip, provided headphones and read the following instructions: “My colleague has asked me to play an online audio segment to act as background noise as you are playing this game, so can I please get you to just turn the volume as loud as possible without it being uncomfortable (loud condition) OR as quiet as possible without it being incomprehensible (quiet condition)? When you are done, you can start the game by clicking ‘play’. Please let me know when the game is finished”. After the game finished in approximately four minutes, participants were led to believe that before they move on to an ostensible ‘main’ questionnaire, they were to complete some “standard information including a mood scale followed by some demographic information”. Unbeknownst to the participants, the ‘mood scale’ contained our dependent variables – mood, anger, loneliness, hurt feelings and a social exclusion manipulation check.

In line with previous research (Zadro et al., 2004), mood during the game was measured by averaging participants’ responses to four bipolar items each with 9-point scales (*good-bad*, *happy-sad*, *relaxed-tense*, *aroused-not aroused*), whereas anger, loneliness and hurt feelings were each assessed by a single item asking participants if they felt these emotions during the game. Participants responded on 9-point scales (1 = *not at all* and 9 = *very much so*) before completing the demographic information and answering the social exclusion manipulation check where they indicated the degree to which they thought they were included by other ‘players’ using the same scale (Zadro et al., 2004). Finally, participants were probed, debriefed, and thanked.

Results and Discussion

A 2 (socially included vs. excluded) x 2 (loud vs. quiet volume exposure) MANOVA on negative mood, anger, hurt feelings and loneliness revealed a significant main effect of social exclusion, Pillai’s Trace = .26, F (4, 121) = 10.70, $p < .001$, $\eta_p^2 = .26$. This indicates that excluded (vs. included) participants generally experienced greater levels of adverse psychological effects. A significant main effect of volume exposure was also found, Pillai’s Trace = .21, F (4, 121) = 7.79, $p < .001$, $\eta_p^2 = .21$, indicating that participants exposed to high (vs. low) volume generally experienced lower levels of adverse psychological effects. Importantly, the main effects were qualified by a significant inclusion x volume interaction effect both at the multivariate level (Pillai’s Trace = .18, F (4, 121) = 6.74, $p < .001$, $\eta_p^2 = .18$) and at the univariate level for each of the dependent variables (see Table S2). Planned contrasts revealed that among excluded participants, those exposed to high volume experienced lower levels of negative mood, anger, hurt feelings and loneliness than those exposed to low volume, (all *p*s < .001, Cohen's *d* = -0.94 to -1.59). We found no significant difference in adverse psychological effects across volume conditions for included participants (all *p*s > .36, *d* = 0.21 to -0.23; see Table S3). These results support our predictions and suggest that exposure to loudness can ameliorate the negative psychological effects of social exclusion, but does not affect the psychological well-being of socially included individuals.

Finally, to determine whether exposure to loudness is partially or fully effective as a buffer against adverse psychological effects of social exclusion, exploratory pairwise comparisons were conducted. No significant differences in adverse psychological effects were found between excluded participants exposed to high volume and both included participants exposed to low volume (all *p*s > .088, Cohen's *d* = 0.01 to 0.43) and included participants exposed to high volume (all *p*s > .269, Cohen's *d* = 0.04 to 0.28; see Table S4). Figure 3 depicts mean levels of adverse psychological effects (with 95% CIs) experienced during the Cyberball game reported by each condition. These findings suggest that, surprisingly, exposure to high volume is able to fully, rather than partially, mitigate detrimental psychological effects of social exclusion.

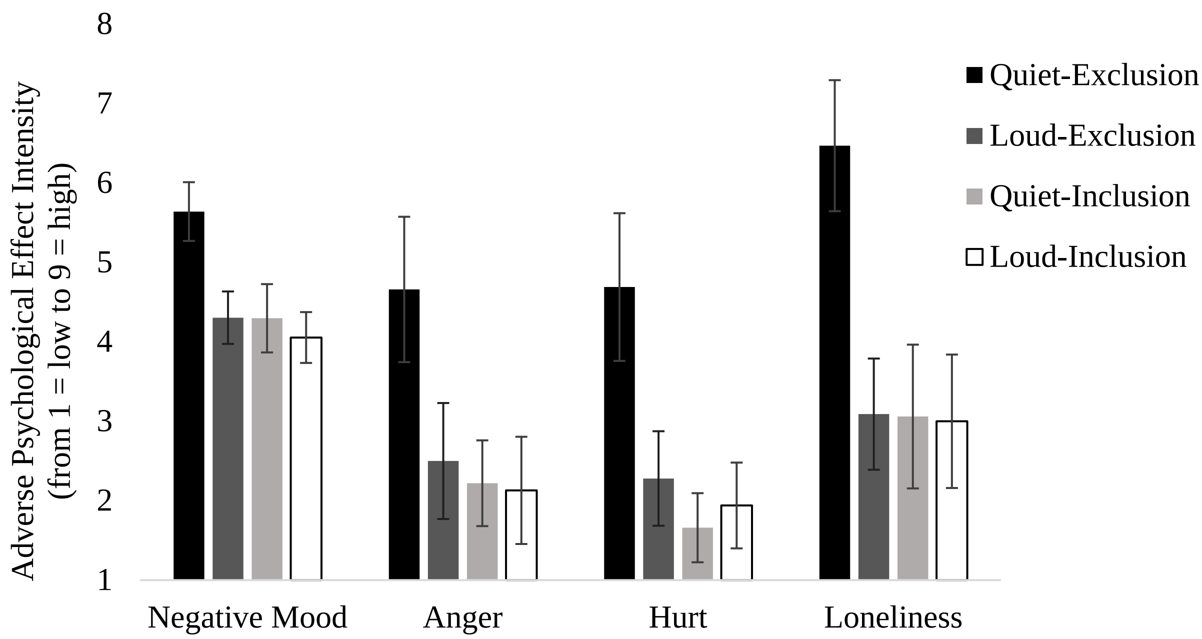

Figure. 3. Mean levels of adverse psychological effects (with 95% CIs) experienced during the Cyberball game in each condition in Study 6.

Internal Meta-Analysis

Finally, an internal meta-analysis across the applicable experiments (*k* = 9) revealed medium-sized averaged sample-weighted effect sizes for perceived physical proximity (*d* = 0.45, 95% CI [0.33, 0.56], *N* = 1413) and perceived social proximity (*d* = 0.48, 95% CI [0.37, 0.58], *N* = 1412). These results support the robustness of the loudness-interpersonal closeness effect.

It is important to note that heterogeneity statistics were non-significant (all *p*s > .297), indicating homogeneity of effect size magnitudes despite seemingly varied effect sizes across studies (*d*s range from 0.21 to 0.66). While this precluded us from predicting significant moderation effects, given the diversity of audio stimuli used in the present research, we still proceeded to analyse factors such as the language and arousal level of the audio stimuli since they may provide moderation trends. Expectedly, we did not find any statistically significant moderation effects of audio stimuli-related variables (all *p*s > .258). Further details of the internal meta-analysis and moderator analyses such as forest plots and heterogeneity statistics are reported in the SOM.

General Discussion

In the present study, we examined whether loudness and interpersonal closeness concepts were mentally associated such that the experience of one activated perceptions of the other. Results of 12 experiments provided broad support for the predicted association. Our findings demonstrated that individuals listening to a loud (vs. quiet) audio clip felt that there were more people near them (Study 1a) and selected a self-nominated person with whom they had a closer relationship (Study 1b), presumably because loudness implicitly activates mental concepts of interpersonal closeness (Studies 1c and 1d). This loudness-interpersonal closeness effect was replicated in demographically different samples (Studies 2a and S1), for longer auditory exposure intervals (Study 2b), and in natural settings (Studies 3a, and 3b). Bidirectionality of the loudness-interpersonal closeness relationship was also established. Participants instructed to reflect on a social exclusion-related memory rated their surroundings as quieter compared to those reflecting on an acceptance-related memory (Study 4). Interestingly, our studies also revealed that participants made to feel socially excluded (vs. accepted) reported a preference for louder auditory volume (Study 5), and that exposure to loud (vs. soft) auditory stimuli mitigated the detrimental psychological effects of social exclusion (Study 6).

Taken together, our findings suggest that associations between loudness and interpersonal closeness perceptions manifest not only in everyday language expressions, such as ‘the lonely silence’, but also in people’s experiences of the world. Moreover, our findings offer comprehensive insight on the nature of the loudness-interpersonal closeness link by illustrating that it is bidirectional, and that it contains a compensatory element.

Theoretical and Practical Implications

The present research makes several unique theoretical contributions. First, our findings augment the broad and multidisciplinary literature of auditory loudness effects and preferences by showing that loudness cues not only affect people cognitively (Hygge et al., 2002), biologically (Evans et al., 1995), and clinically (Hiller & Goebel, 2007), but also affect social cognition constructs. Specifically, loudness cues confer a sense of interpersonal closeness, which entails a sense of physical and social proximity with others. Conversely, people's preference for louder volumes may not be solely driven by physiological reasons, such as wanting to obtain more sensory pleasure from loud music, but may also be driven by their need for social connection. Perhaps seeking a sense of companionship and avoiding a sense of loneliness may explain why people often prefer to turn the television or radio on for 'background noise' even when they do not intend to attend to it. After all, background noise of any kind would bear closer resemblance to lively social interactions compared to silence. Given that auditory loudness is an ever-present sensory dimension in everyday life, our study makes an important contribution by illuminating a novel social cognition element of auditory loudness.

Next, our research contributes to the literature on perceptions of interpersonal closeness and social exclusion in important ways. Previous research in this domain has examined a multitude of social and physiological consequences when individuals' need for sociality are deprived or fulfilled (Beekman et al., 2016; Carter-Sowell et al., 2008; DeWall & Baumeister, 2006; Zadro et al., 2004). However, with respect to what causes people to feel a sense of interpersonal closeness or social exclusion, most studies have focused on social factors (e.g., Muraru et al., 2017). It is therefore unclear whether and how various sensory factors may affect feelings of interpersonal closeness (with the exception of ambient temperature; Schilder et al., 2014). The present study sheds light on this understudied research domain by providing empirical evidence for the causal role of ambient loudness on feelings of interpersonal closeness. While sensory factors may be traditionally thought of as unrelated to social experiences, our findings suggest that antecedents of social experiences need not be confined to those that are social in nature, they can also be sensory cues from the environment. Interestingly, the current research also demonstrates the inverse relationship – that feelings of social acceptance and exclusion made people perceive their surroundings to be louder and quieter, respectively. This bidirectional relationship is consistent with the hypothesis that concepts of loudness and interpersonal closeness share similar mental representational networks, perhaps as a result of their repeated coactivations from experiential co-occurrences.

In addition, the present work expands the literature on compensatory strategies and behavioral alterations that individuals adopt following social exclusion. Previous research has largely investigated social exclusion induced behavioral changes that are social in nature, such as displaying greater levels of social loafing (Williams et al., 2000), social attention (Gardner et al., 2000), and an increased tendency to purchase conspicuous products that can be shown to others (Lee & Shrum, 2012; Wan et al., 2014). Here, we show that individuals who were made to feel socially excluded showed a spontaneous preference for higher volume sounds compared to those who were made to feel socially accepted. Most critically, we also observed powerful protective effects of loudness in the face of social exclusion. Individuals who were made to feel socially excluded while being exposed to loud (vs. soft) stimuli responded more positively on a range of affective measures. As such, akin to how money may promote feelings of self-sufficiency and serve as a buffer against social pain (Zhou et al., 2009), loudness seems to promote feelings of interpersonal closeness, which may also help protect individuals from social pain.

Taken together, these findings highlight a previously untested compensatory strategy that people adopt following social exclusion, one that is sensory, rather than social, in nature. These findings also help carve out the compensatory nature of the loudness-interpersonal closeness link such that a deprivation in feelings of interpersonal closeness leads to a desire for louder auditory stimuli. It is important to note that while the present study is not the very first to illuminate sensory preference changes as a potential compensatory strategy following social exclusion (Pfundmair et al., 2019), it is the first to empirically demonstrate the effectiveness of such sensory preference changes. Specifically, we demonstrated that loud auditory stimulus is not just sought after following social exclusion, it is also effective in mitigating the detrimental psychological effects of social exclusion. Perhaps people display a preference for louder volume sounds following social exclusion because loud stimuli are capable of serving as a substitute for interpersonal companionship. These findings provide novel insight on the existing social exclusion literature because they show that not only do people engage in sensory preference changes as potential compensatory strategies following social exclusion, such changes are also functionally meaningful. In revealing these more nuanced and downstream effects of the loudness-interpersonal closeness relationship, our findings connect the social exclusion (Blackhart et al., 2009) and loudness perception (Ljung et al., 2009) literatures, which, until now, have largely proceeded in parallel.

The present findings also carry important implications for everyday life. Exposure to auditory loudness appears to be a virtually cost-free, intuitive, and convenient coping strategy that may be used in contexts where interpersonal companionship is deprived. Whether people are working solitary jobs or living alone, turning on some form of auditory stimulus and cranking the volume up may alleviate negative emotions such as loneliness, presumably because of the sense of companionship it provides. Our findings could be of particular pertinence to settings in which people may be more prone interpersonal isolation and feelings of loneliness, such as prisons, hospitals, and retirement homes.

Limitations and Future Research

While the use of diverse samples, a broad range of audio stimuli, and different exposure durations help substantiate the generalizability and robustness of the predicted phenomenon, some limitations should be noted. First, the auditory stimuli used in our experiments, while diverse, all contained an interpersonal element, however remote. For instance, the audiobook segment (Studies 1a, 1b, 5, and 6) may be associated with everyday social interactions, and the music clips (Studies 1c, 2a, 2b, 3a, 3b, and S1) may be associated with social occasions where music is played in the background. Even the sound of the operating air-conditioner (Study 1d) may be associated with *man*-made environments and hence, people. This common denominator inevitably leaves open the question of whether feelings of interpersonal closeness are affected by the loudness of *all* sounds. It certainly seems improbable that the loudness of sounds without a human element, such as that of thunder, can affect feelings of interpersonal closeness (at least not as potently as more socially relevant sounds such as the laughter of a close friend). As such, to establish boundary conditions on the present findings, future studies are encouraged to explore a greater variety of sound sources.

