Synchronised dyadic interactions increase self-monitoring during response inhibition: An fNIRS study

R. E. Moffat[1,4*], N. Caruana[1], E. S. Cross[1,2,3,4*].

[1] School of Psychological Sciences, Macquarie University, Macquarie University NSW 2109, Australia

[2] MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Westmead Innovation Quarter Building U, Westmead NSW 2145, Australia

[3] Institute of Neuroscience and Psychology, University of Glasgow, Glasgow, G12 8QB, United Kingdom

[4] Professorship for Social Brain Sciences, ETH Zurich, Zurich 8092, Switzerland

Contact information:

Ryssa Moffat (0000-0002-0981-3353): ryssa.moffat@gess.ethz.ch

Nathan Caruana (0000-0002-9676-814X): nathan.caruana@mq.edu.au

Emily S. Cross (0000-0002-1671-5698): emily.cross@gess.ethz.ch

* *to whom correspondence should be addressed*

Acknowledgements

We thank Louis Klein for statistical advice, and our confederates, Hannah Cahill and Sabrina Diep, for their consistency and dedication, and the Macquarie University Research and Innovation team for their technical expertise. Emily Cross and Ryssa Moffat were supported by the European Research Council (ERC) under the European Union's Horizon 2020 Research and Innovation Programme (Grant agreement no. 677270 to EC) and the Leverhulme Trust (Grant number PLP-2018-152 to EC). Nathan Caruana was supported by a Macquarie University Research Fellowship (9201701145).

Keywords

Inhibitory control, motor synchrony, interpersonal coordination, social alignment, fNIRS, self-monitoring

Abstract
Developing motor synchrony with a peer (through interventions such as the mirror game) can yield collaborative, cognitive, and social benefits. However, it is also well established that observation by an audience can improve cognition. The combined and relative advantages offered by synchronisation and audience effects are not yet understood. It is important to address this gap to determine to which extent synchronising activities might interact with the positive effects of an audience. In this pre-registered study, we investigate the extent to which response inhibition may be improved when observed by a synchronised peer. We compare behavioural and cortical (functional near-infrared spectroscopy; fNIRS) measures of inhibition between synchronised and non-synchronised dyads and find that the presence of a synchronised peer-audience introduces a speed-accuracy trade-off, consisting of slower reaction times and improved accuracy. This co-occurs with cortical activation in bilateral inferior frontal and middle prefrontal cortices, which are implicated in monitoring and maintenance of social alignment. Our findings suggest that synchronising activities with carers or support-people may be valuable for rehabilitating inhibition and social skills in clinical settings.

1 Introduction

Motor synchrony, the alignment of bodily movements in space and time, has been shown to act as a form of 'social glue' that supports communication, collaboration, and prosocial behaviour, as well as enhancing our perceptions of the people we interact with and our subjective experiences during these interactions (Lakin et al., 2003; Mogan et al., 2017; Rennung & Göritz, 2016; Vicaria & Dickens, 2016). A growing number of studies demonstrate that motor synchrony interventions can improve aspects of social cognition, such as joint attention and social mimicry (Koehne et al., 2016; Landa et al., 2011; Morris et al., 2021; Srinivasan et al., 2015). More recently, two studies demonstrated that motor synchrony that takes place between participants and trained confederates may also enhance cognition more generally (Keisari et al., 2020; Nahardiya et al., 2022; Pärnamets et al., 2020; Rauchbauer et al., 2020). Specifically, Rauchbauer et al. (2020) showed that such synchrony interventions can lead to improved automatic imitation inhibition, while Keisari et al. (2020) demonstrated the positive impacts of such interventions on working memory and attentional function. Both studies assessed participants' cognitive performance after the synchronised partner (i.e., a confederate) left the room, offering insight into the impact of induced synchrony on subsequent cognitive performance, but neither study shed light on whether the continued presence or attention of the synchronised partner influences cognitive performance. However, given that synchrony is most likely to emerge during sustained interactions, it is also pertinent to understand how cognition is influenced in the presence of a synchronised social partner. Thus, an important question remains concerning *how a synchronised partner's presence might influence cognitive performance?* Drawing on the wealth of empirical evidence that an audience–even a single peer–can lead to improved cognitive performance (Hamilton & Lind, 2016), we conducted a pre-registered investigation to explore the extent to which a synchronised audience improves cognitive performance more than a non-synchronised audience.

1.1 Motor synchrony and social connectedness

Motor synchrony can occur spontaneously (Lakin et al., 2003; Rennung & Göritz, 2016; Sebanz et al., 2006) or be induced using exercises with a partner, such as performing arm curls, lifting fingers at a specified tempo or matching arm movements in a mirror game (Feniger-Schaal et al., 2021; Rauchbauer et al., 2020; Ravreby et al., 2022). Both spontaneous and induced motor synchrony are reliably associated with increased prosocial behaviours and experiences of closeness (Mogan et al., 2017; Rennung & Göritz, 2016; Vicaria & Dickens, 2016), such as increased self-other overlap on questionnaire reports (Miles et al., 2010; Paladino et al., 2010). According to Shamay-Tsoory et al. (2019), motor synchrony, or alignment, overlaps with emotional and cognitive alignment, in that all three are complementary manifestations of social connectedness. Following on from this explanation, individuals who experience social difficulties are likely to engage in these forms of alignment less frequently. Indeed, reduced spontaneous motor synchrony is observed in clinical populations known to exhibit social difficulties, such as individuals diagnosed with attention-deficit/hyperactive disorder (ADHD), autism, bipolar disorder, and social anxiety (Asher et al., 2020; Dean et al., 2021; Fitzpatrick et al., 2017; Kupper et al., 2015; R. Zimmermann et al., 2021).

Shamay-Tsoory et al.'s (2019) *extended integrative model of alignment*, comprises three components: First, a gap-monitoring system, linked to dorsal anterior cingulate cortex (ACC), dorsal medial prefrontal cortex (PFC), and anterior insulae evaluates the predicted and existent alignment with a social partner. When a gap in alignment is detected, the alignment system, or observation-execution system activates the inferior frontal gyrus (IFG), inferior parietal lobule, premotor cortex, and superior temporal sulcus to facilitate alignment by perceiving a behaviour and initiating the same behaviour. When no gap is detected, the reward system, associated with the ventral striatum, orbitofrontal cortex, and ventral medial PFC, is activated and drives maintenance of alignment. This model posits that adults typically seek to align with social partners by default, and that the social connectedness experienced during induced motor synchrony, likely to be processed by the reward system, is socially motivating.

1.2 Observed-audience dynamics and cognitive performance

Awareness of an observer, or an audience, is known to change behaviour (Hamilton & Lind, 2016). In social-observation scenarios, the observed individual's behaviour may be influence by the task and/or social dynamics of the observed individual and their audience. An early meta-analysis by Bond & Titus (1983) reported that task complexity mediated the audience effect, with simple tasks resulting in improved performance, and complex tasks resulting in poorer performance under observation. In a meta-analysis demonstrating that task complexity alone could not capture the social dynamics of an audience and observed individual, Uziel (2007) synthesised 14 studies centred on personality traits of the observed individual, revealing that elevated extraversion and self-esteem were associated with improved performance under observation, whereas neuroticism and low self-esteem were associated with poorer performance.

