Investigating the Influence of Partner Gaze on the Relationship Between Interpersonal Coordination and Social Anxiety

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Abstract

Interpersonal coordination is a key determinant of successful social interaction but is disrupted for people who experience social anxiety. Effective coordination rests on individuals directing their attention toward others, an effect well-documented in previous literature. Yet, little research has considered the concurrent behaviour of interaction partners. Using a novel virtual reality task, we investigated how partner gaze (i.e., direct vs. averted) influenced the emergence of interpersonal coordination. The results revealed two novel effects: (i) spontaneous coordination was diminished in the averted (cf. direct) gaze condition; (ii) spontaneous coordination was positively related to symptoms of social anxiety, but only when partner gaze was averted. This latter finding contrasts the extant literature and points to interaction intensity as a factor governing the social anxiety-coordination association. More broadly, this work provides further evidence that emergent patterns of interpersonal coordination fluctuate as a function of changes in social context and the behaviour of others.

Keywords: interpersonal coordination; social anxiety; gaze behaviour; virtual reality

Introduction

Interpersonal coordination is crucial for fostering social connections. Aligning actions with others promotes affiliative prosocial behaviour (e.g., Mogan et al., 2017; Vicaria & Dickens, 2016), but is undermined by negative contextual factors that stymie social interaction (e.g., rudeness, argument, poor mental health; Miles et al., 2010; Paxton & Dale, 2013; Varlet et al., 2014). Effective coordination relies on information exchange between individuals, typically via visual attention (Kelso, 1995; Oullier et al., 2008; Tognoli et al., 2020). However, research documenting this effect has concentrated on the attentional patterns of individual participants (e.g., Richardson et al., 2007; Varlet, et al., 2012), with less focus given to the concurrent behaviour of their interaction partner. This prompts an important question: does the gaze of an interaction partner impact the emergence of interpersonal coordination?

Related research indicates that mental health conditions known to impact reciprocal social behaviour, such as social anxiety disorder (SAD), reduce interpersonal coordination (e.g., Asher et al., 2020; Varlet et al., 2014). Importantly, this disorder is also characterised by atypical responses to gaze cues (DSM-5; American Psychiatric Association, 2013). With these findings in mind, the current research employed virtual reality to examine: (i) how the gaze patterns of an interaction partner influence the emergence of interpersonal coordination; and (ii) whether partner gaze impacts the relationship between subclinical variation in symptoms of SAD and interpersonal coordination.

Attention, Social Context, and Interpersonal Coordination

How people attend to others plays a pivotal role in the emergence of interpersonal coordination (Haken et al., 1985), and can have profound effects on the social context in which an interaction unfolds (Langton et al., 2000; Senju & Johnson, 2009). At the most fundamental level, a partner's gaze direction (i.e., direct vs. averted) can specify the focus of their attention (e.g., self vs other) and affiliative goals (Argyle & Cook, 1976). For instance, direct gaze is typically associated with positive interactions, promoting approach behaviour, and enhancing perceptions of trustworthiness and closeness (Adams & Kleck, 2003; Cui et al., 2019; Schulze, et al., 2013). In contrast, averted gaze patterns are associated with avoidance, disinterest, and exclusion (Capellini et al., 2019; Cui et al). Simply being looked at, or not, can polarise social context, shifting behavioural tendencies from prosocial and affiliative, to pro-self and exclusionary.

It follows therefore that an interaction partner's gaze behaviour may, via shaping social context, impact the emergence of interpersonal coordination. When negative social contexts arise through aversive or ill-mannered behaviour (e.g., being rude, late, or argumentative), the extent to which people coordinate with the perpetrator decreases (Miles et al., 2010; Paxton & Dale, 2013). On the other hand, in more affiliative contexts (e.g., speed dating), a higher level of behavioural coordination is a robust predictor of positive interpersonal goals (e.g., romantic interest, Chang et al., 2021). Social context, in particular the evaluative and affective elements, can direct the emergence of coordination.

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Gaze Behaviour, Coordination, and Social Anxiety

To gain insight into the relationship between partner gaze and interpersonal coordination, it is also important to consider mental health disorders related to impairments in reciprocal social behaviour. A growing body of literature demonstrates a robust link between social anxiety disorder (SAD) and coordination (e.g., Varlet et al., 2014). For individuals with social anxiety, interpersonal coordination is disrupted. Importantly, recent work indicates that this pattern of effects extends beyond diagnostic categories – subclinical symptoms of SAD also negatively impact interpersonal coordination (Macpherson et al., 2020; Macpherson & Miles, 2023). As such, in line with contemporary continuum-based models of psychopathology (Bögels et al., 2010; Kashdan, 2007), the present research employed a subclinical sample.