Since Study 4 was aimed primarily at establishing bidirectionality of the proposed effect, we did not investigate the effect of social exclusion on perceived ambient quietness the way we investigated the basic effect, i.e., with mediation, moderation, no-exposure control condition etc. This limitation means we could not address some salient ancillary questions, such as whether it is social exclusion that makes the environment seem quieter or social acceptance that makes the environment seem louder. Future studies are therefore encouraged to examine this phenomenon further.

What stood out the most from the present findings was perhaps the larger than expected effect sizes obtained in Study 6. We demonstrated that by listening to a neutral audiobook segment simply at high, instead of low, volume while experiencing social exclusion, individuals' exclusion induced feelings of negative mood, anger, hurt, and loneliness completely vanished (*d*s = -0.94 to -1.59; see Table S3). Results of this magnitude should be interpreted with caution. It certainly does not seem plausible that the false sense of companionship evoked by the exposure to loud stimuli can be as protective as real companionship in the face of social exclusion. Perhaps loud stimuli was protective against social exclusion because it was also more effective at distracting individuals from the experience of social exclusion. We speculate that the very large effect sizes could be because both mechanisms were at play – loudness may have evoked a sense of companionship, and simultaneously served as a more potent distractor, both leading to protective effects against the detrimental psychological concomitants of social exclusion. Future studies are encouraged to ascertain this speculation and potentially delineate the relative contributions of these mechanisms.

Findings of the present study also open up additional avenues for future research. First, additional downstream social effects of loudness cues could be explored, for instance, by investigating whether loudness plays a role in impression formation processes. As an example, future research may investigate whether a louder voice gives off an increased sense of interpersonal closeness during first encounters, and consequently make louder individuals seem more approachable. Studies could also explore the effects of other dimensions of auditory perception on social cognition constructs. For instance, would the pitch or pace of auditory stimuli affect social cognition outcomes in the same way loudness does? Given that people rely heavily on their hearing, and that noise is an ever-present feature of the environment, further illumination of how the mind is affected via audition is imperative to further understanding of human cognition and behavior more broadly.

Finally, research has shown that social exclusion may differentially affect people from individualistic and collectivistic cultures (Uskul & Over, 2017). Future studies are therefore encouraged to explore in a systematic way whether the interplay between loudness and social exclusion established in the present study manifests differently in people from different cultures.

Conclusion

The present research highlights a novel mental association between auditory loudness and feelings of interpersonal closeness. Our results suggest that auditory loudness is not only a vessel by which sensory information is communicated, but also a means by which people make social inferences. Perhaps people tend to associate ‘loud’ with ‘lively’ and ‘silence’ with ‘lonely’ semantically, and through the use of metaphor, because past experiences of companionship tend to coincide with ambient loudness and past experiences of solitude tend to coincide with ambient quietness. While there is still much to learn about the psychological effects of loudness, the present study provides preliminary evidence that loudness can be harnessed to combat feelings of loneliness.

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Supplementary Online Materials for "Loudness Perceptions Influence Feelings of Interpersonal Closeness and Protect Against Detrimental Psychological Effects of Social Exclusion"

This Supplementary Online Materials file includes:

Pretest; Study S1

Detailed method, results and discussion sections for Studies 1a – 3b

Data exclusions for Studies 4 - 6 and post-hoc sensitivity power analysis for Study 4

Tables S2 to S4

Assumption violations, non-parametric tests, manipulation checks for Study 6, and notes

Additional limitations and future directions

URLs of audio clips used in each experiment

Internal meta-analysis

References for the Supplementary Online Materials

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Pre-test – The Association between Loudness, and Physical and Social Connectedness

The objective of this study was to ascertain whether people believe that events reflecting physical and social proximity are usually accompanied by ambient loudness. We tested this prediction by measuring participants' perceived physical and social proximity, and the perceived loudness of a range of everyday activities. Our predictions would be supported if perceived loudness is positively associated with both perceived physical (operationalized as perceived crowdedness of the activity) and social (operationalized as relationship closeness with others with whom they shared the activity) proximity. This study was pre-registered online: http://aspredicted.org/blind.php?x=6hr7ek.

Method

Online crowdsourced members of the public were recruited via Amazon's Mechanical Turk (N = 198; 66 female; M_{age} = 35.29 years, SD_{age} = 9.68). Participants were presented with 14 everyday activities in random order (going to the library; jogging; grocery shopping; video gaming; playing team sports; studying; working individually; working as a team; cooking; sleeping; eating with others; eating alone; watching TV; browsing social media), and were asked to rate each activity on four items using 7-point scales from 1 (*not at all*) to 7 (*very much*). The first item was a filler item that measured their perception of how bright the activity usually is. Then, they were asked to rate if there is usually many people around (as a measure of perceived physical proximity), followed by how loud it usually is during the activity, and finally, how close they were with those whom they do the activities with (as a measure of social proximity). Participants were then asked to provide some demographic details and were debriefed.

Results and Discussion

Correlations between the key variables are reported in Table S1. Overall, the louder participants rated an activity, the more crowded it was also rated (correlations ranged from .19 to .87; all *p*s < .01). Furthermore, the louder participants rated an activity, the closer they rated themselves to be with those they share the activity with (correlations ranged from .25 to .80; all *p*s < .001). When looking across situations, we found positive and statistically significant correlations among mean levels of loudness and physical proximity, $r(14) = .82$, $p < .001$, and between mean levels of loudness and social proximity, $r(14) = .55$, $p = .041$.

Results suggest that, as predicted, activities that are generally shared with people with whom individuals had close (vs. distant) relationships, and activities that usually take place in crowded (vs. uncrowded) settings, are both associated with perceptions of ambient loudness. These associations were established across a wide range of daily activities, both across and within activity.

Table S1

Zero Order Correlations for Each Activity

Situation	Loudness-psychological proximity correlation	Loudness-physical proximity correlation
Library	.68	.55
Jogging	.62	.79
Grocery shopping	.33	.19**
Video gaming	.56	.64
Playing team sports	.49	.48
Studying	.80	.87
Working individually	.80	.86
Working as a team	.50	.65
Cooking	.37	.77
Sleeping	.25	.90
Eating with others	.31	.69
Eating alone	.76	.89
Watching TV	.28	.58
Browsing social media	.64	.67

Note. all correlations significant at $p < .001$ except that denoted by ** which indicates significance at $p < .01$

Study S1: An Online Pilot Study for Field Replications

Studies 3a and 3b tested the effects of auditory loudness on ecologically valid measures of perceived interpersonal closeness in natural settings. Given the difficulty of obtaining ethical clearance and organizational permissions in these field replications, as well as the various logistic arrangements involved, we conducted a supplementary study in advance to serve as a pilot for the field studies. Specifically, we conducted an online version of Study 3b. This study targeted undergraduate students at an Australian university in an attempt to further diversify our existing samples.

Method

In Study S1, undergraduate students (N = 200; 130 female; M_{age} = 22.55 years, SD_{age} = 6.74) were randomized and individually tested using a single factor two-level between-participant design (volume: loud vs quiet). We pre-registered the present study on OSF, and consistent with our pre-registration (https://osf.io/9y8fq/?view_only=3152aafc84634894bd0069377620be09), the minimum sample size was predetermined in accordance to the conservative rule-of-thumb of 100 participants per condition – double the recommended sample size for laboratory studies (Simmons et al, 2013), in consideration of the less controlled online environment. We tried to overshoot as much as possible to account for inattentive responding tendencies in undergraduate student samples (Huang et al., 2012). Regardless, data was not examined before termination of data collection. A total of 299 participants took part in the present study, however, 99 participants were excluded for failing the attention check, leaving a total of 200 in the final sample. Given that the present study has a set of requirements on the participants' environment and equipment, participants were shown the eligibility criteria via the information sheet prior to participation. These included

1) they must be alone in a quiet place with headphones/earphones, and 2) they must complete this study using a computer since the study is incompatible with mobile devices.

Measures

Perceived Physical Proximity

Participants were asked to rate the extent to which they agree with two general statements: “1: My university campus is a lively place” and “2: My university campus is a crowded place”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree;* $r = .29$, $p < .001$). The mean of the two items constituted perceived physical proximity.

Perceived Social Proximity

Participants were asked to rate the extent to which they agree with two general statements: “1: I feel a lack of companionship from people in my University social network” and “2: I feel close with people in my University social network”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree;* $r = .70$, $p < .001$). The first item was reverse scored, and the mean of the two items constituted perceived physical proximity.

Manipulation Check

Participants were asked a single question that served both as a manipulation check and also as an attention check: “To show that you have been paying attention to the present study thus far, please indicate below at what volume you are listening to the clip at”. Responses were gathered on 7-point scales (1 = *extremely low volume* and 7 = *extremely high volume*). Participants with a response opposite to their expected response (i.e., responding with 5, 6, or 7 when in the quiet condition or responding with 1, 2, or 3 when in the loud condition) were considered as having failed this check.

Attention Check

To defend against data contamination from inattentive response tendencies in university student samples (Huang et al, 2012), the present study incorporated an additional attention check item. Participants were asked: "To confirm that you have been complying with the instructions, please select from the options below the musical instrument used in this clip as stated in the clip's title". Participants chose from four choices – "Piano", "Violin", "Bamboo flute", and "None of the above". Participants who did not choose the correct answer (Bamboo flute) were considered as having failed this attention check.

Filler Items

Participants were asked: "1: Please calculate the following without a calculator as quickly as you can (if you cannot finish within 2 minutes, please move on to the next page): 31 X 40; 221/17; 86927 – 4961", and "2: Please give an estimate as to how long it took you in total to work out all 3 answers (if unfinished, please ignore this question)".

Probe

Participants were asked: "Before we move on, please answer the question below: if you think you know the study's hypothesis already (for example if you have participated in a study in the same series), please write below what you think the hypothesis is. If you are unaware or not sure, simply write 'n/a'".

Procedure

Participants selecting the URL were directed to a landing web page where they provided informed consent. Next participants were presented with the following instructions: “Thank you for taking part in the present study! We are interested to explore the effect of background music on our arithmetic ability. First, please wear headphones/earphones, and copy the following link (https://www.youtube.com/watch?v=6ixhN9umyp4&t=4s) and paste it into your browser. Please listen to it (and depending on their condition) at the highest volume possible without it being uncomfortable OR lowest volume possible so that it’s barely audible. Once you have started listening, please click next”. To ensure compliance and attentiveness, participants were then presented with the attention check item, followed by: “We want you to please continue to listen to it for one more minute before moving on to the arithmetic task. Therefore, we have also added a short student experience survey (as part of a larger survey, unrelated to the present experiment) on the next page for you to complete while you listen to the clip. Once this is done, please move on to the arithmetic questions on the subsequent page. Please click next when you are ready”. Participants were then shown the perceived physical and social proximity measures in random order, followed by the manipulation check, the filler items, the probe, and some demographic questions before being presented the debriefing sheet.

Results and Discussion

A manipulation check showed that participants in the loud condition (*M* = 5.87, *SD* = 1.01) selected significantly higher subjectively perceived volume levels than those in the quiet condition (*M* = 1.64, *SD* = 0.87), *t*(198) = 31.73, *p* < .001, Cohen’s *d* = 4.49, 95% CI for the mean difference = [3.97, 4.49].

Independent *t*-tests revealed that participants in the loud condition rated their university campus as providing a greater sense of physical proximity (*M* = 4.68, *SD* = 1.18) compared to participants in the quiet condition (*M* = 3.93, *SD* = 1.24), $t(198) = 4.40$, $p < .001$, Cohen's *d* = 0.62, 95% CI for the mean difference = [0.42, 1.09]. Participants in the loud condition also reported significantly higher levels of social proximity with their university social network (*M* = 4.73, *SD* = 1.55) compared to participants in the quiet condition (*M* = 3.90, *SD* = 1.70), $t(198) = 3.58$, $p < .001$, Cohen's *d* = 0.51, 95% CI for the mean difference = [0.37, 1.28]. These findings suggest that auditory loudness affects not only people's immediate construals of interpersonal closeness, but also their global perceptions of interpersonal closeness. Specifically, students who listened to a louder (vs quieter) audio clip perceived their university campus to be more lively and crowded, and also felt a greater level of companionship from, and closeness to, their university social network. These findings also complement those of Studies 3a and 3b by extending their generalizability across different demographics, and to the online experimental format.

Detailed Method and Results for Studies 1a – 3b

Study 1a: Loudness Induces a Sense of Physical Proximity

Method

In Study 1a, undergraduate students from a university in Singapore (*N* = 100; 49 female; M_{age} = 22.08 years, SD_{age} = 2.91) were randomized and individually tested using a single factor two-level between-participants design, with volume (loud vs. quiet) as the single independent factor. An initial total of 101 participants was recruited, however, one participant failed to follow instructions and was excluded from the analyses, leaving a final sample of 100 participants. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's *d* = 0.57, with a two-tailed alpha of 5%.

Participants sat in a quiet laboratory opposite the experimenter. After providing informed consent, participants were provided with headphones and told that they would be required to listen to a brief audio clip, at the end of which they would see a question on the computer screen that they needed to answer quickly. As a cover story, participants were led to believe that this study was surveying people's ability to make accurate estimations. Depending on allocated condition, participants were then instructed to listen to an audiobook segment at either the "loudest volume possible without it being uncomfortable" (loud condition) or "quietest volume possible without it being incomprehensible" (quiet condition). It is important to note that this audio segment was used as the auditory stimulus because we sought to select an audio segment that was neutrally valenced, calm, and balanced in terms of male to female dialogue ratio to minimize potential confounding effects (IJzerman & Semin, 2009). Volume was adjusted by the experimenter and participants were instructed to say 'stop' when the appropriate volume level was reached. Initial volume was set to 10 out of 100 and the experimenter turned the volume either progressively up or progressively down depending on the participant's condition[1]. After two minutes, participants were shown and answered the following question on the computer screen: "Pretend that you are the center of a sphere, if you had to make a quick guess, how many people do you think are there within a 30 meter radius in this very moment?[2]" Participants then completed some demographic information and were probed for suspicion, debriefed, and thanked. It is important to note that in all applicable studies, we took the dependent measures during the auditory exposure interval rather than after termination of the auditory stimulus. This was aimed at maximizing replicability of our hypothesized effects, since mental associations are more reliably activated *during*, not after, participants' exposure to cues responsible for the formation of such associations (Barsalou, 2016b).