Though meta-analyses exist that summarise effects of task-type and characteristics of the observed individual, a meta-analysis of audience characteristics has yet to be curated. While we await this, we must draw evidence from individual studies, which often do not disentangle task complexity and audience characteristics. From existing work, we learn that an attentive audience (e.g., signalled by direct gaze) enhances performance more than an inattentive or invisible audience (Huguet et al., 1999). A friendly, non-expert, peer audience with little knowledge of the task goal can improve performance, whereas a higher status or expert audience can worsen performance if their knowledge of the task is not made explicit (Belletier et al., 2015; Eastvold et al., 2012; Huguet et al., 1999; Klein et al., 2020). Klein et al. (2020) propose that an audience's explicit knowledge of the goal may induce more commitment to the goal, and thereby improved performance. Further, increased rapport between a higher status, expert audience and observed individual can also improve performance (Barnett et al., 2018, 2022). Several studies also document that rapport, or the ease of social interaction, improves with increasing motor synchrony between individuals (Bernieri, 1988; Miles et al., 2009; Sharon-David et al., 2019). Thus, it stands to reason that induced motor synchrony between an individual and an audience–for arguments sake, a peer of the same status with no task-related expertise–has the potential to increase rapport and yield improved cognitive performance.

1.3 Enhancing inhibitory control with a motor synchrony activity

To date, only two studies have sought to quantify changes in cognitive performance resulting from a motor synchrony activity (Keisari et al., 2020; Rauchbauer et al., 2020). Rauchbauer et al. (2020)

report that young adult participants, whose body movements were implicitly mimicked by a confederate for 20 minutes prior to performing an automatic imitation task, showed better inhibition than participants who were not mimicked by the confederate. Keisari et al. (2020) investigated the influence of the mirror game on elderly individuals' cognitive performance, reporting improved working-memory span and recognition of speech-in-noise scores after elderly individuals played the mirror game relative to when they participated in a group exercise class. In both studies, the cognitive tasks were performed under the supervision of an experimenter and the synchronised partner was not in the room. These studies offer evidence that motor synchrony can enhance cognitive performance generally, while Rauchbauer et al. (2020) demonstrates that inhibition of motor responses can be improved by prior synchrony with a peer. We further note that studies examining benefits of Tai Chi (which involves synchronous group movement) on inhibitory control in elderly and substance-addicted populations report improvement after interventions lasting several weeks (Menglu et al., 2021; Yang et al., 2020).

The rationale for improving response inhibition, whether using novel interventions such as those presented in the studies reviewed here or through specific response inhibition training (Allom et al., 2016; Hartmann et al., 2016; Schroder et al., 2020), stems from the need to provide therapeutic options for individuals with reduced inhibitory abilities (National Institute of Mental Health, 2017)–a common characteristic of clinical populations diagnosed with disorders including ADHD, autism, schizophrenia, and social anxiety (Altmann et al., 2020; Dean et al., 2021; Ramseyer & Tschacher, 2011; Reinecke et al., 2022). In addition to reduced response inhibition, individuals with these disorders also show reduced spontaneous motor synchrony (Wright et al., 2014). Moreover, in clinical settings, the degree of spontaneous motor synchrony with a therapist has been demonstrated to predict therapy duration and outcomes (Altmann et al., 2020; Ramseyer & Tschacher, 2011; Reinecke et al., 2022) and adherence to treatment recommendations (Dean et al., 2021) among individuals with ADHD, autism, schizophrenia, and social anxiety. It follows, that an intervention targeting two symptoms (response inhibition and motor synchrony) of these mental disorders would be valuable in clinical settings.

1.4 Current study

This study assessed the extent to which inducing synchrony between an observed individual and their audience boosts the observed individual's ability to suppress motor responses (i.e., inhibitory control). This was achieved using measures of behavioural performance (reaction times and error rates) and cortical haemodynamic brain activity recorded over frontal brain regions using functional near-infrared spectroscopy (fNIRS). These are measured from and compared between a Synchronised group, in which participant-audience motor synchrony is induced via the mirror-game (Feniger-Schaal et al., 2021), and a non-synchronised Control group, in which each member of the observed participant-audience pair takes a turn observing the other member move their arms. To obtain performance and cortical measures of inhibitory control, we employ a Go/NoGo task after the movement task.

Using fNIRS, we recorded changes in cortical oxygenation from the frontal brain regions reported to be activated by inhibitory control and observation by an audience. Functional magnetic resonance imaging (fMRI) and fNIRS studies measuring the influence of an audience on haemodynamic brain activity report increased activity in medial PFC, anterior cingulate cortex (ACC), and striatum–brain areas associated with self-monitoring and reward systems (Chevrier et al., 2007; Chib et al., 2018; Finger et al., 2006; Hamilton & Lind, 2016; Izuma et al., 2010; Somerville et al., 2013; R. Zhang et al., 2017). Studies investigating inhibitory control, i.e., response suppression, report increased activity in prefrontal and inferior frontal brain regions, as well as the ACC, insulae and thalami (Aron et al., 2004; Cai et al., 2014; Chevrier et al., 2007; Gavazzi et al., 2021; Kaga et al., 2020; Nguyen et al., 2021; Schulz et al., 2009; R. Zhang et al., 2017). We measured changes in cortical oxygenation as a proxy for neural activity in five regions of interest: left and right IFG, as well as left, right, and middle PFC. We did not measure from the subcortical structures mentioned above, as the penetration depth of fNIRS is approximately 1.5 cm beneath the scalp (Pinti et al., 2020), and our hypotheses pertain to cortical regions involved in social processing (Hamilton & Lind, 2016).

As preregistered (https://osf.io/87xnj/), we hypothesised that both groups should respond more quickly during blocks requiring no inhibition of motor responses **(Hypothesis 1)**. We also hypothesised that the Synchronised group will respond faster than the Control group across blocks, regardless of response inhibition requirements **(Hypothesis 2)** and will fail to inhibit responses less frequently than the Control group **(Hypothesis 3)**. With respect to the changes in cortical oxygenation measured using fNIRS, we hypothesised that blocks that require response inhibition will evoke greater cortical activation than blocks that do not in right PFC (as right PFC activation is more commonly observed with fNIRS while right IFG is more commonly observed with fMRI), but not in other ROIs for both groups **(Hypothesis 4)**. Finally, we evaluated an exploratory hypothesis that the Synchronised group relative to Control group may differ between block types and/or per ROIs **(Hypothesis 5)**.

2 Methods

2.1 Participants

A total of 68 participants were recruited from Macquarie University in Sydney, Australia. All participants met the self-reported inclusion criteria being right-handed, aged 18-40, having no history of head injury, neurological or psychiatric diagnoses, and not currently taking a psycho-pharmaceutical medication (SSRIs or Ritalin). Following König et al. (2021), we added further inclusion criteria that participants must report no alcohol consumption within the 12 hours prior or tetrahydrocannabinol (THC) use/exposure within the 24 hours prior to the study, and not playing videogames frequently (e.g., more than once a week, as inhibition is a skill required in many videogames, and we did not wish to recruit expert inhibitors). Of the 68 participants who met each of these initial inclusion criteria for participation, nine were excluded following data collection: Five were not deceived by the story explaining the confederate's presence, two did not perform the Go/No-Go task correctly, one reported playing video games frequently during the session (after reporting they did not during initial screening), and one participant's session was interrupted by a fire alarm.

The remaining 59 participants were pseudo-randomly assigned to either the Synchronised group or non-synchronised (Control) group. To ensure a balanced sample, groups were counterbalanced for gender, age, and confederate (n = 2, both female, aged 21 and 30) in a continuous fashion, with additional participants recruited following exclusions. The Synchronised group consisted of 30 participants (14 female, 16 male; mean age = 22.10 ± 5.78 years) and the Control group of 29 participants (15 female, 13 male, 1 other; mean age = 21.00 ± 4.93 years). Participants' consumption of caffeine and alcohol prior to the experiment was recorded to ensure equal distribution across the two groups (Supplementary Materials [S1]).