Of relevance to the current enquiry, symptoms of SAD are associated with atypical responses to the gaze of others (American Psychological Association, 2013). In SAD, individuals are noted to be fearful of eye contact and as a result show an avoidance of direct gaze during social interactions (Schulze et al., 2013). Here, a 'vigilance-avoidance' model has been proposed (Horley et al., 2004), whereby individuals high in social anxiety initially orient their attention towards the direct gaze of an interaction partner (vigilance), before rapidly averting their own gaze so as to deter eye contact (avoidance). In the context of the current work, direct gaze behaviours exhibited by an interaction partner may exacerbate the mental health-coordination relationship, leading to lower levels of coordination among individuals higher in social anxiety.

Methodological Challenges in Interpersonal Coordination Research

Assessing the influence of the behaviour of an interaction partner on interpersonal coordination poses methodological challenges. Previous research has typically paired a participant with a confederate (e.g., Miles et al., 2010) or experimenter (e.g., Hove & Risen, 2009), an approach that sacrifices experimental control for the benefits of a more naturalistic interaction. However, such a trade-off can call into question the generalisability of findings. For instance, Vicaria and Dickens (2016) argue that employing a confederate can inflate the degree to which interpersonal coordination emerges. These authors suggest that after repeatedly experiencing the same procedure, confederates will make unintentional adjustments to their behaviour due to their familiarity with the norms of the interaction context. Even the most consistent confederate will introduce unwanted variability to the behaviour of interest that may bias outcomes and preclude replication.

To avoid the pitfalls of contrived and non-repeatable interactions (e.g., with a confederate or experimenter), coordination researchers have also focused on actual dyads or groups. In the mental health domain this has taken the form of case-control studies for research at the clinical level (e.g., Varlet et al., 2014), or pairs of naïve participants in subclinical work (e.g., Macpherson et al., 2020). The use of a genuine dyad however, means that two independent 'sets' of mental health symptoms must be combined in order to estimate symptomology at the collective level. While, to date, researchers have employed combinatory approaches such as averaging (e.g., Macpherson et al., 2020) and difference scores (e.g., Asher et al., 2020; Macpherson & Miles, 2023) with some success, these approaches are blunt and unlikely to reflect the complex interactions of symptoms and behaviours that unfold over the course of an interactive social exchange.

To address these problems, researchers have turned to using virtual reality (VR) in interpersonal coordination research (e.g., Tolston et al., 2014; Varlet et al., 2013; Zhao et al., 2015). VR offers a high-fidelity immersive environment that affords precise control over experimental manipulations along with unobtrusive means to capture behaviour. The use of a virtual partner (i.e., avatar) in place of a confederate eliminates the potential for unintended variability as all manipulations of behaviour (including attentional patterns) are pre-programmed, thereby ensuring that all participants have equivalent interactions. Further, because no actual dyad is required, using VR eliminates the conceptual and statistical issues associated with estimating mental health symptoms at the collective level. Although some concerns have been raised regarding the generalisability of social behaviour from virtual to real-world contexts (e.g., Vasser & Aru, 2020), reassuringly multiple studies have now demonstrated that not only do virtual environments reliably reflect the same dynamics that support the emergence of interpersonal coordination outside of VR (e.g., Tolston, et al.), but there are also high levels of consistency between virtual and face-to-face interactions when considering the impact of social factors on behavioural coordination (e.g., Sun et al., 2019).

Current Research

The gaze behaviours of an interaction partner convey an abundance of important social information, yet little is known about their influence on the emergence of interpersonal coordination. To address this issue, in VR participants interacted with what was allegedly another participant, but in reality was a pre-programmed avatar that either looked directly at them (direct gaze condition) or looked away and shifted their gaze frequently (averted gaze condition). Participants were asked to perform a simple movement task and form an impression of their interaction partner while their actions and gaze behaviours were recorded. Participants completed two trials, initially without any further instructions about their movements (spontaneous coordination), and then with directions to match their movements with the 'other participant' (intentional coordination). Coordination was varied in this way as a means to manipulate task stability (Kelso, 1995). To quantify mental health symptoms, participants completed a standardised questionnaire designed to measure subclinical variation in SAD (Liebowitz, 1987).

Drawing from the extant literature, here we make two broad predictions. Given the distinction in social context associated with direct (i.e., signifying affiliative behaviour) versus averted (i.e., signifying avoidant behaviour) gaze (e.g., Argyle & Cook, 1976; Cui et al., 2019), we expect to observe more coordination when the avatar looks at, compared to away from, the participant. In a more exploratory manner, we also anticipate the relationship between symptoms of SAD and interpersonal coordination to be impacted by partner gaze. Given the aversion to eye-contact associated with SAD (Schulze et al., 2013), it follows that the negative relationship between SAD and interpersonal coordination will be stronger in the direct (cf. averted) gaze condition.