Results

For Study 1a, a manipulation check showed that participants in the loud condition (*M* volume = 80.60% of maximum volume, *SD* = 22.91%) selected significantly higher volume levels than those in the quiet condition (*M* volume = 3.06%, *SD* = 2.98%), $t(50.66) = 23.74$, $p < .001$, Cohen's $d = 4.75$, 95% CI for the mean difference [70.98, 84.10].

An independent samples *t*-test[3] revealed that participants in the loud condition estimated significantly greater numbers of people within a 30 meter radius (*M* = 77.24, *SD* = 101.14)

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[1]In consideration of individual differences in hearing sensitivity, we prioritized *perceived* loudness over absolute loudness. To this end, for some studies, including Study 1a, participants were asked to self-determine the precise volume level after being randomly allocated to either the loud or quiet condition. For instance, one participant might have chosen 87% of desktop volume as the "loudest volume possible without it being uncomfortable", but this number might have been 61% for another participant. Manipulation checks were subsequently conducted to ensure that participants correctly followed the instructions, i.e., that participants in the loud condition did select higher volume levels compared to those in the quiet condition.

[2]Across experiments, participants occasionally responded to this measure of perceived physical proximity with a range. In such cases, the arithmetic midpoint was taken as their response (e.g., '3' was coded as their response if they responded with '1 – 5'). Participants also responded occasionally with non-sensical answers (e.g., 35000 people within a 30 metre radius). Such responses were treated as missing values.

[3]For our analyses across all studies, where statistical assumptions were violated, non-parametric tests were conducted but not reported given that they yielded identical results to the parametric tests. Information pertaining to statistical assumption violations and non-parametric test results can be found in a later section of this SOM.

compared to participants in the quiet condition (*M* = 28.98, *SD* = 23.30), $t(54.19) = 3.29$, p = .002, Cohen's *d* = 0.66, 95% CI for the mean difference [18.84, 77.68].

Study 1b: Loudness Increases Feelings of Social Proximity

Method

Undergraduate students from a university in Singapore (*N* = 100; 52 female; M_{age} = 20.74 years, SD_{age} = 2.49) were randomized and individually tested in a single factor two-level between-participant design (volume: loud versus quiet). An initial total of 101 participants was recruited, however, one participant was interrupted by a phone call and was therefore excluded from the analyses, leaving a final sample of 100 participants. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's *d* = 0.57, with a two-tailed alpha of 5%.

In line with previous research (e.g., IJzerman et al., 2018; IJzerman & Semin, 2009), perceived social proximity with others was operationalized as ratings of relationship closeness with self-nominated individuals. As such, Study 1b replicated Study 1a with one key difference: instead of estimating the number of people nearby, participants indicated their perceived closeness with a self-nominated individual using the Inclusion of Other in Self (IOS) scale (Aron et al., 1992). Respondents were required to rate their relationship closeness with their self-nominated individual using circles on a 7-point scale (1 = *two minimally overlapping circles* and 7 = *two maximally overlapping circles*) (Aron et al., 1992).

Results

A manipulation check showed that participants in the loud condition (mean volume = 75.12% of maximum desktop volume, *SD* = 26.59%) selected significantly louder volume levels than those in the quiet condition (mean volume = 1.14%, *SD* = 0.50%), $t(49.03) = 19.67$, $p <$ .001, Cohen's $d = 3.93$, 95% CI for the mean difference [66.42, 81.54].

An independent samples *t*-test revealed that participants in the loud condition reported that they were significantly more intimate with their self-nominated individual ($M = 4.22$, $SD =$ 1.73) compared to participants in the quiet condition ($M = 3.40$, $SD = 1.58$), $t(98) = 2.48$, $p =$ .015, Cohen's $d = 0.50$, 95% CI for the *M* difference [0.16, 1.48].

Study 1c: Loudness Increases Feelings of Interpersonal Closeness by Activating Mental Concepts of Interpersonal Closeness

The primary aim of Study 1c was to test the mechanism underlying the basic effect: Does loudness alter individuals' perceptions of interpersonal closeness by activating closeness-related mental concepts? This is important to ascertain not only because it clarifies the nature of the basic effect, and whether it is indeed the result of mental associations, but also because it allows us to rule out potential alternative explanations. To this end, Study 1c aimed to establish whether mental accessibility of closeness-related concepts mediates the basic effect.

Studies 1a and 1b demonstrated the basic effect that loudness (relative to quietness) cues induce a sense of interpersonal closeness. In these studies, however, we only compared the quiet and loud conditions without incorporating a no-exposure control condition. This is because we treated the quiet condition as the control condition due to the inherent quietness of the laboratory. To eliminate the alternative possibility that exposure to low volume actually decreased perceptions of interpersonal closeness, rather than exposure to high volume increasing perceptions of interpersonal closeness, a no-exposure control condition was included in Study 1c.

Method

In Study 1c, undergraduate students from a university in Singapore (*N* = 150; 92 female; M_{age} = 22.89 years, SD_{age} = 5.54) were randomized and individually tested using a single factor three-level between-participants design (volume: loud, quiet, and no-exposure). The eligibility criterion was that participants must not be able to speak Greek. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's *d* = 0.57, with a two-tailed alpha of 5% for each pairwise comparison across conditions.

Measures

Perceived Physical Proximity

As with Study 1a, participants were asked to estimate the number of people within a given radius. To maximize the robustness of our results, however, instead of using a single item measure, participants were asked to make the same estimation for a 30m, 50m, and 20m radius. The mean of the three estimates constituted perceived physical proximity.

Perceived Social Proximity

As with Study 1b, participants were asked to rate their relationship closeness with a self-nominated individual using the IOS. To maximize robustness of our results, instead of rating a single person, participants were asked to rate their relationship closeness with three self-nominated individuals. The mean of the three ratings constituted perceived social proximity.

Accessibility to Closeness-Related Mental Concepts

Participants were asked to complete a brief adapted Lexical Decision Task (LDT; Meyer & Schvaneveldt, 1971). This computerized task presented participants with letter strings and participants were instructed to decide whether each letter string was a word or a non-word by pressing the correct computer key ('1' for non-word, '0' for word). There were 40 trials in total, consisting of two blocks of 20 unique letter strings. Of these, seven were random word fillers generated from an online word generator (e.g., 'VALLEY'), three were closeness-related words (e.g., 'CONNECTED[4]'), and the remaining ten were non-words generated from an online letter generator (e.g., 'YTWOXVL'). Participants' reaction times to the closeness-related stimuli relative to the filler items were used as a reflection of their accessibility to closeness-related concepts, with faster reaction times indicating greater accessibility levels. The 40 trials were presented in random order and were preceded by six practice trials with a different set of filler-word and non-word stimuli. All trials commenced with a 1000ms blank screen followed by a 500ms fixation cross. The letter string subsequently appeared for 250ms with an additional 1000ms blank screen before the commencement of the next trial, resulting in a 1250ms stimulus onset – response deadline asynchrony. Participants were instructed to complete the LDT as quickly as possible without compromising accuracy. The task took approximately two minutes to complete.

Procedure

On arrival at the laboratory, participants were invited to a quiet booth housing a computer and provided informed consent. Participants were then told that their first task was a quick computer task, the instructions of which would be displayed on the screen. Participants in the loud and quiet conditions were also given headphones and asked to listen to a Greek song

[4] For the reaction time tasks used in Studies 1c and 1d, we did not provide separate word stimuli for physical and social proximity. Instead, we conceptualized interpersonal closeness as a single variable that envelopes both physical and social proximity. This is because the word stimuli used (e.g., 'CLOSE', 'DISTANT", 'CONNECTED') can often be interpreted from both a physical proximity perspective and a social proximity perspective, and therefore it was difficult to isolate the physical component from the social component. The linguistic association between physical and social proximity is also supported by (a) conventional wisdom, since people tend to be spatially closer with others whom they are psychologically more intimate with, and (b) theoretical and empirical evidence, such as those in the propinquity effect literature, that intrinsically tie spatial closeness with psychological intimacy (Caporael, 1997; IJzerman & Semin, 2010; Shin et al., 2019).

compilation audio clip as background music during the experiment. The audio file used was a short *Youtube* clip converted into an MP3 file so that it could be played on a loop. Depending on the condition, participants were asked to listen to the clip at the "loudest volume possible without it being uncomfortable" (loud condition) or "quietest volume possible without it being inaudible" (quiet condition). Upon volume adjustment by participants (from the default volume of zero out of 100 using the desktop volume bar) in the loud and quiet conditions, all participants were administered the LDT. Upon completion of the LDT, participants were handed a single handout with the measures of perceived physical and social proximity in random order, followed by some demographic questions. When this was completed, participants were probed for suspicion, debriefed, and thanked for their time.

Results and Discussion

One participant failed to comply with the instructions of the measure of mental accessibility due to an insect in the laboratory booth that was removed before the dependent measures were taken. Another participant's mental accessibility results failed to save due to a computer error. These two participants were therefore excluded from the mediation analyses, but were included in the main analyses.

Manipulation Check

A manipulation check showed that participants in the loud condition (*M* volume = 53.06% of maximum desktop volume, *SD* = 20.07%) selected significantly louder volume levels than those in the quiet condition (*M* volume = 1.22%, *SD* = 0.47%), $t(49.05) = 17.73$, $p < .001$, Cohen's $d = 3.55$, 95% CI for the mean difference [45.97, 57.72].

Perceived Physical and Social Proximity

Univariate ANOVAs revealed a significant main effect of condition on perceived physical (F (2, 147) = 7.15, p = .001, η_p^2 = .09) and social (F (2, 147) = 4.80, p = .010, η_p^2 = .06) proximity. Pairwise comparisons revealed that participants in the loud condition estimated significantly greater numbers of people in the three given radii (M = 85.94, SD = 76.59) compared to participants in the quiet condition (M = 46.86, SD = 41.54), t(75.53) = 3.17, p = .002, Cohen's d = 0.63, 95% CI for the mean difference [14.54, 63.62]. Participants in the loud condition also reported significantly higher levels of relationship closeness with their three self-nominated individuals (M = 4.47, SD = 1.09) compared to participants in the quiet condition (M = 3.89, SD = 1.18), t(98) = 2.56, p = .012, Cohen's d = 0.51, 95% CI for the mean difference [0.13, 1.03]. These findings replicated the basic effects of Studies 1a and 1b, and support our prediction that relative to low volume, exposure to high volume confers in people greater feelings of physical and social proximity.

Pairwise comparisons also revealed that participants in the loud condition estimated significantly greater numbers of people in the three given radii (M = 85.94, SD = 76.59) compared to participants in the no-exposure condition (M = 47.68, SD = 53.52), t(87.64) = 2.90, p = .005, Cohen's d = 0.58, 95% CI for the mean difference [12.00, 64.52]. Participants in the loud condition also reported significantly higher levels of relationship closeness with their three self-nominated individuals (M = 4.47, SD = 1.09) compared to participants in the no-exposure condition (M = 3.81, SD = 1.24), t(98) = 2.86, p = .005, Cohen's d = 0.57, 95% CI for the mean difference [0.20, 1.13]. On the other hand, participants in the quiet condition did not differ significantly from those in the no-exposure condition in either measures (all ps > .720). These findings show that the no-exposure condition yielded results that were not statistically different from that of the quiet condition, and using either condition as the reference group produced the same results.

Mediation Analyses

To investigate whether mental accessibility of closeness-related concepts mediates the effect of loudness cues on perceptions of interpersonal closeness, we first calculated an accessibility index for all participants[5]. Specifically, participants' mean LDT reaction time to closeness-related words were subtracted from their mean reaction time to filler words. To facilitate ease of interpretation, a constant value was subsequently added so that the resultant accessibility indices were all positive, with higher values reflecting higher mental accessibility of closeness concepts. A series of multiple regressions showed that exposure to loud stimuli (2 = loud, 1 = quiet) increases accessibility of closeness-related concepts, $b = 29.74$, $SE = 11.81$, $t(96) = 2.52$, $p = .013$, and perceived physical proximity, $b = 39.08$, $SE = 12.45$, $t(96) = 3.14$, $p = .002$. Accessibility of closeness-related concepts also positively predicted perceived physical proximity, $b = 0.46$, $SE = 0.10$, $t(96) = 4.64$, $p < .001$. When both loudness and accessibility were entered as predictors of perceived physical proximity, the effect of loudness was attenuated but still significant, $b = 27.12$, $SE = 11.95$, $t(96) = 2.27$, $p = .025$, while the effect of accessibility remained significant, $b = 0.40$, $SE = 0.10$, $t(96) = 4.02$, $p < .001$. This partial mediation was further corroborated by Bootstrapped regression analyses using the PROCESS SPSS macro (Model 4; 5000 bootstraps; Hayes, 2013). Specifically, the indirect

[5] The mean number of errors in the LDT was 5.42 ($SD = 4.59$) which is equivalent to 13.55% of total trials. The reason for this slightly inflated figure is that in the present study, errors included both actual errors, where the wrong key was pressed, and responses outside of the one second response window. Furthermore, many participants reported making mistakes in the first few trials as it took them a few trials to get accustomed to the pace of the task where the letter-strings were only presented for 250ms each. This is also likely due to the brevity of the practice trials (only 6 trials).

effect of loudness on perceived physical proximity via accessibility was significant (*b* = 12.11, 95% CI = [2.41, 26.50]) while the direct effect of loudness on perceived physical proximity was also significant (*b* = 26.28, 95% CI = [2.35, 50.20]).

The same analyses were conducted for the mediation model with perceived social proximity as the dependent variable. Results demonstrated that exposure to loud stimuli increases accessibility of closeness-related concepts, *b* = 29.74, *SE* = 11.81, *t*(96) = 2.52, *p* = .013, and perceived social proximity, *b* = 0.58, *SE* = 0.23, *t*(96) = 2.53, *p* = .013. Accessibility of closeness-related concepts also positively predicted perceived social proximity, *b* = 0.01, *SE* = 0.00, *t*(96) = 3.44, *p* = .001. When both loudness and accessibility were entered as predictors of perceived social proximity, the effect of loudness became non-significant, *b* = 0.41, *SE* = 0.23, *t*(96) = 1.82, *p* = .072, while the effect of accessibility remained significant, *b* = 0.01, *SE* = 0.00, *t*(96) = 2.92, *p* = .004. This complete mediation was again corroborated by Bootstrapped regression analyses using the PROCESS SPSS macro (Model 4; 5000 bootstraps; Hayes, 2013). Specifically, the indirect effect of loudness on perceived social proximity via accessibility was significant (*b* = 0.16, 95% CI = [0.02, 0.35]) while the direct effect of loudness on perceived physical proximity was non-significant (*b* = 0.44, 95% CI = [0.00, 0.89]). The abovementioned mediation results support our hypothesis and suggest that loudness increases perceived physical and social proximity by activating mental concepts of interpersonal closeness (see Figure S1).