Ethical approval for this study was obtained from the Macquarie University Human Research Ethics Committee (Ref: 520221102239451). Written informed consent was obtained from participants before beginning the session, at which time participants were told that a confederate was a new student volunteer visiting the lab for the first time. Consent was renegotiated after the completion of the Go/NoGo task, when participants were given the opportunity to withdraw their data if they were not comfortable with the minor deception about the confederate. No participants withdrew their consent. Participants received course credit or a cash honorarium (AUD $30) for their involvement.

2.2 Questionnaires

To explore whether extraversion may influence our measures of interest (reaction times, commission errors, or cortical activation) and need to be included in our models, we conducted exploratory preliminary analyses (described in Section 2.5). Participants completed a questionnaire based on the International Personality Item Pool (IPIP) representations of the extraversion subscale of the Goldberg (1992) Big Five markers and the Rosenberg (1965) self-esteem scale. Participants completed the questionnaire on their mobile phone before being welcomed to the laboratory, thereby ensuring a sense of privacy and confidentiality prior to the experiment (i.e., neither the experimenter nor confederate saw how the participant responded). The extraversion scale used a 5-point Likert scale (1 = *very inaccurate* to 5 = *very accurate*) to respond to 5 positively and 5 negatively worded items (*'I feel comfortable around people'* or *'I don't talk a lot'*). The self-esteem scale used a 4-point Likert scale (0 = *strongly disagree*, 3 = *strongly agree*) to respond to 5 positively and 5 negatively worded items *('I know my strengths'* or *'I am less capable than most people'*). Both scales were scored by summing the points, with the points for negatively worded items reversed. In our analyses, Extraversion refers to the summed extraversion and self-esteem scores per participant.

2.2 Procedure

The experimenter greeted all participants, introduced the confederate as a student volunteer visiting the lab for the first time, and asked the participants if they would feel comfortable if the confederate observed, and participated in certain easy activities, in place of the experimenter (script available at https://osf.io/87xnj/). Participants next completed the synchronising or control movement activity with the confederate, then afterward, completed the Go/NoGo task under the observation of the confederate.

Synchronising/Control movement activities. Participants in the Synchronised group completed a synchronising activity with the confederate, and participants in the Control group completed a movement observation activity with the confederate.

Synchronised group: synchronising activity. The participant and the confederate were instructed that they would be playing the mirror game, where they were to mirror the other person's upper body movements as closely as possible, that each person would take a turn as the leader for 2:30 minutes, and that the leader should try to vary their movements, to encourage participants to make use of the space around them. The participant was always assigned to lead the first turn and the confederate led the second.

Control group: movement-observation activity. The participant and the confederate were instructed that they would be doing a movement activity, where each person would take a turn moving their upper body for 2:30 minutes while the other person observed and completed an observation task. As in the synchronising activity, they were instructed that the person moving should try to vary their movements. Before beginning, the participant and the confederate each drew an observation task from a hat (e.g., *'count the number of times your partner raises their right hand above their ear'*). To reduce social awkwardness, the confederate always took the first turn moving their upper body, and the participant took the second turn.

The synchronising and control activities were identical in that participants sat face-to-face, looking at each other, and engaged in movements of similar intensity across both groups. The only differences were whether the participants moved synchronously or separately and whether the participant or confederate moved first. We selected this control activity on the basis that, relative to a passive observation task, it is engaging for both parties, and relative to an anti-mirror task (i.e., moving simultaneously, but avoiding matching each other's movements), it eliminates the possibility of temporally contingent motor patterns, which are also a form of synchrony (Rauchbauer & Grosbras, 2020). The duration of 2:30 minutes was selected on the basis that once each person took a turn leading, the 5-minute duration would be consistent with recent work (Feniger-Schaal et al., 2021), while also maximising the influence of this manipulation without inducing boredom.

For these activities, the confederate and participant were seated facing each other (1.2 m apart) with a pair of GoPro HERO3+ video-cameras (GoPro, San Mateo, California, USA) between them, one facing each person (Figure 1, A and B). Recordings were made using OBS studio (https://obsproject.com/). The experimenter attended to the recording computer in the corner of the room, approximately 2.5 m away from the participant and confederate.

Go/NoGo task. A Go/NoGo task adapted from Young et al. (2018) was used to obtain behavioural and cortical measures of inhibition. Each participant sat in front of a computer in a sound-shielded room and was instructed that they would see the letters T, H, N, W, and M on the screen, and that they should press the space bar on the keyboard when they saw T, H, N, W, but not when they saw M. They were also instructed to respond as quickly and accurately as possible. As such T, H, N, W were presented in Go trials, and M was presented in NoGo trials. Participants completed 40 blocks of 12 trials with 20 blocks consisting of only Go trials (AllGo blocks; no Ms included) and 20 blocks consisting of 66% Go trials and 33% NoGo trials (Mixed blocks). Before each block, the type of block was presented on the screen for 2 s (‘Only T, H, N, W’ or ’Ms included’ followed by ‘Respond as quickly and accurately as possible’). The letters were presented for up to 500 ms followed by a blank screen for up to 500 ms, allowing 1000 ms for a response (Figure 1D). Between trials and before the first trial, a fixation cross was displayed with a jittered intertrial interval (ITI) of 500-1500 ms. Between blocks, a blank screen was shown for a jittered interstimulus interval (ISI) of 16-22 s. ITIs were jittered to avoid cyclic responding to the motor task, thereby promoting higher accuracy (Lee et al., 2015; Wodka et al., 2009). The letter stimuli and the 4:1 ratio of Go:NoGo stimuli (T, H, N, W : M) with 33% NoGo, as well as the ITIs of 500-1500 ms were selected to maximise both the number of commission errors (i.e., button-presses on NoGo trials; failed response inhibition) and the signal-to-noise ratio (Wessel, 2018; Young et al., 2018). ISIs were jittered to reduce participants’ anticipation of the onset of upcoming block, as well as to ensure that blocks were not temporally synchronised with changes in intracranial blood pressure regulation, i.e., Mayer waves (Julien, 2006; Luke, Shader, et al., 2021). The experiment was programmed and presented using PsychoPy (Peirce et al., 2022) and can be retrieved from https://osf.io/87xnj/.

Participants were familiarised with the task by completing one AllGo and one Mixed block before donning the fNIRS cap. Cap in place, participants completed the Go/NoGo task with no breaks in ~26 minutes with the confederate observing from ~1.5 m, facing the participant at a 90˚ angle (Figure 1C). This was the maximal distance possible in the lab facilities, and the 90˚ angle allowed the confederate to remain in the participants’ peripheral vision without inducing stress by positioning the confederate too close to the participant (Bogdanova et al., 2021; Huguet et al., 1999). Unbeknownst (we assume) to the participants, the experimenter observed from an adjacent room via a video camera.

2.3 fNIRS equipment

Spectrometer. fNIRS recordings were made with a NIRScoutX (NIRx Medical Technologies LLC) with 24 LED sources and 32 avalanche photodiode detectors and NIRStar software. The sources emitted wavelengths of 760 and 850 nm with a sampling rate of 4.5 Hz. The optodes were mounted onto mesh caps marked with International 10/10 positions (Easycap GmbH) using grommets and spacers to maintain a maximum 30-mm separation (NIRx Medical Technologies LLC).