Method

Participants and Design[1]

One hundred and forty-seven undergraduates took part in return for course credit. Only individuals aged 18 years or over with no injury or impairment that impacted arm movement were eligible. Eleven participants were excluded after indicating they did not believe the cover story (i.e., the avatar was controlled by another person), and technical problems meant no movement data was available for three participants. Within the final sample (n = 133; 94 female, 39 male; aged 18-50 years, M = 20.1 years, SD = 4.5 years), one participant was also missing movement data, but only for the intentional coordination trial. The remaining data from this participant was retained.

The experiment employed a 2 (avatar gaze: direct vs. averted) x 2 (coordination: spontaneous vs. intentional) mixed design, with repeated measures on the second factor. Participants were randomly assigned to interact with an avatar who either looked at them (direct gaze condition, n = 68) or away from them (averted gaze condition, n = 65) for the duration of the interaction. To ensure that the instruction to coordinate in the intentional condition did not influence performance during the spontaneous condition, the order of the coordination conditions was fixed (i.e., spontaneous first). The research was approved by the Human Research Ethics Committee at the University of Western Australia.

Procedure and Materials

Participants were recruited to a study examining how people attend to themselves and others in virtual reality (VR). The study was described as involving a movement task with another participant, first in a virtual context, and subsequently in-person.[2] Upon arrival participants were told that the other participant was present and located in a nearby laboratory. In reality the ‘other participant’ was a pre-programmed virtual avatar, and no face-to-face interaction took place. Participants provided their consent and basic demographic information (age and gender; free-response format) before completing the Liebowitz Social Anxiety Scale[3] (sample range = 9-119, M = 55.43, SD = 23.52), to assess typical variation symptoms of SAD (LSAS; Liebowitz, 1987). This scale has strong psychometric properties when used in community samples (e.g., Fresco et al., 2001), and has been routinely employed in interpersonal coordination research (e.g., Macpherson et al., 2020; Macpherson & Miles, 2023; Varlet et al., 2014). To help maintain the cover story, while participants were completing the questionnaires, the experimenter briefly left the room, allegedly to “check on the other participant”.

Next, participants were introduced to the VR system (Vive Pro Eye, HTC Corporation, Taiwan). They were fitted with a head-mounted display (HMD) to view the virtual environment which was developed using the Unity3D Game Engine (v 2018.4.8f1). The HMD has dual OLED 3.5” screens (1440 x 1600 pixels per eye, 110° x 106° field of view). Participants were given handheld controllers (Vive Pro 2018) which, when in the virtual environment, were represented as hands. Once familiar with the equipment, participants were reminded that they would be interacting with the other participant in VR, and this would involve a simple arm movement task.

The procedure began with a practice trial intended to familiarise the participant with VR and to establish a target movement frequency. The practice trial took place in a generic grey virtual environment with no visual distractors. Participants were asked to perform arm curls (i.e., flexion/extension about the elbow) in time with a metronome (84 bpm) for 20s. The metronome was played through the HMD headphones and participants held the controllers throughout the trial. The experimenter verbally corrected the participant if they did not perform the movement correctly (e.g., if they did not keep in time with the metronome or did not display the full range of movement). All task instructions were visually presented in the HMD and verbally reiterated by the experimenter.

Next, participants were told that they would be performing two further arm curl trials, but this time while watching the other participant do the same. It was explained that both themselves and the other participant would be represented as virtual avatars that precisely reflected their respective real-world behaviour including arm, body, and head movements. They were placed into a virtual laboratory setting (5.34 m x 4.34 m) and told to perform the arm curls at the same pace as

[1] The data reported here is part of a wider project concerning the relationships between mental health, social attentional processes, and interpersonal coordination.

[2] This cover story was intended to increase naturalistic behaviour by giving participants the impression they were engaging in a real-time social exchange, in that the avatar was being controlled by another person rather than pre-programmed (see Miles et al., 2011 and Lumsden et al., 2012 for similar approaches when studying unidirectional interpersonal coordination). Additionally, the potential for a future in-person encounter can lead to more naturalistic social behaviour during virtual interactions (e.g., stronger adherence to social norms when attending to others; Gregory & Antolin, 2019), hence the initial (false) indication of a face-to-face stage of the procedure following the virtual interaction.

[3] Possible LSAS scores range from 0-144.

in the practice trial. It was stated that they should begin as soon as the other participant appeared, and to focus on forming an impression of them. As this served as the spontaneous coordination condition, no further instructions were given, and no mention was made of coordination. The trial lasted 90 s during which the avatar faced the participant (standing approximately 1.5 m away) and performed arm curls at the same pace as the practice trials. At the end of the 90 s the avatar disappeared, signaling the end of the trial. Following a short delay, the intentional coordination trial was initiated, whereby participants were instructed to match their movements with the ‘other participant’ (i.e., they were asked to perform in-phase coordination with the avatar). All other aspects were identical to the spontaneous coordination trial. During both coordination trials, participants’ arm movements were captured (50 Hz) via tracking the hand-held controllers.