An additional series of multiple regressions using the no-exposure condition as the control group showed that exposure to loud stimuli (2 = loud, 0 = no-exposure) increases accessibility of closeness-related concepts, *b* = 17.59, *SE* = 6.99, *t*(97) = 2.52, *p* = .014, and perceived physical proximity, *b* = 19.13, *SE* = 6.61, *t*(98) = 2.90, *p* = .005. Accessibility of closeness-related concepts also positively predicts perceived physical proximity, *b* = 0.32, *SE* =

0.09, *t*(97) = 3.42, *p* = .001. When both loudness and accessibility were entered as predictors of perceived physical proximity, the effect of loudness was attenuated but still significant, *b* = 14.34, *SE* = 6.65, *t*(96) = 2.16, *p* = .034, while the effect of accessibility remained significant, *b* = 0.27, *SE* = 0.09, *t*(96) = 2.85, *p* = .005. This partial mediation was further corroborated by Bootstrapped regression analyses using the PROCESS SPSS macro (Model 4; 5000 bootstraps; Hayes, 2013). Specifically, the indirect effect of loudness on perceived physical proximity via accessibility was significant (*b* = 4.68, 95% CI = [0.80, 10.81]) while the direct effect of loudness on perceived physical proximity was also significant (*b* = 14.34, 95% CI = [1.14, 27.54]).

The same analyses were conducted for the mediation model with perceived social proximity as the dependent variable. It was shown that exposure to loud stimuli increases accessibility of closeness-related concepts, *b* = 29.74, *SE* = 11.81, *t*(96) = 2.52, *p* = .013, and perceived social proximity, *b* = 0.33, *SE* = 0.12, *t*(98) = 2.86, *p* = .005. Accessibility of closeness-related concepts also positively predicts perceived social proximity, *b* = 0.01, *SE* = 0.00, *t*(97) = 2.85, *p* = .005. When both loudness and accessibility were entered as predictors of perceived social proximity, the effect of loudness was attenuated but still significant, *b* = 0.26, *SE* = 0.12, *t*(96) = 2.17, *p* = .032, while the effect of accessibility remained significant, *b* = 0.00, *SE* = 0.00, *t*(96) = 2.27, *p* = .025. This partial mediation was further corroborated by Bootstrapped regression analyses using the PROCESS SPSS macro (Model 4; 5000 bootstrapped replications; Hayes, 2013). Specifically, the indirect effect of loudness on perceived social proximity via accessibility was significant (*b* = 0.07, 95% CI = [0.00, 0.16]), as was the direct effect of loudness on perceived social proximity (*b* = 0.26, 95% CI = [0.02, 0.49]). These results again show that using either the no-exposure or the quiet condition as the reference group produced the same results. The present study therefore eliminated the alternative possibility that exposure to low volume actually decreased perceptions of interpersonal closeness.

Finally, to ensure that the quiet and no-exposure control conditions were not statistically different, bootstrap regressions using the PROCESS SPSS macro (Model 4; 5000 bootstrapped replications; Hayes, 2013) were conducted to compare the two conditions using mediation. Specifically, the indirect effect of loudness on perceived physical proximity via accessibility was non-significant (*b* = 1.10, 95% CI = [-4.38, 6.73]), as was the direct effect of loudness on perceived physical proximity (*b* = -1.44, 95% CI = [-20.00, 17.12]). Furthermore, the indirect effect of loudness on perceived social proximity via accessibility was non-significant (*b* = 0.02, 95% CI = [-0.07, 0.18]), as was the direct effect of loudness on perceived social proximity (*b* = 0.02, 95% CI = [-0.45, 0.49]).

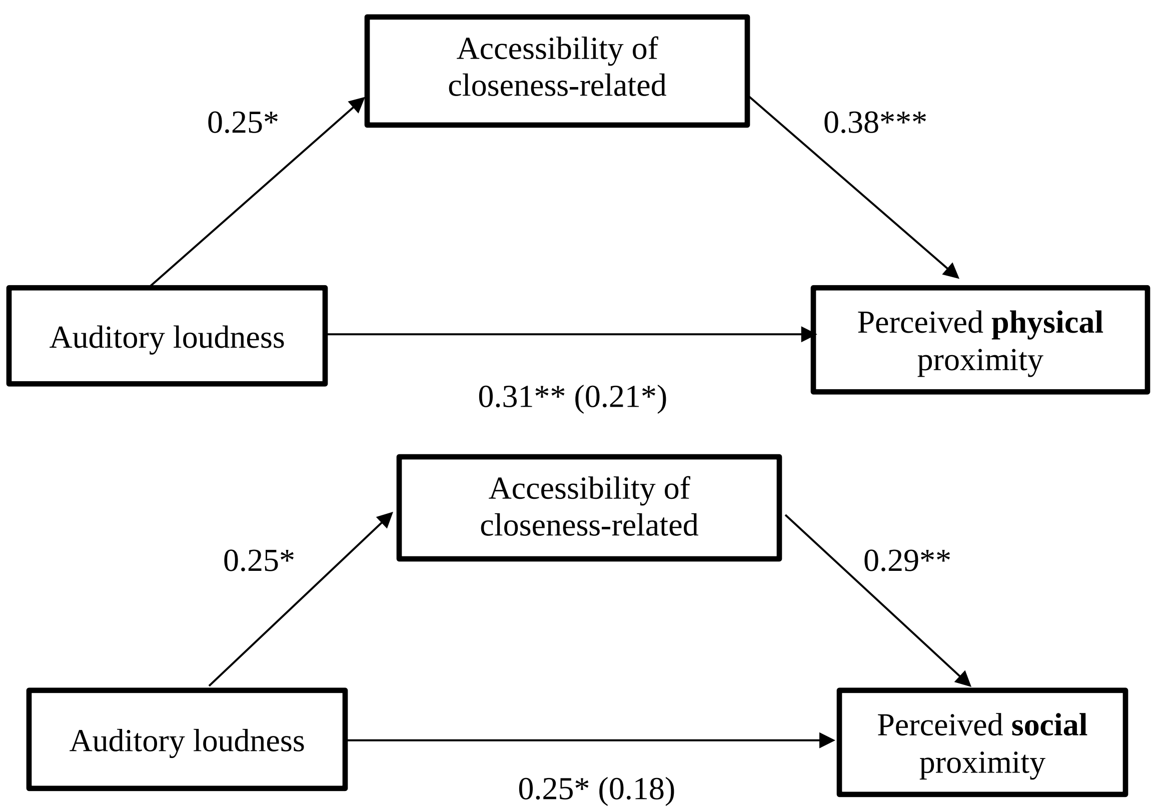


Figure. S1. Mediation models (Study 1c) portraying accessibility of closeness-related concepts mediating the effect of auditory loudness on perceived physical (top) and social (bottom) proximity. Values inside parentheses depict direct effects after controlling for the mediator, values outside parentheses show total effects. Standardized coefficients are displayed.

* $p < .05$; ** $p < .01$; *** $p < .001$.

Study 1d: Loudness-Interpersonal Closeness Implicit Association Strength Moderates the Loudness-Interpersonal Closeness Effect

Study 1c showed that loudness increases perceived interpersonal closeness by activating mental concepts of interpersonal closeness. It follows then, that the effect of loudness on perceived interpersonal closeness should be more pronounced in individuals that tend to associate loudness with closeness more strongly. To investigate this, and to further corroborate the mechanistic process underlying the effect of loudness on perceived interpersonal closeness, Study 1d measured individuals' dispositional tendency to associate loudness with closeness using a modified version of the Implicit Association Test (IAT; Greenwald et al., 1998).

A secondary goal of Study 1d was to test whether the basic loudness-interpersonal closeness effect generalizes to a different type of auditory stimulus. In the previous studies, we demonstrated the basic effect for a neutral audiobook segment and songs in an unfamiliar language, but the possibility remains that this effect could be specific to sounds containing human voices since the outcome variable was perceived *interpersonal* closeness. To investigate whether the basic effect can be observed for loud sounds in general and not only sounds containing human voices, the sound of an operating air-conditioner was chosen as the auditory stimulus for Study 1d.

Method

In Study 1d, undergraduate students from a university in Singapore (N = 100; 61 female; M_{age} = 22.56 years, SD_{age} = 2.44) were randomized and individually tested using a single factor two-level between-participants design (volume: loud vs quiet). Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's d = 0.57, with a two-tailed alpha of 5%. Additional measures and analyses are reported in the SOM.

Measures

Perceived Physical Proximity

In line with Study 1c, participants were asked to estimate the number of people within a 30m, 50m, and a 20m radius. The mean of the three estimates constituted the measure of perceived physical proximity.

Perceived Social Proximity

In line with Study 1c, participants were asked to rate their relationship closeness with three self-nominated individuals on the IOS. The mean of the three ratings constituted the measure of perceived social proximity.

Strength of Loudness-Closeness Implicit Associations

The strength of participants' loudness-closeness implicit association was measured using a modified version of the IAT (Greenwald et al., 1998), which required participants to classify stimulus words presented in the center of the screen into categories. The categories included the concepts of "loud" and "quiet", and the attributes of "close" and "distant". The left and right sides of the screen each corresponded to one concept paired with one attribute, such as "loud" and "close" on the left and "quiet" and "distant" on the right. As stimulus words related to these categories (e.g., “lively”, “stranger”, and “friend”) were presented in the centre of the screen one at a time, participants were required to sort them into their corresponding categories by pressing the “E” and “I” keys for categories on the left and right respectively. Participants were instructed to complete the IAT as quickly as possible without compromising accuracy. The IAT contained seven blocks. Following the first four blocks, the concept and attribute categories switched sides and more trials were administered. Reaction times are assumed to be faster if the concept and attribute pairings are intuitive, and consequently more strongly associated in memory. An implicit association bias is thus revealed if participants react to one set of concept-attribute pairings (e.g., “loud and close” and “quiet and distant”) faster than they do for the opposite set (e.g., “loud and distant” and “quiet and close”). Blocks 1, 2, and 5 were single dimension practice blocks (e.g., categorizing stimuli into either the loudness or closeness categories), each containing 20 trials. Of the remaining four blocks, the first block of each pairing contained 20 trials while the second block contained 40 trials.

The IAT reaction times were scored in accordance with the improved IAT scoring procedures (Greenwald et al., 2003). Specifically, (a) only the four non-practice blocks were scored; (b) all error trials were retained; (c) trials with response latencies slower than 10,000 ms or faster than 400 ms were discounted; and (d) participants with an error rate of more than 20% were excluded. Mean latencies from corresponding blocks were first subtracted and then divided by the standard deviation of all trials from those blocks. This resulted in two scores that were then averaged into an overall D score, where a higher D value indicated a stronger association between loudness and closeness concepts.

Procedure

On arrival at the laboratory and after providing informed consent, participants were provided with a cover story in which the present study aimed to investigate the effect of music on thought processes, but that they have been allocated to the control group. As such, they were asked to take a seat in an isolated booth housing a computer and complete the handout containing the dependent measures in random order and some demographic information while bearing with the background noise played by the computer. The background noise used was a clip of an operating air conditioner. Depending on random allocation, the volume[6] of the clip was set at the desktop volume of either 1 (quiet condition) or 10 (loud condition) out of 100. When this was completed, the audio clip was paused, and participants were instructed to complete an Implicit Association Task (IAT; used in moderation analyses, see the SOM), after which they were probed for suspicion, debriefed, and thanked for their participation.

Results and Discussion

One participant failed to meet the minimum response accuracy requirement (80%; Greenwald et al., 2003) for the IAT and was therefore excluded from the moderation analyses but not the main analyses.

Perceived Physical and Social Proximity

Independent samples *t*-tests revealed that participants in the loud condition estimated significantly greater numbers of people in the three given radii (M = 67.29, SD = 60.62) compared to participants in the quiet condition (M = 38.45, SD = 43.71), t(89.11) = 2.73, p =

[6]In Study 1d, we deviated from the pre-registered procedures by using slightly lower volume levels - 1 and 10 out of 100, rather than 2 and 20. This is because we realized, after the study was pre-registered, that unlike audio books and music clips, people may be more prone to feelings of discomfort when exposed to loud air-conditioner sounds. Furthermore, excessively loud air-conditioner sounds are also less ecologically valid since people are usually exposed to them at low volume levels in everyday life. To ensure that perceived discomfort did not have an overshadowing effect on our results, and to increase ecological validity, we decided to conduct this experiment with the aforementioned methodological deviation.

.008, Cohen's *d* = 0.55, 95% CI for the mean difference [7.83, 49.83]. Participants in the loud condition also reported significantly higher levels of relationship closeness with their three self-nominated individuals (*M* = 4.59, *SD* = 1.61) compared to participants in the quiet condition (*M* = 3.79, *SD* = 1.56), $t(98) = 2.55$, $p = .012$, Cohen's *d* = 0.51, 95% CI for the mean difference [0.18, 1.43]. These findings suggest that the basic effect of loudness on feelings of interpersonal closeness can be generalized to loud auditory stimuli that does not contain human voices.

Moderation Analyses

To examine the predicted moderation effects, we conducted moderation analyses using the PROCESS SPSS macro (Hayes, 2013). In the first test, loudness condition was specified as the predictor, physical proximity was specified as the outcome, and participants' loudness-closeness implicit association strength was specified as the moderator. In line with our prediction, the interaction effect between loudness condition and loudness-closeness implicit association strength was statistically significant, $F(1, 95) = 5.84$, $p = .018$, $\Delta R^2 = .051$, $b = 56.87$. Next, the same model was tested with social proximity specified as the outcome. Again, the interaction effect between loudness condition and loudness-closeness implicit association strength was statistically significant, $F(1, 95) = 6.51$, $p = .012$, $\Delta R^2 = .058$, $b = 1.80$.