Optode positions (montage). A montage of 14 sources, 11 detectors, and 8 short detectors was used to record from bilateral and middle PFC, as well as bilateral IFG (Figure 1, E and F). To cover these brain areas, our montage comprised 38 long channels (source–detector pairs ~30 mm apart), along with 8 short channels (source–detector pairs 8 mm apart), distributed across the ROIs to account for location-dependent heterogeneity in the extracerebral signals (Brigadoi & Cooper, 2015; Gagnon et al., 2012; Y. Zhang et al., 2015). Optode positions were determined using the AAL2 atlas in the fOLD toolbox (Rolls et al., 2015; Tzourio-Mazoyer et al., 2002; Zimeo Morais et al., 2018).

2.4 Manipulation check

To verify that participant–audience synchrony was indeed increased in the Synchronised group relative to the Control group, we quantified and compared the mean similarity of a dyad's poses–their upper-body position–in each frame of the video-recorded movement activity. This analysis was exploratory and not preregistered.

To obtain a dyad's mean pose similarity, we employed OpenPose software (Cao et al., 2019) to identify the confederate and participants' left and right wrist, elbow, shoulder, and their neck in the video-recording of the movement activity (Figure 1B). Next, we used OpenPose to estimate and write x and y coordinates, and a measure of the algorithm's confidence in these estimates between 0-1, per body part per person to a JSON file per frame. From here, we converted extracted JSON files for each dyad to a CSV file using a R script adapted from de Jonge-Hoekstra (https://osf.io/6s73d/). Missing values were replaced with the median for that joint, and the timeseries for each joint was subsequently smoothed using a Savitzky-Golay filter (window length = 13 frames, polynomial order = 2) implemented with the signal R package (signal developers, 2014). Then, using R code adapted from Broadwell & Tangherlini (2021), we estimated the Euclidian distance between all pairs of body parts for each person in a frame, storing these in a separate 'pose matrix' per person, and then comparing (via Laplacian procedure) the pose matrices for each frame. Pose similarity was returned as a value between 0 = *no similarity* and 1 = *identical* per frame. The mean per dyad was calculated across all frames from the video (~9000 frames per video).

2.5 Data analysis

For our preregistered analyses, we employed a Bayesian approach to multi-level regression (McElreath, 2020), using the brms package (Bürkner, 2017) in the R language (R Core Team, 2022) within the RStudio IDE (RStudio Team, 2020). This approach allowed us to build models incrementally (Barr, 2013) and to use leave-one-out cross-validation (LOO; Vehtari et al., 2017) to estimate and compare the out-of-sample accuracy between simpler and more complex models. In other words, LOO informs us about the degree to which increasing complexity enhances the accuracy of our models. For key parameters in the most complex model, we report and interpret the posterior distribution with a 95% credible interval, which we calculate using the highest posterior density region (HPD) method (McElreath, 2020). For readers more accustomed to a Frequentist approach with p-values, we recommend perusing Kruschke & Liddell (2018), and we offer the following (simplified) heuristic for interpreting HPDs: Comparisons can be said to entail substantial differences when HPD does not contain zero and to be trends when the tip of an HPD-tail overlaps with zero.

All models were built beginning with only varying intercepts per participant (ID) and block type where relevant. Next, simple predictors were added one at a time, followed by 2-way then 3-way interactions between predictors (Barr, 2013). We used treatment coding for group (Synchronised = 1, Control = 0) and block type (AllGo = 0, Mixed = 1). We set weakly informed priors to impose a constrained distribution on our expected results, thereby acknowledging the limits of our knowledge as to our expected results, allowing for possible large effects, and allowing the data to dominate the posterior distribution structure (Gelman, 2006; Lemoine, 2019). These priors were set using parameter values extracted from pilot data (collected using a very similar Go/NoGo task completed by 16 participants while recording fNIRS signals). Full models, comparison to simpler models, and visualisation of all model parameters are reported in Supplementary Material (S2).

Preliminary analysis–Extraversion. We preregistered an exploratory analysis of the relationship between our measure of Extraversion and each of our data sources (reaction times, commission errors, or cortical haemodynamic responses amplitudes [HbO only for this specific analysis]). Uziel's (2007) meta-analysis concludes that extraversion impacts how individuals perform on cognitive tasks when observed, reporting a positive correlation between extraversion and performance. With this knowledge, we seek to determine whether including Extraversion as predictor in our other planned analyses constitutes a parsimonious addition. The extraversion data were modelled using gaussian regression models, with priors based on summed parameter values for extraversion and self-esteem from previous studies (Guenole & Chernyshenko, 2005; Sinclair et al., 2010). The detailed results of this analysis, as well as the models used, are reported in the Supplementary Materials (S3). In summary, extraversion did not covary meaningfully with reaction times, commission errors, or HbO amplitudes. We thus did not include Extraversion in our main analyses. However, for reaction times and HbO, some evidence of covariance with other terms (i.e., group, block type) was observed. To account for this in our models for each reaction times and cortical oxygenation, we included Extraversion as a random slope per participant.

Go/NoGo reaction times and commission errors. To assess if the Synchronised group responded to Go trials faster than the Control group in both AllGo and Mixed blocks (Hypothesis 2), we modelled the data using lognormal models. We examined whether the Synchronised group made fewer commission errors (failed suppression of response) than the Control group (Hypothesis 3) using poission regression models.

Haemodynamic response amplitude: First level.
Analyses were performed using MNE (Gramfort et al., 2013), MNE-NIRS (Luke, Larson, et al., 2021), and NiLearn (Abraham et al., 2014). The generalised linear model (GLM) approach was taken to quantify the amplitude of evoked haemodynamic responses per ROI and Condition (Huppert, 2016). Waveforms for visual inspection are presented in the Supplementary Materials (S4). The sampling rate of the recorded signal was reduced from 4.5 to 0.6 Hz (Luke, Larson, et al., 2021). The signal was converted from raw intensity to optical density, using absolute raw intensity values. Next, the signal was converted to concentrations of HbO and HbR using the Modified Beer-Lambert Law (Delpy et al., 1988; Kocsis et al., 2006) with a partial pathlength factor of 0.1, accounting for both differential pathlength factor (DPF) and partial volume correction (PVC), where (DPF = 6)/(PVC = 60) is equal to 0.1 (Santosa et al., 2018; Strangman et al., 2003). The GLM was fit to the long-channel data—isolated by rejecting channels <20 mm or >40 mm. The design matrix for the GLM was generated by convolving a 16-s boxcar function at each event-onset-time with the canonical haemodynamic response function (Glover, 1999; Santosa et al., 2019). The GLM also included all principal components of short-detector channels to account for extracerebral and physiological signal components. Further, drift orders accounting for signal components up to 0.01 Hz were included as regression factors (Huppert, 2016). The GLM was performed with a lag-1 autoregressive noise model, to account for the correlated nature of the fNIRS signal components. Individual coefficient estimates were then averaged for each ROI, weighted by the standard error.

Second-level. To investigate whether Mixed blocks evoked greater cortical activation than AllGo blocks in right PFC only, as well as the influence of group on haemodynamic response amplitudes, we employed Bayesian multivariate gaussian models. Fitting both HbO and HbR within the same model allows for the correlated natures of the HbO and HbR response amplitudes to inform the model fit, exploiting the available information without the risks of multicollinearity incurred by treating chromophore (i.e., HbO/HbR) as a categorical factor. Full model reported in Supplementary Material (S2).