Importantly, each participant was randomly assigned to one of the two avatar gaze conditions, whereby the avatar either looked directly at the participant (i.e., the direct gaze condition; Figure 1, Left Panel) or looked away and shifted their gaze frequently (i.e., the averted gaze condition; Figure 1, Right Panel) for the duration of each trial. The avatar was created using Adobe Fuse CC (Beta version 2017.1.0; San Jose, CA, USA) and rigged using Mixamo (www.mixamo.com) to resemble a typical university student in Australia (i.e., female, aged approx. 20-25 years, 1.64m tall, casual clothing). To ensure realistic avatar behaviour, initially the movements of one of the experimenters were captured (100 Hz) using a Rokoko Smartsuit Pro and Rokoko Studio (Rokoko, Copenhagen, Denmark). The movements comprised arm curls performed in time with a metronome (84 bpm) and head movements such that it appeared as though the avatar averted their gaze away from the participant for the duration of each trial. Two sets of movements were captured and used to animate the avatar for each of the coordination trials, with the order of the pre-recorded movements counterbalanced across participants. For the direct gaze condition, the pre-recorded head movement was overridden using the Animator Controller in Unity3D, such that the head of the avatar followed the participant’s position for the duration of each trial.

As a manipulation check of any differences in social context resulting from the variation of avatar gaze, immediately after the intentional coordination trial, participants completed a composite affiliation scale, consisting of the Inclusion of Other in the Self Scale (IOS; Aron et al., 1992), and seven items (e.g., “*How much do you like the other participant?*”, “*How similar to you is the other participant?*”) adapted from previous interpersonal coordination research (see Lumsden et al., 2014; Wiltermuth, 2012). Comparison between conditions revealed that, as expected, participants reported higher affiliation ratings in the direct (cf.) averted gaze condition, t (131) = 2.07, p = .04, d = 0.36.

Finally, participants were funnel debriefed (Bargh & Chartrand, 2000) to ascertain whether they believed the cover story (i.e., that the avatar was controlled by another participant). They were asked what they were trying to do whilst forming an impression of their partner, followed by what they thought the study was trying to achieve, and if anything seemed unusual. Participants who indicated that they did not believe another participant was present were excluded from analysis (n = 11). Finally, participants were debriefed as to the true purpose of the experiment and dismissed.

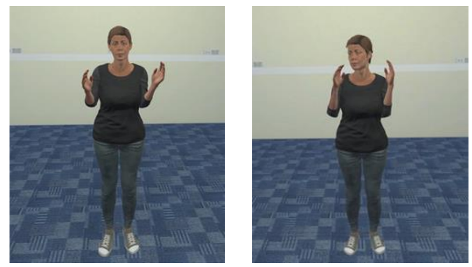

Figure 1: Snapshot of the avatar during the ‘interactive’ trials. The left panel depicts the direct gaze condition, and the right panel depicts the averted gaze condition.

Data Reduction and Estimation of Coordination

Consistent with previous research (e.g., Miles et al., 2011; Varlet et al., 2014), the first 6 s of each trial were removed to eliminate any transient activity that may have occurred when initiating the arm curls, resulting in a standardised duration of 84 s. Each time series was centred around 0 and low-pass filtered using a 10 Hz Butterworth filter. Coordination stability (i.e., rho) was estimated using custom Matlab scripts[4] that considered the relationship between the movements of the right arm of the participant and the left arm of the avatar.[5] Here the distribution of relative phase relationships (ϕ) between participant and avatar arm movements was calculated using the Hilbert transform (Pikovsky et al., 2003), and normalised to a range of 0^{o} – 180^{o}. The circular variance (rho) of the distribution of ϕ was calculated for each trial separately, and standardised using a Fisher transformation (Varlet et al., 2014). Rho provides an index of coordination stability ranging from 0 (i.e., no synchronisation) to 1 (i.e., perfect synchronisation; Batschelet, 1981; Schmidt & Fitzpatrick, 2019).

Results

To address the research questions, linear mixed-effects models (LMMs) were constructed using the lme4 package (Bates et al., 2015) and the lmerTest package (Kuznetsova et al., 2017) in R (R Core Team, 2019). All predictor variables

[4] github.com/xkiwilabs

[5] Analysis using the opposite configuration (participant left arm, confederate right arm) revealed identical patterns of results and therefore are not reported here.

were centred prior to their inclusion in the models.[6] Degrees of freedom and *p*-values were estimated using the Satterthwaite approximation. The random effects structure for each model comprised a by-participant random intercept. Interaction effects were decomposed by estimating Tukey-corrected post-hoc comparisons using the emmeans package (Lenth, 2021).