To probe the aforementioned interaction effects, spotlight analyses (±1 *SD*; Aiken & West, 1991) were conducted. Consistent with our predictions, the analysis revealed that the effect of loudness on perceived physical proximity emerged only for participants with strong loudness-closeness implicit associations (loud: *M* = 88.96, quiet: *M* = 35.54), $b = 53.42$, $SE = 14.63$, $t(97) = 3.65$, $p < .001$, 95% CI = [24.38, 82.47], but not for those with weak loudness-closeness implicit associations (loud: *M* = 44.17, quiet: *M* = 41.12), $b = 3.05$, $SE = 14.54$, $t(97) = 0.21$, $p = .834$, 95% CI = [-25.81, 31.91] (see Figure S2a). Likewise, the effect of loudness on perceived social proximity emerged only for participants with strong loudness-closeness implicit associations (loud: M = 5.21, quiet: M = 3.63), b = 1.57, SE = 0.44, $t(97)$ = 3.58, p < .001, 95% CI = [0.70, 2.45], but not for those with weak loudness-closeness implicit associations (loud: M = 3.94, quiet: M = 3.96), b = -0.02, SE = 0.44, $t(97)$ = -0.05, p = .958, 95% CI = [-0.89, 0.84] (see Figure S2b). These results support the prediction that the effect of loudness on feelings of interpersonal closeness is moderated by participants' loudness-closeness implicit association strength. Our results specifically showed that the effect of loudness on feelings of interpersonal closeness evaporates for individuals with weak (vs. strong) dispositional loudness-closeness implicit associations. These findings corroborate those of Study 1c and suggest that mental associations between loudness and closeness-related concepts are likely the reason why loudness perceptions can influence feelings of interpersonal closeness.

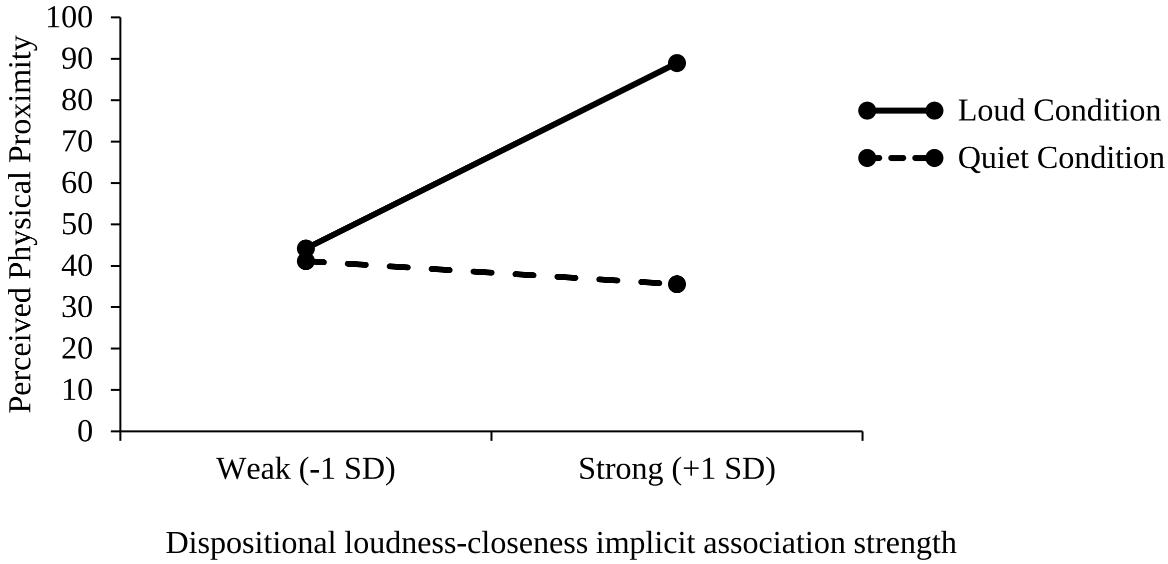
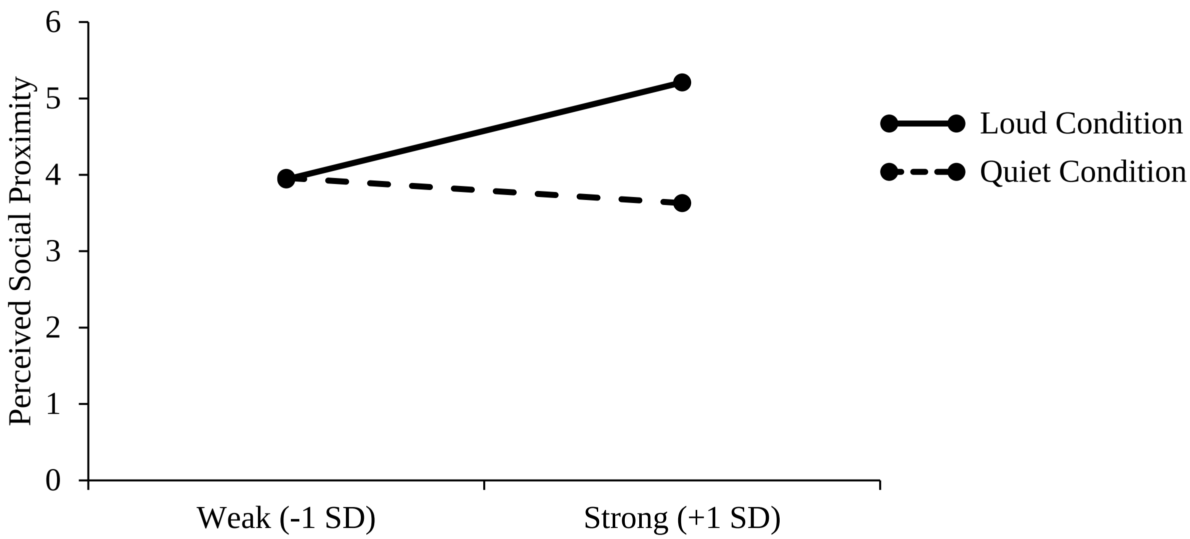


Figure. S2a. The interactive effect of participants' loudness condition and dispositional loudness-closeness implicit association strength on perceived physical proximity (Study 1d).



Dispositional loudness-closeness implicit association strength

Figure. S2b. The interactive effect of participants' loudness condition and dispositional loudness-closeness implicit association strength on perceived social proximity (Study 1d).

Study 2a: Replicating the Loudness-Interpersonal Closeness Effect in a Different Demographic

Thus far our findings have come from laboratory studies conducted at a university in Singapore. While this allows us to minimize the potential clouding effects of extraneous variables, participants were all undergraduate students, with the majority being ethnically Asian with English as their first language. To test whether the basic effect would be replicated in a Caucasian, non-student sample, Study 2a sought to replicate the basic effect using *Prolific* – an online crowdsourcing platform with a participant pool largely consisting of members of the public from the UK and the US.

A secondary aim of Study 2a was to explore whether the basic effect is moderated by explicit general beliefs about the association between loudness and interpersonal closeness. In Studies 1c and 1d, we have established the implicit nature of the mechanism underlying the basic effect. This begs the question of whether the underlying mechanism only operates at the implicit level or if it also operates at the explicit level. Since Study 1d showed that the strength of implicit associations between loudness and closeness concepts moderates the basic effect, the extent to which individuals believe that loudness reflects interpersonal closeness should also moderate the basic effect. The reason for this is that both implicit associations and explicit general beliefs are shaped by experience. For example, individuals who often encounter loud and crowded occasions (e.g., concerts) may associate loudness with closeness more strongly compared to individuals who often encounter quiet and crowded situations (e.g., crowded libraries). We predicted that the basic effect of loudness on perceived closeness should be attenuated in individuals who do not harbor the general belief that loudness is associated with interpersonal closeness, since such individuals likely do not hold strong corresponding implicit associations. We tested this in Study 2a.

Method

In Study 2a, crowdsourced members of the public (N = 205; 96 female; M_{age} = 28.44 years, SD_{age} = 9.41) were randomized into a single factor two-level between-participant online design (volume: loud vs quiet) and were each paid 0.6 UK pounds for their time. Consistent with our pre-registration (https://osf.io/m3ahv/?view_only=e96abfe8c91341e4bbf7f5e682faac78), the minimum sample size was predetermined in accordance to the conservative heuristic of 100 participants per condition – double the recommended sample size for laboratory studies (Simmons et al., 2013), in consideration of the less controlled online environment. We also tried to overshoot by 20% to account for potential exclusions. We opened a HIT for 240 slots. A total of 238 individuals participated in the present study. One individual participated twice, presumably due to a system error. Two participants failed the suspicion probe. Another two participants provided non-sensical answers in key measures, and 28 participants failed the attention check. These 33 participants were therefore excluded from the analyses, which resulted in a final sample size of 205 participants. Given that the present study has a set of requirements on the participants and their environment and equipment, participants were shown the eligibility criteria via Prolific prior to participation. These included the following: (a) they must not be able to speak Greek, (b) they must be alone in a quiet room with headphones/earphones, and (c) they must complete this study using a computer since the study is incompatible with mobile devices. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's d = 0.39, with a two-tailed alpha of 5%.

Measures

Perceived Physical Proximity

In line with the previous studies, participants were asked to estimate the number of people within three given radii - 30m, 50m, and 20m. The mean of the three estimates constituted perceived physical proximity.

Perceived Social Proximity

In line with the previous studies, perceived social proximity was measured by asking participants to rate their relationship closeness with three self-nominated individuals on 7-point scales (1 = *not close at all* and 7 = *extremely close*). The mean of the three ratings constituted perceived social proximity.

General Beliefs about Loudness and Interpersonal Closeness

Participants were asked: "Based on your personal experience, to what extent do you agree with the following general observations. 1: Crowded places are louder, uncrowded places are quieter. 2: Social situations are louder when members have close relationships with each other, social situations are quieter when members are socially distant from one another. 3: It is easy for me to conjure up an image of what Greek cities look like. 4: Most people I know are interested in Greek culture”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree*) and items were presented in random order. Important to note is that only the means of items 1 and 2 constituted participants’ general beliefs index ($r = .25$, $p < .001$), since items 3 and 4 were fillers to minimize suspicion.

Attention and Manipulation Check

Participants were asked a single question as both an attention check and a manipulation check: “Before moving on, to confirm that you have been paying attention to the experiment, please answer this question – at what volume did you listen to the music?” Responses were gathered on a 7-point scale (1 = *extremely low volume* and 7 = *extremely high volume*). Participants with a response opposite to their expected response (i.e., responding with 5, 6, or 7 when in the quiet condition or responding with 1, 2, or 3 when in the loud condition) were considered as having failed this check.

Filler

Participants were asked: “If you had to take a quick guess, which language do you think is the most difficult to learn?”

Probe

Participants were asked: “Before we move on, please answer the question below: if you think you know the study’s hypothesis already (for example if you have participated in a similar study), please write below what you think the hypothesis is. If you are unaware or not sure, simply write N/A”.

Procedure

Upon accessing the online survey link, participants were first presented with the information sheet. After confirming their consent to participate in the study, participants were instructed: “Thank you for taking part in this study! We are exploring the effects of background music on our thought processes. First, please paste the URL link (of a Greek song compilation clip on *Youtube*) below to a web browser and simply start listening to the clip using earphones/headphones at the highest volume possible without it being uncomfortable OR lowest volume possible so that it’s barely audible (depending on their condition). Please then move on to complete the remaining questions while you listen to the clip. https://www.youtube.com/watch?v=0M0a2Kw3eNk”. Participants then moved on to the filler, and then the measures of physical and social proximity presented in random order, followed by the attention check, general beliefs questions (for moderation analyses; see SOM), the probe, and some demographic questions. Finally, participants were shown the debriefing sheet and thanked for their time.

Results and Discussion

Manipulation Check

A manipulation check showed that participants in the loud condition (*M* subjective perceived loudness = 5.96, *SD* = 1.09) selected a significantly louder volume level than those in the quiet condition (*M* subjective perceived loudness = 1.50, *SD* = 0.98), $t(203) = 30.76$, $p <$ .001, Cohen’s $d = 4.30$, 95% CI for the mean difference [4.18, 4.75].

Perceived Physical and Social Proximity

Independent samples *t*-tests revealed that participants in the loud condition estimated significantly greater numbers of people in the three given radii (*M* = 157.52, *SD* = 159.28) compared to participants in the quiet condition (*M* = 100.22, *SD* = 118.28), *t*(191.77) = 2.93, *p* = .004, Cohen's *d* = 0.41, 95% CI for the mean difference [18.77, 95.82]. Participants in the loud condition also reported significantly higher levels of relationship closeness with their three self-nominated individuals (*M* = 5.54, *SD* = 1.03) compared to participants in the quiet condition (*M* = 5.11, *SD* = 1.23), *t*(203) = 2.71, *p* = .007, Cohen's *d* = 0.38, 95% CI for the mean difference [0.12, 0.74]. These findings suggest that the basic effect of loudness on feelings of interpersonal closeness can be generalized to a Caucasian, non-student demographic.

Moderation Analyses

To examine the predicted moderation effects, we conducted moderation analyses using the PROCESS SPSS macro (Hayes, 2013). In the first test, loudness condition was specified as the predictor, physical proximity was specified as the outcome, and mean general beliefs was specified as the moderator. However, the interaction effect between condition and general beliefs did not reach statistical significance, although this was marginal, *F*(1, 201) = 3.81, *p* = .052, ΔR^2 = .018. Next, the same model was tested with social proximity specified as the outcome. Again, the interaction effect between condition and general beliefs was not statistically significant, *F*(1, 201) = 0.09, *p* = .765, ΔR^2 = .000. These results do not support the prediction that the basic effect is moderated by general beliefs. As such, it suggests that the mechanism behind the effect of loudness on perceived interpersonal closeness is confined to the implicit level, and does not extend to the explicit level.

Study 2b: Loudness Affects Perceived Interpersonal Closeness Even After a Longer Auditory Exposure Period

Thus far, our studies have tested the effects of auditory loudness on perceptions of interpersonal closeness all within a span of several minutes. The results therefore only support the hypothesized effect for brief levels of exposure to auditory stimuli. Study 2b therefore aimed to replicate the basic effect using a longer auditory exposure interval.

Method

In Study 2b, undergraduate students from a university in Singapore (N = 100; 36 female; M_{age} = 21.30 years, SD_{age} = 3.47) were randomized and individually tested using a single factor two-level between-participants design (volume: loud vs quiet). A total of 101 participants was recruited, one participant failed to adhere to the experimental instructions and was therefore dropped from the analysis, leaving a total of 100 participants in the final sample. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's d = 0.57, with a two-tailed alpha of 5%.

Measures

Perceived Physical Proximity

In line with the previous studies, participants were asked to estimate the number of people within a 30m, 50m, and 20m radius. The mean of the three estimates constituted perceived physical proximity.