For exploratory analyses, we also derived HbO-HbR difference values by subtracting HbR from HbO estimates per participant, ROI, and block type. This difference measure is commonly employed in fNIRS studies addressing clinical questions (Kaynezhad et al., 2019; Kolyva et al., 2014) and has recently been shown to be useful in answering questions in cognitive neuroscience (Moffat, Başkent, et al., 2023; Moffat & Cross, in prep). The HbO-HbR difference offers three main advantages when communicating and interpreting changes in cortical oxygenation measured with fNIRS. First, by synthesising a pair of HbO and HbR estimates into a single value, the complexity of models and the potential for multicollinearity is strongly reduced. Second, the sign (+/-) of an HbO-HbR difference value is informative: Positive difference values correspond to canonical haemodynamic responses, while negative values respond to inverted responses (also called negative BOLD responses). Third, the relationship between HbO and HbR estimates can be used to categorise responses very conservatively as systemic phenomena (blood-pressure changes) or true cortical responses. Here, negatively-correlated HbO-HbR pairs are more likely to represent cortical activation (Wolf et al., 2002), while positively-correlated pairs are more likely to represent physiological confounding phenomena such as blood pressure changes, muscle oxygenation or extracerebral changes (Yücel et al., 2021; Zimeo Morais et al., 2017), and the latter can easily be excluded for more conservative analyses (Moffat, Başkent, et al., 2023; Moffat & Cross, in prep). We present results from exploratory models fit to negatively-correlated HbO-HbR pairs here, and models fit to all HbO-HbR pairs in Supplementary Materials (S5). Parameter estimates from models were contrasted using the emmeans package (Lenth, 2021).

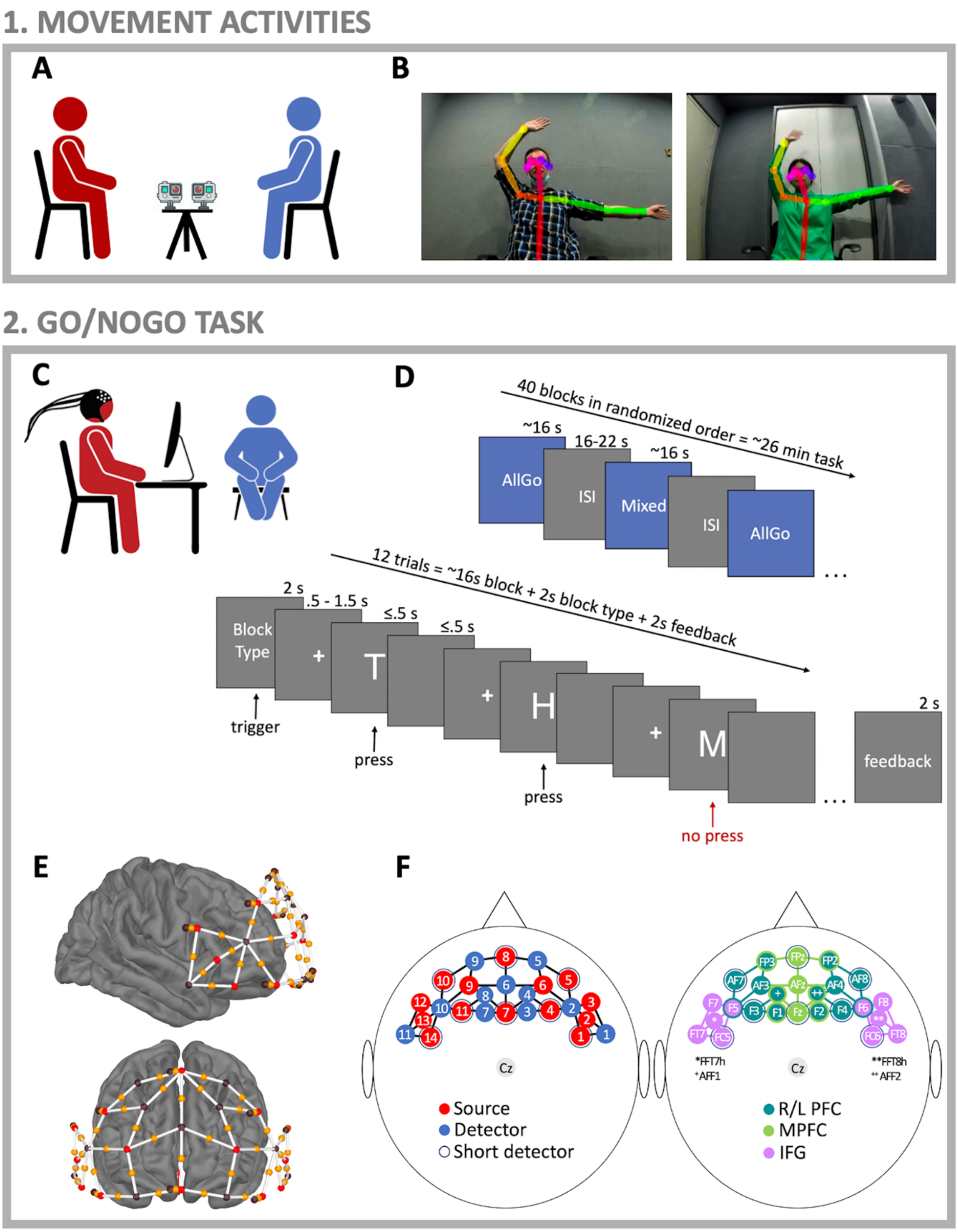

Figure 1. A) First, participants completed either a synchronising or control movement activity with a confederate. The activity was video-recorded using a pair of GoPros positioned between the participant and confederate dyad, who were seated for the activity. B) The similarity of each dyad's movements was calculated using coordinates of each person's joints per frame, as estimated with OpenPose. C) Next, the participant completed a Go/NoGo task while the confederate observed from ~1.5 m away, in the participant's peripheral vision. D) The Go/NoGo task consisted of AllGo blocks (100% Go trials) and Mixed blocks (66% Go and 33% NoGo trials). E) fNIRS recordings were made using a montage covering the inferior-frontal and prefrontal brain regions. White bars = channels between source-detector pairs; red spheres = sources, black spheres = detectors, yellow spheres = point of measurement. F) 10-10 positions of source and detector optodes, as well as the channels belonging to each region of interest; enlarged version in supplementary materials.

3 Results

3.1 Manipulation check

Before proceeding to our planned analyses, we first verified that the level of motor synchrony during the movement activities indeed differed (not preregistered). We quantified the spatial and temporal similarity of each dyads' upper-body movements, yielding a movement similarity score (0 = *no similarity* and 1 = *identical*). The mean similarity is 0.43 (SD = 0.12) for the Control group and 0.80 (SD = 0.06) for the Synchronised group, with a difference between means of 0.37. Figure 2 illustrates this substantial difference between groups and further demonstrates that similarity scores are not influenced by who is leading the mirror game (i.e., participant or confederate). One might expect values closer to zero in the Control group, however, during the movement observation activity, both members of the dyad keep their torsos and heads relatively still. This, in itself, is a form of synchrony, explaining why the Control group mean similarity is substantially above zero.