We first constructed an LMM that considered the influence of avatar gaze (direct/averted) and coordination type (spontaneous/intentional) on coordination stability (i.e., rho).

Table 1: Fixed effects of coordination (spontaneous/ intentional) and avatar gaze (direct/averted), on rho.

Predictors	B	SE	*t*	*p*
(Intercept)	0.67	0.03	22.80	<.001
Coordination	0.26	0.04	6.53	<.001
Avatar gaze	-0.12	0.04	-2.79	.006
Coord*avatar gaze	0.13	0.06	2.28	.024

The model revealed main effects of avatar gaze (direct > averted) and coordination (spontaneous < intentional), which were qualified by an interaction between these factors (Table 1). Post hoc comparisons revealed higher levels of coordination stability when the avatar looked directly at the participant during spontaneous ($b = 0.12$, $SE = 0.04$, $t = 2.79$, $p = .03$), but not intentional ($b = -0.01$, $SE = 0.04$, $t = -0.27$, $p = .99$) coordination (Figure 2).

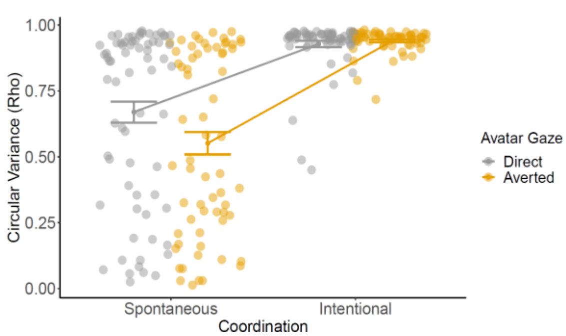

Figure 2: Rho as a function of coordination (spontaneous/intentional) and avatar gaze (direct/averted). The error bars represent 1± standard error.

Next, we constructed an LMM that considered the relationship between LSAS and coordination stability (i.e., rho). This model specified fixed effects for avatar gaze (direct/averted), coordination type (spontaneous/intentional), and LSAS scores.

Table 2: Fixed effects of coordination (spontaneous/ intentional), avatar gaze (direct/averted), and LSAS on rho.

Predictors	B	SE	*t*	*p*
(Intercept)	0.67	0.03	22.95	<.001
Coordination	0.26	0.04	6.68	<.001
Avatar gaze	-0.12	0.04	-2.96	.003
LSAS	-0.00	0.00	-0.96	.338
Coord*gaze	0.14	0.06	2.41	.018
Coord*LSAS	0.00	0.00	0.90	.372
Gaze*LSAS	0.01	0.00	2.96	.003
Coord*gaze*LSAS	-0.01	0.00	-2.29	.024

The model revealed a two-way interaction between avatar gaze (direct/averted) and LSAS score, and a three-way interaction between avatar gaze, coordination type (spontaneous/intentional) and LSAS score (Table 2). Post hoc comparisons revealed contrasting relationships between LSAS and rho as a function of avatar gaze in the spontaneous coordination condition (Figure 3, Top Panel). Specifically, LSAS scores were positively related to rho when the avatar averted their gaze ($b = 0.10$, $SE = 0.03$, $t = 3.13$, $p = .002$), but not when gaze was direct ($b = -0.03$, $SE = 0.03$, $t = -0.96$, $p = .34$). No relationships were revealed in the intentional coordination condition (Figure 3, Bottom Panel).

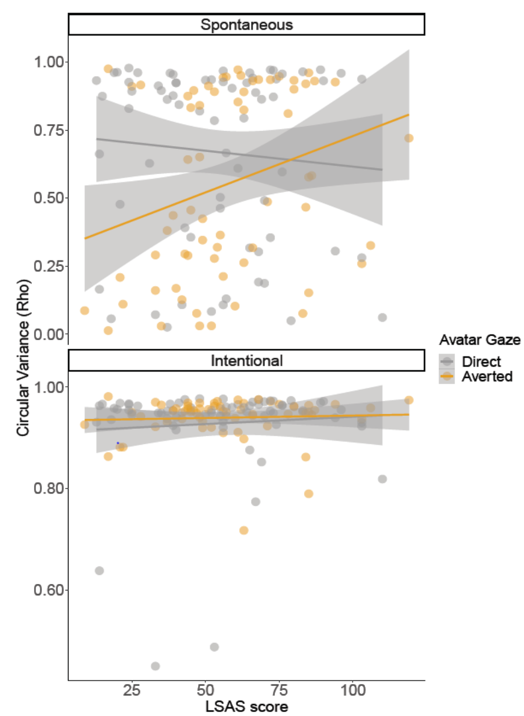

Figure 3: Rho as a function of LSAS score, coordination (spontaneous/intentional) and avatar gaze (direct/averted). The shaded area around the regression line represents the 95% confidence interval.