Perceived Social Proximity

In line with the previous studies, participants were asked to rate their relationship closeness with three self-nominated individuals using the IOS. The mean of the three ratings constituted perceived social proximity.

Filler

Participants were asked a single open-ended question: “Please write below in a couple of sentences what you have learnt or accomplished in the study session”.

Probe

Participants were asked one single question at the end of the experiment: “Before we move on, if you think you know the study’s hypothesis already (for example if you have participated in a study in the same series), please write below what you think the hypothesis is. If you are unaware or not sure, simply write ‘n/a’ below”.

Procedure

University student passersby on campus were approached and provided with a cover story informing them the study was recruiting volunteers to explore the effect of background noise on concentration. Students who expressed interest in volunteering were therefore told to bring with them some study materials (e.g., laptop, books) for their preferred time slot. On arrival at the laboratory and after providing informed consent, an experimenter, blind to the aims and hypothesis of the study, instructed participants to sit in a quiet booth and study for the next 30 minutes without touching the computer. Depending on their condition, the computer played an audio clip at the desktop volume of either 3 (quiet condition) or 13 (loud condition) out of 100. The audio segment used was an instrumental piece of music on *Youtube* but formatted to

MP3 to enable it to be played on a loop. Following this, participants were asked to complete the measures of physical and social proximity in random order followed by the filler, some demographic information, and the probe. Finally, participants were provided with the debriefing sheet and thanked for their time.

Results and Discussion

Independent samples *t*-tests revealed that participants allocated to the loud condition estimated significantly greater numbers of people in the three given radii (M = 70.12, SD = 100.54) compared to participants in the quiet condition (M = 30.11, SD = 50.53), $t(70.79) = 2.18$, $p = .033$, Cohen's $d = 0.50$, 95% CI for the mean difference [2.95, 67.06]. Participants in the loud condition also reported significantly higher levels of relationship closeness with their three self-nominated individuals (M = 4.09, SD = 1.33) compared to participants in the quiet condition (M = 3.49, SD = 1.30), $t(98) = 2.26$, $p = .026$, Cohen's $d = 0.46$, 95% CI for the mean difference [0.07, 1.12]. These findings suggest that the basic effect of loudness on perceived interpersonal closeness can be observed even when individuals have been exposed to the auditory stimuli continuously for 30 minutes.

Study 3a: Replicating the Loudness-Interpersonal Closeness Effect in the Field: a Hindu Temple

Thus far, our studies have all been advertised and conducted overtly as a psychology experiment, confining the applicability of our findings primarily to the laboratory setting. The dependent measures used have also been rather technical, requiring participants to estimate the number of people nearby and rate their relationship closeness with self-nominated individuals. To test whether the effect of loudness on perceived interpersonal closeness can be observed in a non-laboratory setting using ecologically valid measures of perceived physical and social proximity, a field study was conducted at a Hindu temple. We disguised our study as a “temple experience survey”, and had volunteers complete the measures while a blind experimenter played a context congruent hymn at either high volume, low volume, or zero volume. In this study, we operationalized perceived physical proximity as participants’ perceptions of how lively and crowded the temple is. Perceived social proximity was operationalized as the extent to which participants’ felt a sense of companionship, and closeness, with their ‘temple friends’.

Method

Visitors to a Hindu temple in Singapore (N = 444; 197 female; M_{age} = 44.62 years, SD_{age} = 13.53) were randomized and tested using a single factor three-level between-participant design (volume: loud, quiet, and no-exposure). We pre-registered the present study on OSF (https://osf.io/f8tp7/?view_only=be2904db37e7433382e009df7322fdc6). Consistent with our pre-registration, the minimum sample size was predetermined in accordance to the conservative heuristic of 100 participants per condition – double the recommended sample size for laboratory studies (Simmons et al., 2013), in consideration of the less controlled non-laboratory environment. We tried to overshoot as much as possible to account for missing values and exclusions. Regardless, data were not examined before termination of data collection. A total of 448 participants took part in the present study, however, 4 participants were excluded for either not following instructions, or not meeting the eligibility criteria of being at least 18 years of age and proficient in English, leaving a total of 444 in the final sample. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen’s d = 0.32, with a two-tailed alpha of 5%, for each pairwise comparisons across conditions.

Measures

Perceived Physical Proximity

Participants were asked to rate the extent to which they agree with two general statements: “This temple is a lively place” and “This temple is a crowded place”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree;* $r = .20$, $p < .001$). The mean of the two items constituted perceived physical proximity.

Perceived Social Proximity

Participants were asked to rate the extent to which they agree with two general statements: “I feel close with my ‘temple friends’ (i.e., friends that I come here with, and/or friends I met here)” and “I feel a sense of companionship from my temple friends”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree;* $r = .82$, $p < .001$) (Van Bel et al., 2009). The mean of the two items constituted perceived social proximity.

Procedure

In the present study, an A3 poster with the words “Volunteers wanted for a 2 minute temple experience survey” was displayed on the wall of a Hindu temple. Immediately next to the poster, an A4 information sheet was displayed which contains the details and eligibility criteria of the study and encourages people to approach the experimenter (blind to the aims and hypotheses of the present study) standing nearby to complete the short anonymous 'survey' if they consent to take part. Volunteers were each provided with a pen and a clipboard with a single page survey containing the measures of perceived physical and social proximity. While participants were completing the measures, a context congruent Hindu hymn was played on the experimenter’s mobile device at either 90% (loud condition), 50% (quiet condition), or 0% (no-exposure condition) of full volume, depending on the condition. Upon completion of the measures, participants were instructed to read the debriefing sheet at the back of the 'survey', and to put the completed 'survey' inside a ballot box nearby before they were thanked for their time. It is important to note that (a) to maximize efficiency, we allowed participants to take part individually or in groups of up to four such that each 'wave' was randomly allocated to one volume condition, and (b) to ensure that loudness manipulations were not affected by environmental noise, data were only collected during quiet times of the day, and participants were also instructed not to communicate with others during the study.

Results and Discussion

Univariate ANOVAs revealed a significant main effect of condition on perceived physical (F (2, 441) = 5.56, p = .004, η_p^2 = .03) and social (F (2, 437) = 9.08, p < .001, η_p^2 = .04) proximity. Pairwise comparisons revealed that participants in the loud condition rated the temple as providing a greater sense of physical proximity (M = 5.81, SD = 1.00) compared to participants in the quiet condition (M = 5.39, SD = 1.23), t(294) = 3.19, p = .002, Cohen's d = 0.37, 95% CI for the mean difference [0.16, 0.67]. Participants in the loud condition also reported significantly higher levels of social proximity with their 'temple friends' (M = 5.67, SD = 1.46) compared to participants in the quiet condition (M = 4.99, SD = 1.71), t(291) = 3.65, p < .001, Cohen's d = 0.43, 95% CI for the mean difference [0.31, 1.04].

Pairwise comparisons also revealed that participants in the loud condition rated the temple as providing a greater sense of physical proximity (M = 5.81, SD = 1.00) compared to participants in the no-exposure condition (M = 5.40, SD = 1.41), t(265.37) = 2.86, p = .005, Cohen's d = 0.33, 95% CI for the mean difference [0.13, 0.68]. Participants in the loud condition also reported significantly higher levels of social proximity with their 'temple friends' (M = 5.67, *SD* = 1.46) compared to participants in the no-exposure condition (*M* = 4.95, *SD* = 1.70), $t(285.11) = 3.91$, $p < .001$, Cohen's $d = 0.45$, 95% CI for the mean difference [0.36, 1.09]. On the other hand, participants in the quiet condition did not differ significantly from those in the no-exposure condition in either measures (all *p*s > .823). These findings showed that the no-exposure condition yielded results that were not significantly different from that of the quiet condition, and using either condition as the reference group produced the same results.

Results of Study 3a suggest that the basic effect of loudness on perceived interpersonal closeness can be observed in natural settings using ecologically valid measures of perceived physical and social proximity. Furthermore, auditory loudness seems to affect not only people's immediate construals of interpersonal closeness, but also their global perceptions of interpersonal closeness. Specifically, temple visitors exposed to a louder background hymn perceived the temple to be more lively and crowded than those exposed to a quieter hymn and those that were not exposed to a hymn, and also felt a greater level of companionship with, and closeness to, their temple friends.

Study 3b: Replicating the Loudness-Interpersonal Closeness Effect in the Field: University Classes

Study 3a was a field study conducted at a Hindu temple. Participants were almost exclusively Hindus of Indian ethnicity. As such, to further corroborate the effect of loudness on perceived interpersonal closeness in natural settings, a second field study was conducted, this time in a University classroom setting. We disguised our study as a 'university experience survey' that students were encouraged to complete along with their tutor evaluation surveys towards the end of the semester. We had students in tutorial classes complete the measures while an instrumental piece of music was played as 'background music' on either high or low volume.

In this study, we operationalized perceived physical proximity as participants' perceptions of how lively and crowded the University is. Perceived social proximity was operationalized as the extent to which participants' felt a sense of companionship, and closeness, with their University friends.

Method

In Study 3b, undergraduate students in tutorial classes at a university in Singapore (*N* = 314; 159 female; M_{age} = 20.68 years, SD_{age} = 2.88) were randomized and tested using a single factor two-level between-participant design (volume: loud vs quiet). Consistent with our pre-registration (https://osf.io/4ct7a/?view_only=ff34931fbde44228afb85707d53846bb), the minimum sample size was predetermined in accordance to the conservative heuristic of 100 participants per condition – double the recommended sample size for laboratory studies (Simmons et al., 2013), in consideration of the less controlled non-laboratory environment. We tried to overshoot as much as possible to account for missing values and exclusions. Regardless, data were not examined before termination of data collection. Post-hoc sensitivity power analyses show that this sample size implies 80% power for an effect size Cohen's *d* = 0.32, with a two-tailed alpha of 5%.

Measures

Perceived Physical Proximity

Participants were asked to rate the extent to which they agree with two general statements: "1: My university campus is a lively place" and "2: My university campus is a crowded place”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree*[7]). The mean of the two items constituted perceived physical proximity.

Perceived Social Proximity

Participants were asked to rate the extent to which they agree with two general statements: “I feel close with people in my university social network” and “I feel a lack of companionship from people in my university social network”. Responses were gathered on 7-point scales (1 = *strongly disagree* and 7 = *strongly agree;* $r = .22$, $p < .001$) (Van Bel et al., 2009). The second item was reverse scored. The mean of the two items constituted perceived social proximity.

Procedure

Administrative staff members of the University approached tutorial classes (between 12 to 29 students each) in the last three weeks of semester to obtain students’ evaluations of their tutors via a questionnaire as part of routine practice. In an attempt to seamlessly merge the present study with an existing administrative process, the experimenter accompanied the staff during these routine sessions as an opportunity to collect data. Following the administrative staff member’s instructions to students relating to the tutor evaluation questionnaire, the experimenter distributed the information sheet of the present study and a handout containing the measures of perceived physical and social proximity in random order. As a cover story, students were told

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[7]The two items for perceived physical proximity in Study 3b were only marginally correlated ($r = .10$, $p = .074$). Closer inspection revealed that while participants in the loud (vs. quiet) condition rated the campus as more lively ($p = .010$), participants in both conditions rated the campus as equally crowded ($p = .815$). We suspect that this is because the study was conducted in the final weeks of semester when the campus was, in actuality, relatively crowded due to the number of students revising for their exams. This objective reality may have overshadowed our experimental manipulation. Regardless, given that the present study and its analysis plan was preregistered, and dropping the ‘crowdedness’ item would unfairly favor our analyses, we still presented the results using the aggregated ratings of both items.

that the university wishes to obtain some additional non-mandatory anonymous feedback. They were also told that (a) if they have already completed this ‘survey’ in another class, they should just ignore it; (b) they will not be observed; (c) the handouts will be collected facedown; and (d) there would be no pressure to complete the handout although it should only take one minute to complete. The experimenter then played an instrumental piece of music on a mobile device at either 90% (loud condition) or 50% (quiet condition) of maximum volume as “background music while the evaluations are being completed”. At the end of the evaluation session, students were verbally debriefed and thanked for their time.

Results and Discussion

Independent *t*-tests revealed that participants in the loud condition rated their university campus as providing a greater sense of physical proximity (*M* = 5.23, *SD* = 1.15) compared to participants in the quiet condition (*M* = 4.98, *SD* = 1.23), although the difference fell short of the a priori cut off alpha value for statistical significance by a trivial margin, $t(312) = 1.88$, $p = .061$, Cohen’s $d = 0.21$, 95% CI for the mean difference [-0.01, 0.52]. Conversely, participants in the loud condition reported significantly higher levels of social proximity with their university social network (*M* = 4.81, *SD* = 1.16) compared to participants in the quiet condition (*M* = 4.16, *SD* = 1.19), $t(312) = 4.91$, $p < .001$, Cohen’s $d = 0.55$, 95% CI for the mean difference [0.39, 0.91]. These findings replicated those of Study 3a in a university classroom setting. Specifically, students exposed to louder (vs. quieter) background music while completing student evaluations perceived their university campus to be more lively and crowded (albeit the finding did not achieve statistical significance), and also felt a significantly greater level of companionship from, and closeness to, their university social network.

Data exclusions for Studies 4 - 6 and post-hoc sensitivity power analysis for Study 4

Study 4 data exclusions and post-hoc sensitivity power analysis

An initial total of 102 participants was recruited, however, two participants failed to comply with the experimental instructions and were excluded from the study, leaving a final sample of 100 participants. Post-hoc sensitivity power analyses indicate 80% power for a medium-sized effect (*d* = 0.57), with alpha set at. 05 (two tailed).

Study 5 data exclusions

Study 5 did not have any data exclusions. Sample size was pre-registered based on previous research, and therefore post-hoc sensitivity power analysis was not conducted.

Study 6 data exclusions

An initial total of 130 participants was recruited, however, two participants expressed suspicion or awareness of the hypotheses and were therefore excluded from the analyses, leaving a final sample of 128 participants. In line with previous research adopting similar paradigms, we initially calculated the a-priori sample size using a medium-to-large effect size (f2(V) = 0.11) which yielded a required sample size of 73. We were concerned that this may be excessively small and hence preregistered the a-priori sample size using a medium effect size (f2(V) = 0.63) instead, and therefore post-hoc sensitivity power analysis was not conducted.