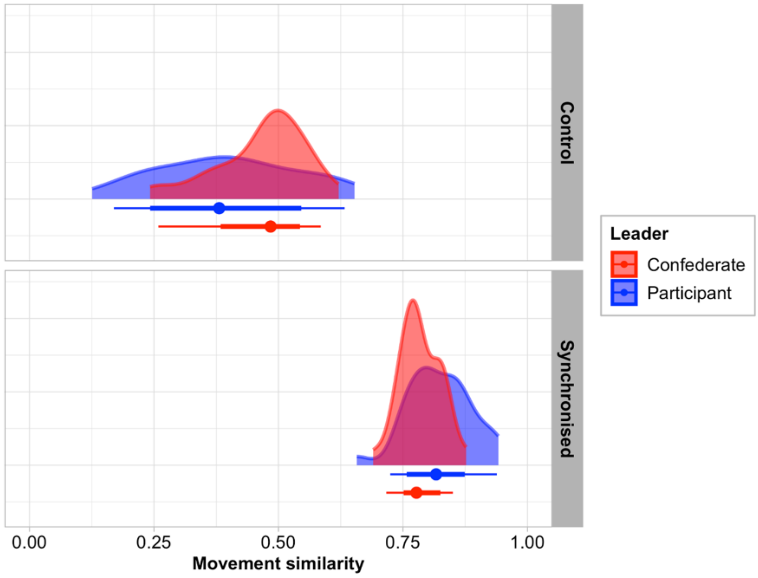

Figure 2. Movement similarity scores for movement activities (Synchronised group = mirror game, Control group = movement observation activity). Score calculated from body-position coordinates estimated by OpenPose: 0 = *no similarity* and 1 = *identical*. Summary point shows median, bars show interval covering 66% and 95% of the raw distribution.

3.2 Reaction times and commission errors

To obtain a proxy for inhibitory control, we recorded the reaction times in blocks with only Go trials requiring button presses (AllGo) and those additionally requiring participants to inhibit motor responses in one third of trials (Mixed), and commission errors (the number of presses on NoGo trials). Our preregistered hypotheses were that (**1**) both groups would respond faster to the Go trials in AllGo than Mixed blocks, (**2**) the watchful eye of a synchronised peer relative to a non-synchronised peer would result in faster reaction times for both block types and (**3**) fewer commission errors. To address these hypotheses, we fit the model *RT ~ 1 + Group*BlockType + (1 + BlockType|ID).* Confirming our first hypothesis, reaction times were faster for AllGo than Mixed blocks (β = 146.8 ms, 95% highest posterior density region: HPD = [144.5, 149.1]) when both groups were considered together (Figure 3). Contrary to our second hypothesis, the Control group responded faster than the Synchronised group in both block types (β = 18.1 ms, HPD = [15.8, 20.4]). No interaction between group and block type was predicted or observed.

Next, we examined commission errors using the model *CE ~ 1 + Group + (1 | ID)*. Consistent with our third hypothesis, the Synchronised group made fewer commission errors than the Control group (β = 2.93 errors, HPD = [0.75, 5.06], or converted to error rate: β = 3.66 %, HPD = [0.94, 6.33]). Exploratory, un-preregistered, analyses revealed a negative relationship, albeit small, between reaction times and commission errors (*ß* = -0.005, HPD = [-0.009, -0.002]), which suggests that for every 200 ms slowing of the response time, participants make one commission error fewer (see S7 of Supplementary Materials for comparison to findings from preregistered models). Further un-preregistered analyses revealed no relationship between mean movement similarity per dyad and reaction times, or between mean movement similarity and commission errors in the Synchronised group (*ß* = -0.06, HPD = [-1.01, 0.87]). A hint of a trend toward fewer commission errors with greater mean movement similarity in the Control group (*ß* = 0.31, HPD = [-0.38, 1.06]) was observed (S7 of Supplementary Materials). No analyses of changes in synchrony over the course of the movement activity and behavioural measures of performance were considered, as these task were completed one after another rather than at the same time.

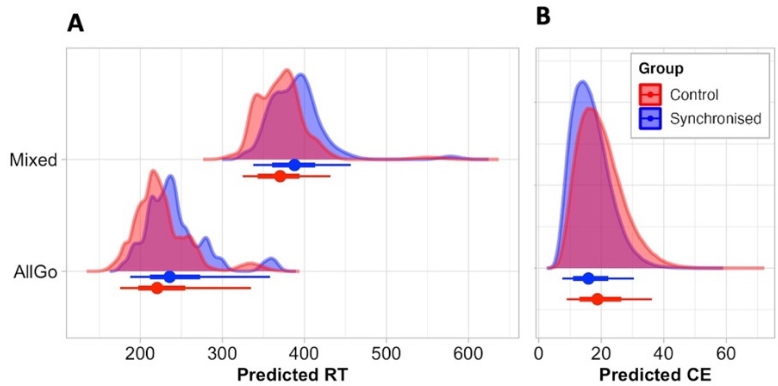

Figure 3. Predicted posterior distributions for A) reaction times (RT) and B) commission errors (CE) per group. Summary point shows median, bars show interval covering 66% and 95% of the raw distribution.

Table 1. Descriptive statistics (mean and standard deviation [SD]) for commission errors and reaction times.

Commission errors	**Group**	**Block type**	**Mean**	**SD**
	Control	Mixed	19.70	8.81
	Synchronised	Mixed	16.70	7.57
Reaction times (ms)				
	Control	AllGo	230.00	23.50
	Synchronised	AllGo	247.00	46.00
	Control	Mixed	367.00	26.10
	Synchronised	Mixed	384.00	42.40

3.3 Cortical haemodynamic activity

We next examined changes in cortical oxygenation evoked by inhibiting motor responses, and the influence of a synchronised peer-audience, employing the multivariate model: *(HbO, HbR) ~ 1 + BlockType * ROI * Group + (1 + BlockType|p|ID)* to obtain the parameter estimates in Figure 3 (note: *p* in this formula links the random effects structure to each of the outcome variables [HbO, HbR]). Our preregistered hypotheses were that (**4**) Mixed compared to AllGo blocks would evoke an enhanced haemodynamic response only in right PFC for both groups, and (**5**) proposed the exploratory analysis of group differences in either ROIs and/or block types. Counter to our fourth hypothesis, contrasts comparing Mixed and AllGo blocks with Control and Synchronised groups combined revealed no difference in right PFC. In fact, right PFC exhibited the smallest difference between block types of all ROIs for HbO (Table 1; Figure 4). Further, left IFG for HbO trends toward a more positive parameter estimate for Mixed than AllGo blocks. Substantial evidence for this same pattern is observed in bilateral IFG for HbR. Subsequent contrasts addressing group differences–our fifth, exploratory, hypothesis–revealed a substantial difference in bilateral IFG for HbO only (Table 3), wherein a greater difference between block types was observed in the Synchronised than Control group. The Synchronised, relative to Control, group showed substantially more positive HbO estimates in bilateral IFG for both Mixed blocks and a more negative estimate in middle PFC. In Mixed blocks, the positive HbO estimates obtained for the Synchronised group are accompanied by positive HbR estimates (Table 3). Of note, these simultaneous increases in HbO and HbR in bilateral

IFG did not accord with the increase in HbO and decrease in HbR expected of cortical activity. To delve further into this pattern which suggest systemic rather than cortical changes in the signal, we exploit the strengths of the HbO-HbR difference as a derived measure synthesising changes in concentration of HbO and HbR.