[6] For each model, coding for factorial variables is as follows: coordination [0 = spontaneous, 1 = intentional], avatar gaze [0 = direct, 1 = averted].

Discussion

The current research revealed two findings of note. First, participants were more likely to spontaneously coordinate with an avatar who looked toward, rather than away from them. To our knowledge this is the first evidence that the gaze behaviour of an interaction partner contributes to the emergence of interpersonal coordination. We suspect that differences in social context implied by the avatar's attentional patterns (i.e., affiliative vs. avoidant) underlie this effect. Specifically, direct gaze may enhance coordination by inviting affiliative behaviour and opportunities for interaction, while averted gaze may have an opposing effect, undermining coordination by indicating disinterest and avoidance (e.g., Argyle & Cook, 1976; Cui et al., 2019). Indeed, our manipulation check revealed more positive impressions of the avatar in the direct gaze condition, lending support to this interpretation. More broadly, this finding adds a novel line of evidence to support claims that social factors can serve to undermine, or enhance, coordinative actions (e.g., Miles et al., 2011; Paxton & Dale, 2013).

Second, while we found evidence that the relationship between symptoms of SAD and interpersonal coordination was impacted by partner gaze, we did not anticipate the direction of this effect. In the spontaneous coordination condition, there was a *positive* association between coordination and symptoms of SAD when the avatar averted their gaze, but no equivalent effect in the direct gaze condition. Although previous work has predominantly reported disruptions to coordination as a function of social anxiety (e.g., Macpherson et al., 2020; Macpherson et al., 2023; Varlet et al., 2014), one exception stands out. Asher et al. (2020) report a negative association between social anxiety and non-verbal synchrony in closeness-generating conversations, but a positive association in small-talk conversations. Together, this work suggests that, conceptually at least, decreased interaction intensity (e.g., a less personal conversation or less intense attentional scrutiny) may buffer against the typically deleterious effects of social anxiety on interpersonal coordination.

Contemporary models of social anxiety may offer additional insight into the positive association between symptoms of SAD and coordination observed here. The vigilance-avoidance model (Hessels et al., 2018; Horley et al., 2004), suggests that averted (cf. direct) gaze patterns may afford more looking time for socially anxious individuals. People experiencing social anxiety are highly attentive to threating social cues such as direct gaze (i.e., vigilance), but rapidly orient away when eye-contact is detected (i.e., avoidance). If eye contact never occurs, those higher in social anxiety may maintain vigilance, continuing to attend to their interaction partner, thereby enhancing coordination.

Further, models of social behaviour indicate that being excluded can lead to increased pro-social behaviour as a means to (re)connect with an interaction partner (e.g., Silva et al., 2020). For social anxiety, this effect appears to be limited to in-group members (Tsumura & Murata, 2015). In the current study, individuals were informed that they would later meet their interaction partner. Consistent with previous work (Miles et al., 2011), we speculate that this context may have led to increased coordination amongst those with higher levels of social anxiety as an attempt to reduce awkwardness associated with the upcoming interaction. Future work should look to evaluate these claims.

Limitations, Implications and Future Directions

The effects reported above were limited to the spontaneous coordination condition. While the literature includes examples of social anxiety impacting both spontaneous (e.g., Asher et al., 2020) and intentional (e.g., Macpherson et al., 2020; Macpherson & Miles, 2023) coordination, the simplicity of the current task may have limited the extent of our effects. As less stable systems are more easily perturbed, they have an increased likelihood of capturing the influence of mental health symptomology (Macpherson et al., 2023). In the current task, intentional coordination was easily maintained, with high levels of stability observed. Further, contrary to expectations, there was no relationship between SAD and coordination in the direct gaze condition, although the negative direction of this effect is consistent with previous literature (e.g., Macpherson et al., 2020; Macpherson et al., 2023; Varlet et al., 2014). Again, we suspect the simplicity of the task is likely to have resulted in a reduction of the size of this effect. Future work should consider implementing tasks with lower levels of inherent stability (e.g., coordinating in orthogonal planes; Romero et al., 2012).

Finally, the current findings have important methodological implications. The use of VR made possible manipulations that are not feasible in a face-to-face context while maintaining appropriate experimental control. By enabling a precise, repeatable manipulation of avatar gaze behaviour, potential biases associated with the use of a confederate were eliminated (Vicaria & Dickens, 2016) Similarly, the use of VR avoids issues associated with estimating mental health symptomology at the dyadic level. The strength of these methodological advantages is underscored by the consistency between the characteristics of interpersonal coordination observed in real-world contexts, and those observed in the present study. In short, consistent with previous reports (e.g., Zhao et al., 2015), VR provides a valid and appropriate methodological tool for studying the social factors that shape interpersonal coordination. Nevertheless, to enhance generalisability, future work should aim to replicate the current results in genuine dyads.