Tables S2 – S4

Table S2.

Univariate F tests and effects sizes from the Analyses of Variance in Study 6

Dependent Variable	Independent Variable	$F(1, 124)$	η_p^2
Negative Mood	Social Exclusion	19.82***	.14
	Volume Exposure	19.44***	.14
	Social Exclusion x Volume Exposure	9.34*	.07
Anger	Social Exclusion	15.50***	.11
	Volume Exposure	9.92**	.07
	Social Exclusion x Volume Exposure	8.34*	.06
Hurt Feelings	Social Exclusion	27.80***	.18
	Volume Exposure	11.02***	.08
	Social Exclusion x Volume Exposure	17.63***	.12
Loneliness	Social Exclusion	18.91***	.13
	Volume Exposure	18.24***	.13
	Social Exclusion x Volume Exposure	16.94***	.12

*p < .05 after Bonferroni correction applied

**p < .01 after Bonferroni correction applied

***p < .001 after Bonferroni correction applied

Tables S3.

Planned Contrasts for the Four Dependent Variables in Study 6

Dependent Variable	Contrast Conditions	*t*(62)	*d*	95% CI[a]
Negative Mood	Exclusion (Loud vs Quiet)	-5.51***	-1.38	[-1.82, -0.85]
	Inclusion (Loud vs Quiet)	-0.92	-0.23	[-0.77, 0.28]
Anger	Exclusion (Loud vs Quiet)	-3.74**	-0.94	[-3.31, -1.00]
	Inclusion (Loud vs Quiet)	-0.22	-0.06	[-0.94, 0.75]
Hurt Feelings	Exclusion (Loud vs Quiet)	-4.44***	-1.11	[-3.49, -1.32]
	Inclusion (Loud vs Quiet)	0.83	0.21	[-0.40, 0.96]
Loneliness	Exclusion (Loud vs Quiet)	-6.37***	-1.59	[-4.44, -2.32]
	Inclusion (Loud vs Quiet)	-0.10	-0.03	[-1.27, 1.15]

[a]95% CI = 95% confidence interval of the mean difference

**$p < .01$ after Bonferroni correction applied

***$p < .001$ after Bonferroni correction applied

Tables S4.

Exploratory Pairwise Comparisons for the Four Dependent Variables in Study 6

Dependent Variable	Contrast Conditions	*t*(62)	*d*	95% CI[a]
Negative Mood	Exclusion Loud vs Inclusion Quiet	0.03	0.01	[-0.53, 0.54]
	Exclusion Loud vs Inclusion Loud	1.11	0.28	[-0.20, 0.70]
Anger	Exclusion Loud vs Inclusion Quiet	0.63	0.16	[-0.61, 1.18]
	Exclusion Loud vs Inclusion Loud	0.77	0.19	[-0.60, 1.35]
Hurt Feelings	Exclusion Loud vs Inclusion Quiet	1.73	0.43	[-0.10, 1.35]
	Exclusion Loud vs Inclusion Loud	0.87	0.22	[-0.45, 1.13]
Loneliness	Exclusion Loud vs Inclusion Quiet	0.06	0.01	[-1.09, 1.15]
	Exclusion Loud vs Inclusion Loud	0.18	0.04	[-0.98, 1.17]

Note. All *p*s > .088

[a]95% CI = 95% confidence interval of the mean difference

Assumption Violations, Non-Parametric Tests, and Manipulation Checks for Study 6

Study 1a Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in both conditions for both the manipulation check and the dependent measure. We conducted a Mann-Whitney U test, which indicated that the selected volume was greater for the loud condition (Mdn = 92.00) than for the quiet condition (Mdn = 2.00), $U = 0.00$, $p < .001$. A second Mann-Whitney U test indicated that the estimated number of people nearby was greater for the loud condition (Mdn = 40.00) than for the quiet condition (Mdn = 20.00), $U = 790.50$, $p = .002$.

Please note that all test statistics reflecting assumption violations for all studies can be found in analyses outputs posted on OSF at https://osf.io/vm8h3/?view_only=8c46bdb495924594a9ee3b304c6ad029.

Study 1b Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in both conditions for both the manipulation check and the dependent measure. We conducted a Mann-Whitney U test, which indicated that the selected volume was greater for the loud condition (Mdn = 85.00) than for the quiet condition (Mdn = 1.00), $U = 0.00$, $p < .001$. A second Mann-Whitney U test indicated that the perceived social proximity was higher for the loud condition (Mdn = 4.00) than for the quiet condition (Mdn = 3.00), $U = 895.50$, $p = .013$.

Study 1c Assumption Violations

Normality and homoscedasticity assumptions were violated for perceived physical proximity. Given that bootstrap regressions are robust to these violations, and given that logarithmic transforming this variable produced the same results, we only reported the conventional test results.

Study 1d Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in both conditions for the two dependent measures. Non-parametric tests revealed the same pattern of results as parametric tests reported in the main manuscript. Specifically, we conducted a Mann-Whitney U test, which indicated that perceived physical proximity was greater for the loud condition (Mdn = 45.83) than for the quiet condition (Mdn = 25.17), $U = 1647.00$, $p = .006$. A second Mann-Whitney U test indicated that perceived social proximity was higher for the loud condition (Mdn = 4.83) than for the quiet condition (Mdn = 3.67), $U = 1688.00$, $p = .002$.

Study 2a Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in both conditions for the dependent measures. Non-parametric tests revealed the same pattern of results as parametric tests reported in the main manuscript. Specifically, we conducted a Mann-Whitney U test, which indicated that perceived physical proximity was greater for the loud condition (Mdn = 96.67) than for the quiet condition (Mdn = 49.33), $U = 6376.50$, $p = .008$. A second Mann-Whitney U test indicated that perceived social proximity was higher for the loud condition (Mdn = 5.67) than for the quiet condition (Mdn = 5.33), $U = 6253.00$, $p = .018$.

In terms of the moderator analyses, normality and homoscedasticity assumptions were violated for perceived physical proximity. However, given that bootstrap regressions are robust to these violations, and given that logarithmic transforming this variable produced the same results, we only reported the conventional test results.

Study 2b Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in both conditions for the dependent measure of perceived physical proximity. Non-parametric tests revealed the same pattern of results as parametric tests reported in the main manuscript. Specifically, we conducted a Mann-Whitney U test, which indicated that perceived physical proximity was greater for the loud condition (Mdn = 15.67) than for the quiet condition (Mdn = 33.33), U = 1527.50, p = .020. A second Mann-Whitney U test indicated that perceived social proximity was higher for the loud condition (Mdn = 3.50) than for the quiet condition (Mdn = 4.17), U = 1589.50, p = .019.

Study 3a Assumption Violations

Normality assumptions were violated for perceived physical and social proximity. However, given that logarithmic transforming this variable produced the same results, we only reported the conventional test results.

Study 3b Assumption Violations

Tests for normality indicated that the data were statistically non-normal in both conditions for the two dependent measures. Non-parametric tests revealed the same pattern of results as parametric tests reported in the main manuscript. Specifically, we conducted a Mann-Whitney U test, which indicated that perceived physical proximity was marginally greater for the loud condition (Mdn = 5.50) than for the quiet condition (Mdn = 5.00), U = 13742.00, p = .075. A second Mann-Whitney U test indicated that perceived social proximity was higher for the loud condition (Mdn = 4.50) than for the quiet condition (Mdn = 4.00), U = 16465.00, p < .001.

Study 4 Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in the social exclusion and inclusion conditions for the dependent measure. We conducted a Mann-Whitney U test, which indicated that the perceived loudness was greater for the social inclusion condition (Mdn = 4.50) than for the social exclusion condition (Mdn = 3.00), $U = 856.50$, $p = .006$.

Study 5 Assumption Violations and Non-Parametric Tests

Tests for normality indicated that the data were statistically non-normal in the social exclusion conditions for the dependent measure. We conducted a Mann-Whitney U test, which indicated that the selected volume was greater for the social exclusion condition (Mdn = 40.00) than for the social inclusion condition (Mdn = 30.50), $U = 1047.00$, $p = .017$.

Study 6 Assumption Violations, Non-Parametric Tests, Manipulation Checks, and Notes

Tests for normality indicated that the data were statistically non-normal in the low volume condition for the manipulation check, and in both conditions for the social exclusion manipulation check. We conducted a Mann-Whitney U test, which indicated that the selected volume was greater for the loud condition (Mdn = 56.00) than for the quiet condition (Mdn = 2.00), $U = 4060.50$, $p < .001$. A second Mann-Whitney U test indicated that the perceived level of social inclusion was higher for the social inclusion condition (Mdn = 6.00) than for the social exclusion condition (Mdn = 3.00), $U = 271.00$, $p < .001$.

Analyses indicated that the assumptions of normality, homogeneity of variance and covariance were violated for the Multivariate Analysis of Variance (MANOVA). Given that there is no equivalent non-parametric test for the MANOVA, we complied with the convention of reporting the most conservative test statistic (Pillai’s trace).

Manipulation Checks

A manipulation check showed that participants in the loud condition (mean volume = 56.23% of maximum desktop volume, *SD* = 22.88%) selected significantly higher volume levels than those in the quiet condition (mean volume = 2.86%, *SD* = 3.63%), $t(66.17) = 18.43$, $p < .001$, Cohen's $d = 3.26$, 95% CI for the mean difference [47.59, 59.16]. An additional manipulation check showed that participants in the social inclusion condition (mean perceived inclusion = 5.86, *SD* = 1.69) felt significantly more included in the game than those in the social exclusion condition (mean perceived inclusion = 2.75, *SD* = 0.96), $t(99.83) = 12.81$, $p < .001$, Cohen's $d = 2.26$, 95% CI for the mean difference [2.63, 3.59].

Additional Notes

We found large effect sizes of the reparatory effects of louder volumes on mood, ranging from $d = 0.94$ for anger to $d = 1.59$ for feelings of loneliness. These effect sizes may strike the reader as unlikely, given the smaller effect sizes typically found in social psychology (Bosco et al., 2015; Richard et al., 2003). We believe that these large effect sizes are a product of the strong manipulations we employed. Specifically, "Cyberball" and our volume manipulations in the present experiment both produced very large manipulation check effect sizes ($d = 2.26$ and $d = 3.26$ respectively). The potent social exclusion effects of Cyberball observed in the present experiment is consistent with previous research findings, where effects of Cyberball on feelings of loneliness, anger, hurt, and negative mood have also been large (e.g., between $d = 1.40$ and $d = 2.00$; Hartgerink et al., 2015). Likewise, the large volume manipulation effect sizes are in line with volume manipulations effect sizes we found in previous experiments of the present research (e.g., $d = 4.75$ and $d = 3.93$ in Studies 1a and 1b respectively). In our view, it is therefore plausible that such large effect sizes generated by our manipulations could generate large effect size in the theoretically close dependent variables that we measured, e.g., mood and feelings of loneliness.

Additional Limitations and Future Directions

An additional limitation pertains to the way in which perceived social proximity was operationalized. Specifically, IJzerman and Semin (2009) measured feelings of social proximity by having participants rate their relationship closeness with a self-nominated individual in one experiment, and with the experimenter in a subsequent experiment. In some studies, we only instructed participants to rate their relationship closeness with self-nominated individuals and not the experimenter. The reason for this was that asking participants to rate their closeness with the experimenter – a stranger, may be considered overly sensitive and hence inappropriate given the cultural context of where the present study was conducted. While the existing measure of social proximity was selected in accordance to previous research (IJzerman et al., 2018; IJzerman & Semin, 2009), the question remains whether individuals listening to louder stimuli would not only think of people whom they are closer with, but also feel closer with people in their immediate surroundings. Research addressing such questions would help triangulate the conclusions of the present study, and provide a more detailed understanding of the loudness-social proximity relationship.

While individual differences and personality traits were not the focus of the present study, the same stimulus could, in principle, evoke different memory-based construals according to the extant personality traits of individuals (Barsalou, 2016b). Future studies should investigate whether the loudness-interpersonal closeness link manifests differentially in people with differences on theoretically-relevant personality traits. For instance, it is well established that individuals high on extraversion tend to prefer, and respond more positively to, louder stimuli, compared to individuals low on extraversion (Campbell & Hawley, 1982; Cetola & Prinkey, 1986; Geen, 1984). As such, while loud music may be associated with positive mental concepts such as interpersonal bonding at parties for those high on extraversion, the same loud music may be associated with negative concepts such as awkwardness and unease at parties for those low on extraversion. Moreover, the results of the present study raises an interesting possibility – could it be that "extroverts" prefer louder environments because loudness provides a sense of companionship, which satisfies their stronger need for social connection compared to "introverts" (Harris et al., 2017; Srivastava et al., 2008)? Establishing the interplay between such personality variables and the loudness-interpersonal closeness link can help add nuance to the present findings/predictions.

URLs of Audio Clips Used in Each Experiment

Studies 1a, 1b, 5, and 6: https://www.youtube.com/watch?v=LgNN-6roFWw&t=191s

Studies 1c and 2a: https://www.youtube.com/watch?v=0M0a2Kw3eNk

Study 1d: https://www.youtube.com/watch?v=OE9bF80KQGk&t=12863s

Study 2b: https://www.youtube.com/watch?v=3Y9tcNl2za0

Study 3a: https://www.youtube.com/watch?v=9Am1iq5a9D8

Studies 3b and S1: https://www.youtube.com/watch?v=6ixhN9umyp4&t=4s

Internal Meta-Analysis

The finding that auditory loudness affects feelings of interpersonal closeness was relatively reliably replicated in the experiments of the present research. However, effect sizes varied considerably across different experiments, possibly due to between-experiment methodological (e.g., auditory content, exposure duration, measures used) and sample (e.g., age, ethnicity, laboratory vs. non-laboratory format) differences. For instance, in Study 3b, the effect of loudness on perceived physical proximity was not successfully replicated, although this was marginal. To examine the robustness of the effect of loudness on feelings of interpersonal closeness, we conducted an internal meta-analysis for Studies 1a through d, 2a, 2b, 3a, 3b, and S1, in which this basic effect was tested. The meta-analysis was conducted using Comprehensive Meta-Analysis (version 3). A random-effects meta-analysis across the applicable experiments ($k = 9$) revealed medium-sized averaged sample-weighted effect sizes for perceived physical proximity ($d = 0.45$, 95% CI [0.33, 0.56], $N = 1413$) and perceived social proximity ($d = 0.48$, 95% CI [0.37, 0.58], $N = 1412$). These results support the robustness of the loudness-interpersonal closeness effect. Figures S3a and S3b below depict the forest plot generated from the meta-analyses for perceived physical and social proximity respectively.