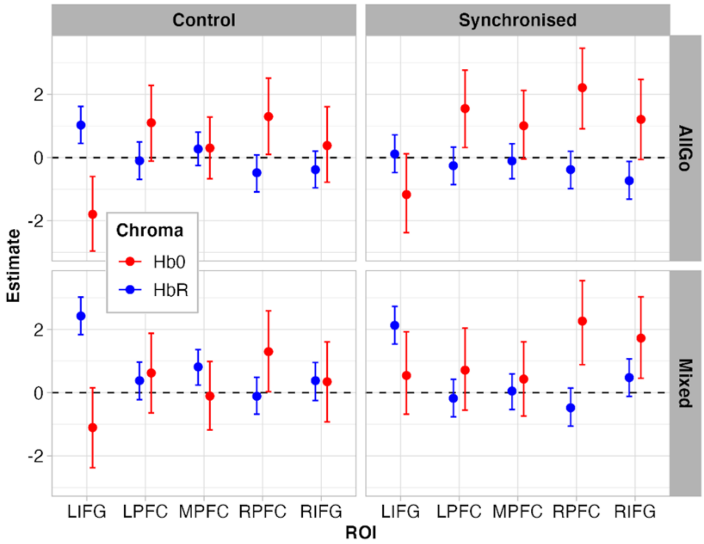

Figure 4. HbO and HbO parameter estimates (*ß*) per ROI, group, and block type with 95% highest posterior density (HPD) region. Error bars show 95% HPD regions.

Table 2. AllGo-Mixed contrast estimates per ROI for HbO, HbR, and negatively-correlated HbO-HbR difference. Positive = AllGo block haemodynamic response estimate more positive, negative = Mixed block more positive. Substantial group differences (i.e., HPD does not contain 0) marked in bold, trends (i.e., 0 in tail of HPD) marked in italics. *β* = estimate; HPD = 95% highest posterior density region.

	HBO		HbR		HbO-HbR difference	
ROI	***β***	**HPD**	***β***	**HPD**	***β***	**HPD**
LIFG	*-1.21*	*[-2.51, 0.06]*	**-1.71**	**[-2.31, -1.11]**	1.02	[-0.77, 2.91]
LPFC	0.66	[-0.67, 1.93]	-0.28	[-0.91, 0.30]	0.71	[-1.10, 2.53]
MPFC	0.49	[-0.64, 1.56]	-0.35	[-0.94, 0.21]	*1.28*	*[-0.07, 2.63]*
RPFC	-0.03	[-1.32, 1.29]	-0.14	[-0.75, 0.45]	-0.26	[-2.00, 1.39]
RIFG	-0.25	[-1.50, 1.07]	**-0.99**	**[-1.59, -0.39]**	0.85	[-0.99, 2.75]

Table 3. Control-Synchronised contrast estimates per block type and ROI for HbO, HbR, and negatively-correlated HbO-HbR difference. Positive = Control group haemodynamic response estimate more positive, negative = Synchronised group more positive. Substantial group differences (i.e., HPD does not contain 0) marked in bold, trends (i.e., 0 in tail of HPD) marked in italics. *β* = estimate; HPD = 95% highest posterior density region.

		HbO		HbR		HbO-HbR difference	
ROI	**Block type**	***β***	**HPD**	***β***	**HPD**	***β***	**HPD**
LIFG	AllGo	-0.63	[-2.27, 0.98]	**0.92**	**[0.08, 1.71]**	**-3.34**	**[-5.48, -1.07]**
LPFC	AllGo	-0.45	[-2.05, 1.17]	0.16	[-0.67, 0.96]	-0.57	[-2.69, 1.43]
MPFC	AllGo	-0.70	[-1.94, 0.52]	0.38	[-0.31, 1.09]	*-1.47*	*[-3.02, 0.11]*
RPFC	AllGo	-0.92	[-2.55, 0.72]	-0.10	[-0.90, 0.72]	-0.54	[-2.58, 1.39]
RIFG	AllGo	-0.82	[-2.52, 0.71]	0.35	[-0.47, 1.16]	-1.02	[-3.10, 1.08]
LIFG	Mixed	**-1.65**	**[-3.39, -0.06]**	0.29	[-0.56, 1.11]	**-3.93**	**[-6.40, -1.57]**
LPFC	Mixed	-0.08	[-1.78, 1.71]	0.56	[-0.30, 1.37]	-0.66	[-3.26, 1.97]
MPFC	Mixed	-0.54	[-1.98, 0.89]	*0.76*	*[-0.01, 1.52]*	**-1.89**	**[-3.68, -0.11]**
RPFC	Mixed	-0.96	[-2.71, 0.82]	0.37	[-0.46, 1.20]	-1.03	[-3.39, 1.24]
RIFG	Mixed	*-1.37*	*[-3.11, 0.40]*	-0.10	[-0.94, 0.74]	*-2.09*	*[-4.68, 0.50]*

3.4 HbO-HbR difference

Our attention was caught by the simultaneous increase in HbO and HbR in bilateral IFG when comparing differences between Control and Synchronised groups' cortical activity during Mixed blocks. This simultaneous increase in both HbO and HbR could plausibly reflect a physiological response, such as blood pressure changes, muscle oxygenation, or extracerebral changes (Yücel et al., 2021; Zimeo Morais et al., 2017), evoked by the participants' anticipation of NoGo trials in the Mixed block. To isolate changes in cortical activity from the plausibly task-induced systemic responses, we proceeded to fit the model *Hbo-HbR.difference ~ 1 + BlockType * ROI * Group + (1+BlockType|ID)* to HbO-HbR to difference values for all difference values, and subsequently, to difference values from negatively-correlated HbO-HbR estimate pairs only. Here, we report estimate from the negatively-correlated difference values (Figure 5), taking a conservative approach that excludes systemic responses not eliminated in the first-level analysis. For comparison of estimates for models with all and negatively-correlated values, refer to Supplementary Materials (S5).

Following our planned analysis of HbO and HbR (Figure 4), we applied the same post-hoc contrasts as for HbO and HbR individually, and again did not find the hypothesised **(4)** difference between AllGo-Mixed blocks in right PFC with groups combined but did observe some evidence for greater middle PFC activity in the Synchronised group (Table 2). Contrasts between groups for each ROI and block type **(5)** indicated larger differences between groups for Mixed than AllGo blocks, whereby the Synchronised group shows greater activation than the Control group in left IFG and middle PFC during AllGo blocks, as well as bilateral IFG and middle PFC during Mixed blocks (Table 3).

Table 4. Associations between behavioural measures and cortical activity as observed in HbO-HbR difference (negatively-correlated HbO-HbR pairs only). Substantial associations (i.e., HPD does not contain 0) marked in bold, trends (i.e., 0 in tail of HPD) marked in italics. β = estimate; HPD = 95% highest posterior density region.

			Reaction Times		Commission Errors	
ROI	**Block type**	**Group**	***β***	**HPD**	***β***	**HPD**
LIFG	AllGo	Control	-0.01	[-0.09, 0.08]	-0.26	[-0.94, 0.53]
		Synchronised	*0.08*	*[-0.01, 0.17]*	0.06	[-0.41, 0.53]
	Mixed	Control	0.05	[-0.04, 0.14]	*-0.20*	*[-0.45, 0.04]*
		Synchronised	**0.13**	**[0.04, 0.21]**	**-0.53**	**[-0.91, -0.14]**
LPFC	AllGo	**Control**	**-0.09**	**[-0.16, -0.01]**	-0.44	[-1.08, 0.17]
		Synchronised	0.04	[-0.02, 0.12]	0.29	[-0.12, 0.70]
	Mixed	Control	-0.01	[-0.09, 0.07]	0.01	[-0.27, 0.26]
		Synchronised	*0.11*	*[-0.01, 0.22]*	-0.27	[-0.77, 0.23]
MPFC	AllGo	Control	-0.03	[-0.10, 0.04]	-0.16	[-0.74, 0.45]
		Synchronised	0.04	[-0.03, 0.11]	0.11	[-0.34, 0.58]
	Mixed	Control	0.01	[-0.05, 0.07]	-0.03	[-0.29, 0.20]
		Synchronised	**0.08**	**[0.00, 0.17]**	-0.23	[-0.66, 0.22]
RPFC	AllGo	Control	*-0.07*	*[-0.15, 0.01]*	-0.34	[-1.00, 0.30]
		Synchronised	0.00	[-0.05, 0.05]	-0.01	[-0.40, 0.38]
	Mixed	Control	-0.03	[-0.11, 0.05]	0.07	[-0.17, 0.30]
		Synchronised	0.04	[-0.05, 0.12]	-0.03	[-0.46, 0.42]
RIFG	AllGo	Control	-0.01	[-0.11, 0.09]	-0.14	[-0.94, 0.64]
		Synchronised	**0.09**	**[0.05, 0.14]**	0.23	[-0.12, 0.60]
	Mixed	Control	*0.06*	*[-0.01, 0.14]*	**-0.29**	**[-0.53, -0.04]**
		Synchronised	**0.12**	**[0.00, 0.24]**	*-0.44*	*[-1.00, 0.10]*