Conclusion

Interpersonal coordination provides a key foundation for successful interaction. Here we demonstrated that the direct gaze an interaction partner enhances coordination compared to an averted gaze. Further, we uncovered a novel positive relationship between symptoms of social anxiety and coordination, but only in the averted gaze condition. These findings add strength to the evidence indicating that emergent patterns of coordination fluctuate as a function of social context and variation in mental health.

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References

Adams Jr, R. B., & Kleck, R. E. (2003). Perceived gaze direction and the processing of facial displays of emotion. *Psychological Science, 14*, 644-647.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.).

Argyle, M., & Cook, M. (1976). *Gaze and mutual gaze.* Cambridge University Press.

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of Other in the Self Scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology, 63*, 596-612.

Asher, M., Kauffmann, A., & Aderka, I. M. (2020). Out of sync: Non-verbal synchrony in social anxiety disorder. *Clinical Psychological Science, 8*, 280-294.

Bargh, J. D., & Chartrand, T. (2000). The mind in the middle: A practical guide to priming and automaticity research. In H. T. Reis, & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology*. Cambridge University Press.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67,* 1–48.

Batschelet, E. (1981). *Circular statistics in biology*. Academic Press.

Bögels, S. M., Alden, L., Beidel, D. C., Clark, L. A., Pine, D. S., Stein, M. B., & Voncken, M. (2010). Social anxiety disorder: Questions and answers for the DSM-V. *Depression and Anxiety, 27*, 168–189.

Capellini, R., Riva, P., Ricciardelli, P., & Sacchi, S. (2019). Turning away from averted gazes: The effect of social exclusion on gaze cueing. *Frontiers in Psychology, 10,* 1000.

Cui, M., Zhu, M., Lu, X., & Zhu, L. (2019). Implicit perceptions of closeness from the direct eye gaze. *Frontiers in Psychology, 9,* 2673.

Fresco, D. M., Coles, M. E., Heimberg, R. G., Liebowitz, M. R., Hami, S., Stein, M. B., & Goetz, D. (2001). The Liebowitz social anxiety scale: A comparison of the psychometric properties of self-report and clinician-administered formats. *Psychological Medicine, 31,* 1025–1035.

Gregory, N.J., & Antolin, J. V. (2019). Does social presence or the potential for interaction reduce social gaze in online social scenarios? Introducing the "live lab" paradigm. *Quarterly Journal of Experimental Psychology, 72,* 779-791.

Haken, H., Kelso, J. A. S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics, 51*, 347–356.

Hessels, R. S., Holleman, G. A., Cornelissen, T. H., Hooge, I. T., & Kemner, C. (2018). Eye contact takes two–autistic and social anxiety traits predict gaze behavior in dyadic interaction. *Journal of Experimental Psychopathology, 9,* jep-062917.

Horley, K., Williams, L. M., Gonsalvez, C., & Gordon, E. (2004). Face to face: visual scanpath evidence for abnormal processing of facial expressions in social phobia. *Psychiatry Research, 127*, 43–53.

Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition, 27,* 949–960.

Kashdan, T. B. (2007). Social anxiety spectrum and diminished positive experiences: Theoretical synthesis and meta-analysis. *Clinical Psychology Review, 27*, 348–365.

Kelso, J. A. (1995). *Dynamic patterns: The self-organization of brain and behavior.* MIT Press.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*, 1–26.

Langton, S. R., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences, 4,* 50-59.

Lenth, R. V. (2021). Emmeans: Estimated Marginal Means, aka Least-Squares Means. [Computer software manual]. R package version 1.7.0. https://CRAN.R-project.org/package=emmeans

Liebowitz, M. R. (1987). Social phobia. *Modern Problems in Pharmacopsychiatry, 22,* 141-173.

Lumsden, J., Miles, L. K., & Macrae, C. N. (2014). Sync or sink? Interpersonal synchrony impacts self-esteem. *Frontiers in Psychology, 5*, 1064.

Lumsden, J., Miles, L. K., Richardson, M. J., Smith, C. A., & Macrae, C. N. (2012). Who syncs? Social motives and interpersonal coordination. *Journal of Experimental Social Psychology, 48,* 746-751.

Macpherson, M. C., & Miles, L. K. (2023). Synchrony and mental health: Investigating the negative association between interpersonal coordination and subclinical variation in autism and social anxiety. *Journal of Experimental Social Psychology, 105,* 104439.

Macpherson, M. C., Marie, D., Schön, S., & Miles, L. K. (2020). Evaluating the interplay between subclinical levels of mental health symptoms and coordination dynamics. *British Journal of Psychology, 111*, 782–804.