It is important to note that heterogeneity statistics were non-significant (all ps > .297), indicating homogeneity of effect size magnitudes despite seemingly varied effect sizes across studies (ds range from 0.21 to 0.66). While this precluded us from predicting significant moderation effects, given the diversity of audio stimuli used in the present research, we still proceeded to analyse the language (familiar – English vs. unfamiliar – Greek vs. no language), type (music vs. non-music), and arousal level (emotive/arousing vs. neutral vs. calming/relaxing) of the audio stimuli since they may provide moderation trends. Expectedly, we did not find any statistically significant moderation effects of the aforementioned variables (all *p*s > .258). Forest plots and associated statistics are reported below in figures S3c – S3h.

Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	1a	0.658	0.205	0.042	0.255	1.060	3.203	0.001
	1c	0.634	0.205	0.042	0.233	1.036	3.095	0.002
	1d	0.546	0.204	0.041	0.147	0.945	2.679	0.007
	2a	0.407	0.141	0.020	0.130	0.684	2.883	0.004
	2b	0.503	0.203	0.041	0.105	0.901	2.475	0.013
	3a	0.375	0.117	0.014	0.145	0.605	3.195	0.001
	3b	0.210	0.113	0.013	-0.012	0.432	1.855	0.064
	S1	0.620	0.145	0.021	0.336	0.904	4.281	0.000
Random		0.446	0.060	0.004	0.327	0.564	7.390	0.000

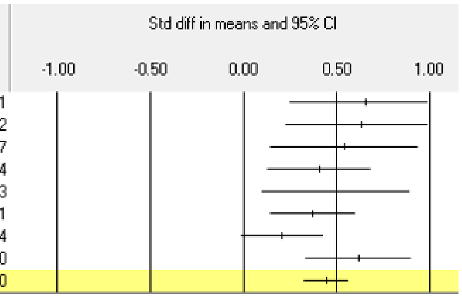

Fig. S3a. Forest Plot of the Internal Meta-Analysis for Perceived Physical Proximity.

Heterogeneity: $Q = 8.42$, df = 7, $p = .297$, $I^2 = 16.84\%$.

Model	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	1b	0.495	0.203	0.041	0.097	0.893	2.438	0.015
	1c	0.511	0.203	0.041	0.112	0.909	2.512	0.012
	1d	0.505	0.203	0.041	0.106	0.903	2.484	0.013
	2a	0.380	0.141	0.020	0.104	0.656	2.694	0.007
	2b	0.456	0.203	0.041	0.059	0.853	2.252	0.024
	3a	0.428	0.118	0.014	0.196	0.659	3.618	0.000
	3b	0.553	0.115	0.013	0.328	0.779	4.809	0.000
	S1	0.511	0.144	0.021	0.229	0.792	3.553	0.000
Random		0.478	0.054	0.003	0.372	0.584	8.854	0.000

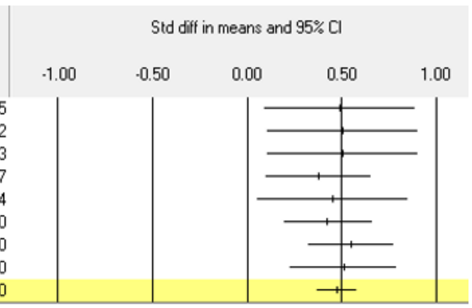

Fig. S3b. Forest Plot of the Internal Meta-Analysis for Perceived Social Proximity.

Heterogeneity: $Q = 1.21$, df = 7, $p = .991$, $I^2 = 0.00\%$.

Model	Group by Audio language	Time point	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Familiar	Blank	1a	0.658	0.205	0.042	0.255	1.060	3.203	0.001
Random	Familiar			0.658	0.205	0.042	0.255	1.060	3.203	0.001
	No language	Blank	1d	0.546	0.204	0.041	0.147	0.945	2.679	0.007
	No language	Blank	2b	0.503	0.203	0.041	0.105	0.901	2.475	0.013
	No language	Blank	3a	0.375	0.117	0.014	0.145	0.605	3.195	0.001
	No language	Blank	3b	0.210	0.113	0.013	-0.012	0.432	1.855	0.064
	No language	Blank	S1	0.620	0.145	0.021	0.336	0.904	4.281	0.000
Random	No language			0.417	0.080	0.006	0.259	0.574	5.187	0.000
	Unfamiliar	Blank	1c	0.634	0.205	0.042	0.233	1.036	3.095	0.002
	Unfamiliar	Blank	2a	0.407	0.141	0.020	0.130	0.684	2.883	0.004
Random	Unfamiliar			0.480	0.116	0.014	0.252	0.708	4.130	0.000
Random	Overall			0.458	0.063	0.004	0.335	0.581	7.278	0.000

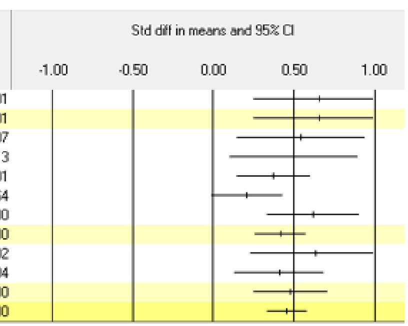

Fig. S3c. Forest Plot of the Moderator Analysis of Audio Language for Perceived Physical Proximity.

Heterogeneity: $Q = 1.25$, df = 2, $p = .536$.

Model	Group by Audio type	Time point	Study name	Statistics for each study							Std diff in means and 95% CI
				Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Music	Blank	1c	0.634	0.205	0.042	0.233	1.036	3.095	0.002	
	Music	Blank	2a	0.407	0.141	0.020	0.130	0.684	2.883	0.004	
	Music	Blank	2b	0.503	0.203	0.041	0.105	0.901	2.475	0.013	
	Music	Blank	3a	0.375	0.117	0.014	0.145	0.605	3.195	0.001	
	Music	Blank	3b	0.210	0.113	0.013	-0.012	0.432	1.855	0.064	
	Music	Blank	S1	0.620	0.145	0.021	0.336	0.904	4.281	0.000	
Random	Music			0.420	0.069	0.005	0.285	0.555	6.100	0.000	
	Non-music	Blank	1a	0.658	0.205	0.042	0.255	1.060	3.203	0.001	
	Non-music	Blank	1d	0.546	0.204	0.041	0.147	0.945	2.679	0.007	
Random	Non-music			0.601	0.145	0.021	0.318	0.885	4.158	0.000	
Random	Overall			0.454	0.062	0.004	0.332	0.576	7.295	0.000	

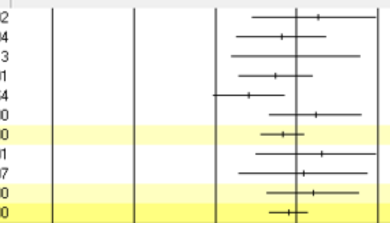

Fig. S3d. Forest Plot of the Moderator Analysis of Audio Type for Perceived Physical Proximity.

Heterogeneity: $Q = 1.28$, df = 1, $p = .258$.

Model	Group by Audio arousal	Time point	Study name	Statistics for each study							Std diff in means and 95% CI
				Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Calming/relaxing	Blank	3b	0.210	0.113	0.013	-0.012	0.432	1.855	0.064	
	Calming/relaxing	Blank	S1	0.620	0.145	0.021	0.336	0.904	4.281	0.000	
Random	Calming/relaxing			0.405	0.205	0.042	0.004	0.806	1.978	0.048	
	Emotive/arousing	Blank	1c	0.634	0.205	0.042	0.233	1.036	3.095	0.002	
	Emotive/arousing	Blank	2a	0.407	0.141	0.020	0.130	0.684	2.883	0.004	
	Emotive/arousing	Blank	2b	0.503	0.203	0.041	0.105	0.901	2.475	0.013	
Random	Emotive/arousing			0.486	0.101	0.010	0.288	0.684	4.814	0.000	
	Neutral	Blank	1a	0.658	0.205	0.042	0.255	1.060	3.203	0.001	
	Neutral	Blank	1d	0.546	0.204	0.041	0.147	0.945	2.679	0.007	
	Neutral	Blank	3a	0.375	0.117	0.014	0.145	0.605	3.195	0.001	
Random	Neutral			0.465	0.091	0.008	0.286	0.643	5.100	0.000	
Random	Overall			0.467	0.064	0.004	0.341	0.593	7.278	0.000	

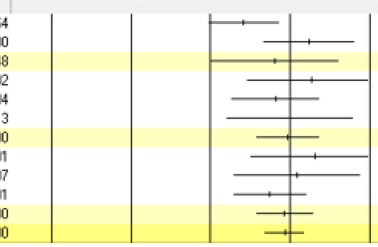

Fig. S3e. Forest Plot of the Moderator Analysis of Audio Arousal for Perceived Physical Proximity.

Heterogeneity: $Q = 0.18$, df = 2, $p = .939$.

Model	Time point	Group by Audio language	Study name	Statistics for each study							Std diff in means and 95% CI
				Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	-1.00 -0.50 0.00 0.50 1.00
	Blank	Familiar	1b	0.495	0.203	0.041	0.097	0.893	2.438	0.015	
Random		Familiar		0.495	0.203	0.041	0.097	0.893	2.438	0.015	
	Blank	No language	1d	0.505	0.203	0.041	0.106	0.903	2.484	0.013	
	Blank	No language	2b	0.456	0.203	0.041	0.059	0.853	2.252	0.024	
	Blank	No language	3a	0.428	0.118	0.014	0.196	0.659	3.618	0.000	
	Blank	No language	3b	0.553	0.115	0.013	0.328	0.779	4.809	0.000	
	Blank	No language	S1	0.511	0.144	0.021	0.229	0.792	3.553	0.000	
Random		No language		0.493	0.064	0.004	0.368	0.619	7.711	0.000	
	Blank	Unfamiliar	1c	0.511	0.203	0.041	0.112	0.909	2.512	0.012	
	Blank	Unfamiliar	2a	0.380	0.141	0.020	0.104	0.656	2.694	0.007	
Random		Unfamiliar		0.422	0.116	0.013	0.195	0.649	3.646	0.000	
Random		Overall		0.478	0.054	0.003	0.372	0.584	8.854	0.000	

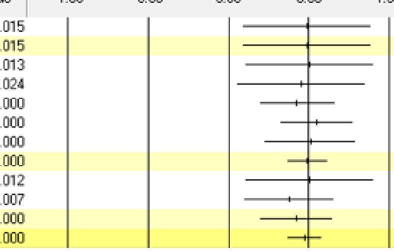

Fig. S3f. Forest Plot of the Moderator Analysis of Audio Language for Perceived Social Proximity.

Heterogeneity: $Q = 0.30$, df = 2, $p = .862$.

Model	Group by Audio type	Time point	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Music	Blank	1c	0.511	0.203	0.041	0.112	0.909	2.512	0.012
	Music	Blank	2a	0.380	0.141	0.020	0.104	0.656	2.694	0.007
	Music	Blank	2b	0.456	0.203	0.041	0.059	0.853	2.252	0.024
	Music	Blank	3a	0.428	0.118	0.014	0.196	0.659	3.618	0.000
	Music	Blank	3b	0.553	0.115	0.013	0.328	0.779	4.809	0.000
	Music	Blank	S1	0.511	0.144	0.021	0.229	0.792	3.553	0.000
Random	Music			0.475	0.058	0.003	0.360	0.589	8.143	0.000
	Non-music	Blank	1b	0.495	0.203	0.041	0.097	0.893	2.438	0.015
	Non-music	Blank	1d	0.505	0.203	0.041	0.106	0.903	2.484	0.013
Random	Non-music			0.500	0.144	0.021	0.218	0.781	3.480	0.001
Random	Overall			0.478	0.054	0.003	0.372	0.584	8.854	0.000

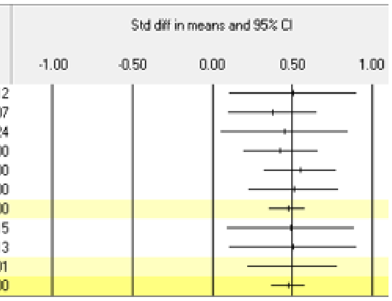

Fig. S3g. Forest Plot of the Moderator Analysis of Audio Type for Perceived Social Proximity.

Heterogeneity: $Q = 0.03$, df = 1, $p = .870$.

Model	Group by Audio arousal	Time point	Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Calming/relaxing	Blank	3b	0.553	0.115	0.013	0.328	0.779	4.809	0.000
	Calming/relaxing	Blank	S1	0.511	0.144	0.021	0.229	0.792	3.553	0.000
Random	Calming/relaxing			0.537	0.090	0.008	0.361	0.713	5.975	0.000
	Emotive/arousin	Blank	1c	0.511	0.203	0.041	0.112	0.909	2.512	0.012
	Emotive/arousin	Blank	2a	0.380	0.141	0.020	0.104	0.656	2.694	0.007
	Emotive/arousin	Blank	2b	0.456	0.203	0.041	0.059	0.853	2.252	0.024
Random	Emotive/arousin			0.431	0.101	0.010	0.234	0.628	4.283	0.000
	Neutral	Blank	1b	0.495	0.203	0.041	0.097	0.893	2.438	0.015
	Neutral	Blank	1d	0.505	0.203	0.041	0.106	0.903	2.484	0.013
	Neutral	Blank	3a	0.428	0.118	0.014	0.196	0.659	3.618	0.000
Random	Neutral			0.457	0.091	0.008	0.278	0.636	5.005	0.000
Random	Overall			0.478	0.054	0.003	0.372	0.584	8.854	0.000

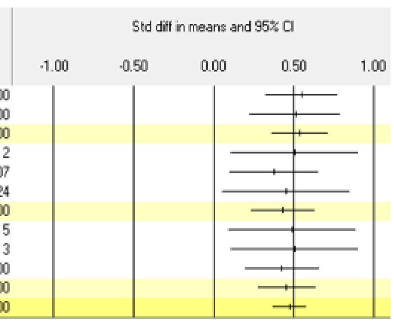

Fig. S3h. Forest Plot of the Moderator Analysis of Audio Arousal for Perceived Social Proximity.

Heterogeneity: $Q = 0.70$, df = 2, $p = .704$.

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