Miles, L. K., Griffiths, J. L., Richardson, M. J., & Macrae, C. N. (2010). Too late to coordinate: Contextual influences on behavioral synchrony. *European Journal of Social Psychology, 40,* 52-60.

Miles, L. K., Lumsden, J., Richardson, M. J., & Macrae, C. N. (2011). Do birds of a feather move together? Group membership and behavioral synchrony. *Experimental Brain Research, 211,* 495-503.

Mogan, R., Fischer, R., & Bulbulia, J. A. (2017). To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *Journal of Experimental Social Psychology, 72,* 13-20.

Oullier, O., de Guzman, G. C., Jantzen, K. J., Lagarde, J., & Kelso, J. A. (2008). Social coordination dynamics: Measuring human bonding. *Social Neuroscience, 3,* 178–192.

Paxton, A., & Dale, R. (2013). Argument disrupts interpersonal synchrony. *Quarterly Journal of Experimental Psychology, 66,* 2092–2102.

Pikovsky, A., Rosenblum, M., & Kurths, J. (2003). *Synchronization: A universal concept in nonlinear sciences.* University Press.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science, 26,* 867-891.

Richardson, M. J., Schmidt, R. C., & Kay, B. A. (2007). Distinguishing the noise and attractor strength of coordinated limb movements using recurrence analysis. *Biological Cybernetics, 96,* 59–78.

Romero, V., Coey, C., Schmidt, R. C., Richardson, M. J. (2012). Movement coordination or movement interference: Visual tracking and spontaneous coordination modulate rhythmic movement interference. *PLoS One, 7,* e44761.

Schmidt, R. C., & Fitzpatrick, P. (2019). Embodied synchronization and complexity in a verbal interaction. *Nonlinear Dynamics, Psychology, and Life Sciences, 23,* 199–228.

Schulze, L., Renneberg, B., & Lobmaier, J. S. (2013). Gaze perception in social anxiety and social anxiety disorder. *Frontiers in Human Neuroscience, 7,* 872.

Senju, A., & Johnson, M. H. (2009). The eye contact effect: mechanisms and development. *Trends in Cognitive Sciences, 13,* 127-134.

Silva, C., Jover, C., Da Fonseca, D., Esteves, F., & Deruelle, C. (2020). Acting on observed social exclusion and pro-social behaviour in autism spectrum disorder. *Autism, 24*, 233-245.

Sun, Y., Shaikh, O., & Won, A. S. (2019). Nonverbal synchrony in virtual reality. *PloS One, 14,* e0221803.

Tognoli, E., Zhang, M., Fuchs, A., Beetle, C., & Kelso, J. S. (2020). Coordination dynamics: A foundation for understanding social behavior. *Frontiers in Human Neuroscience, 14,* 317.

Tolston, M., Ariyabuddhiphongs, K., Riley, M. A., & Shockley, K. (2014). Cross-recurrence quantification analysis of the influence of coupling constraints on interpersonal coordination and communication. In In N. Marwan, M. Riley, A. Giuliani, & Jr. C. Webber (Eds.), *Translational recurrences: From mathematical theory to real-world applications.* Springer International.

Tsumura, K., & Murata, K. (2015). Effects of social anxiety and group membership of potential affiliates on social reconnection after ostracism. *Current Research in Social Psychology, 1*, 18-25.

Varlet, M., Coey, C. A., Schmidt, R. C., & Richardson, M. J. (2012). Influence of stimulus amplitude on unintended visuomotor entrainment. *Human Movement Science, 31*, 541-552.

Varlet, M., Filippeschi, A., Ben-Sadoun, G., Ratto, M., Marin, L., Ruffaldi, E., & Bardy, B. G. (2013). Virtual reality as a tool to learn interpersonal coordination: Example of team rowing. *Presence, 22,* 202-215.

Varlet, M., Marin, L., Capdevielle, D., Del-Monte, J., Schmidt, R. C., Salesse, R. N., … Raffard, S. (2014). Difficulty leading interpersonal coordination: Towards an embodied signature of social anxiety disorder. *Frontiers in Behavioral Neuroscience, 8,* 29.

Vasser, M., & Aru, J. (2020). Guidelines for immersive virtual reality in psychological research. *Current Opinion in Psychology, 36,* 71-76.

Vicaria, I. M., & Dickens, L. (2016). Meta-analyses of the intra- and interpersonal outcomes of interpersonal coordination. *Journal of Nonverbal Behavior, 40,* 335–361.

Wiltermuth, S. S. (2012). Synchronous activity boosts compliance with requests to aggress. *Journal of Experimental Social Psychology, 48,* 453–456.

Zhao, Z., Salesse, R. N., Gueugnon, M., Schmidt, R. C., Marin, L., & Bardy, B. G. (2015). Moving attractive virtual agent improves interpersonal coordination stability. *Human Movement Science, 41,* 240-254.