3.4.1 Linking brain and behaviour

Having established that a speed-accuracy trade-off is induced under the observation of a synchronised peer, we sought to explore whether these behavioural outcomes are associated with participants' cortical activity (via exploratory, un-preregistered analyses). We assessed the relationship between cortical activity and each reaction times and commission errors using the model: *HbO-HbR.difference ~ 1 + BlockType * ROI * Group * ReactionTime * CommissionErrors + (1+BlockTypeID)*. In Mixed blocks, the Synchronised group exhibited substantially greater HbO-HbR differences, i.e., greater cortical activation, with increasing reaction times in bilateral IFG and middle PFC, with left PFC showing a congruent trend (Table 4). For AllGo blocks, the Synchronised group showed greater HbO-HbR difference in bilateral IFG with slowing reaction times, although the evidence is stronger for right than left IFG. The Control group showed some evidence for reduced HbO-HbR differences in right PFC for AllGo blocks and increased HbO-HbR differences in right IFG for Mixed blocks, as reaction times increased. A greater number of commission errors in Mixed blocks is associated with reductions in HbO-HbR differences in bilateral IFG for the Synchronised group, which were more substantial in left than right IFG. The Control group also shows the decreasing HbO-HbR difference in bilateral IFG with increasing commission errors, though more evidence is found for this association in right than left IFG.

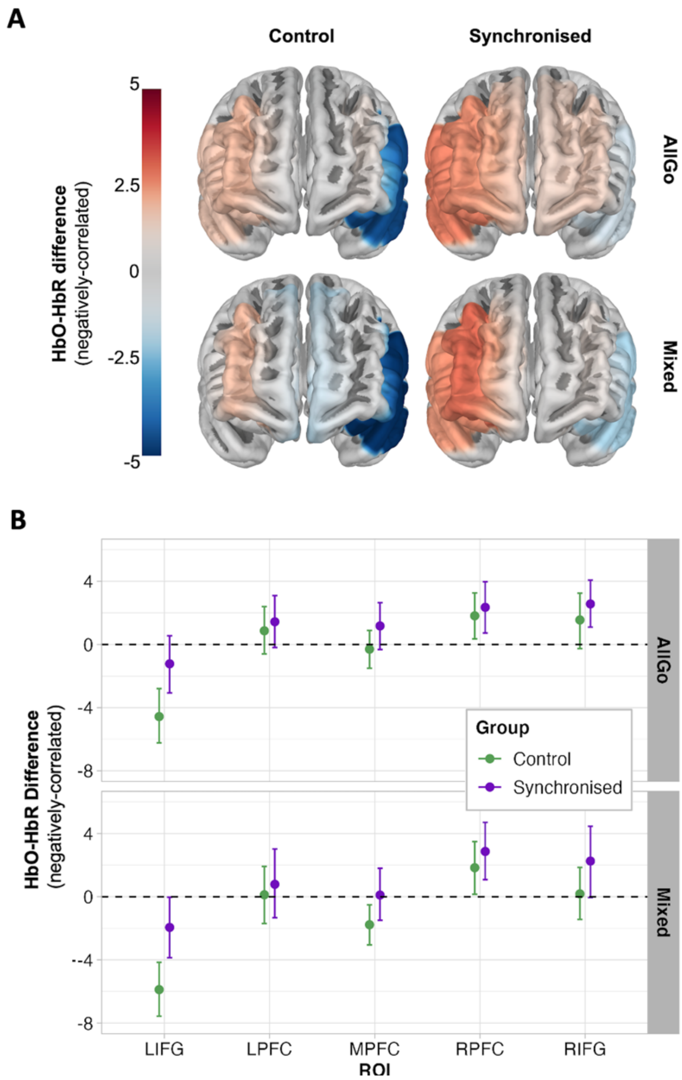

Figure 5. HbO-HbR difference estimates per ROI, group and block type (A) projected onto cortical surface and (B) with error bars showing 95% highest posterior density (HPD) region.

3.5 Additional analyses

As per our pre-registered preliminary analyses, we also fit exploratory models for each reaction times and cortical oxygenation to assess whether including random slopes of Extraversion scores per participant explained the data better. Visual inspection of data split per confederate for each measure (Supplementary Materials [S2]) led to further exploratory models for commission errors and cortical oxygenation with random coefficients (slopes for a categorical variable) of Confederate per participant. We also fit an exploratory model for cortical oxygenation with movement similarity as a random slope per participant to account for difference in achieved motor synchrony. None of these exploratory models offered substantially better out-of-sample predictions (Supplementary Materials [S2]), meaning that the addition of each given variable did contribute meaningfully to the model, and does not influence the outcome variable (i.e., reaction times or cortical oxygenation).

4 Discussion

Combining behavioural and cortical measures, we examined the influence of a synchronised vs. a non-synchronised audience on inhibitory control using a relatively simple task. Slower reaction times, fewer commission errors, and increased activity in bilateral IFG occurred under observation by a synchronised peer. This effect, however, was predominantly right lateralised in the Control group–as would be expected for response inhibition–and was evidently bilateral in the Synchronised group. Middle and left PFC activity increased with increasing reaction times uniquely when the observed individual and audience had completed a synchronising activity. These findings demonstrate that the watchful eye of a synchronised peer incurs a speed-accuracy trade off, accompanied by stronger activation of bilateral IFG, as well as left and middle PFC.

4.1 The presence of an audience results in improved accuracy at the expense of speed

The presence of an audience is widely reported to improve cognitive performance by helping the observed individual ignore task-irrelevant information, yielding faster and more accurate responses (Bond & Titus, 1983; Hamilton & Lind, 2016; Huguet et al., 1999; Keisari et al., 2020; Rauchbauer et al., 2020). Recent evidence also suggests that a synchronising activity can improve cognitive performance (Keisari et al., 2020; Nahardiya et al., 2022; Pärnamets et al., 2020; Rauchbauer et al., 2020) by enhancing self-monitoring processes (Rauchbauer et al., 2020; M. Zimmermann et al., 2022), in addition to enhancing social connectedness, affiliation, feelings of closeness, and self-other overlap (Miles et al., 2010; Mogan et al., 2017; Paladino et al., 2010; Ravreby et al., 2022; Shamay-Tsoory et al., 2019). Although we did not measure affiliation enhancement, feelings of closeness, or self-other overlap in the current study, it seems reasonable to assume that our Synchronised group likely experienced these symptoms of social connectedness, based on the reliability of these effects across previous studies (Mogan et al., 2017; Shamay-Tsoory et al., 2019) and our rigorous quantification of each dyad's movement similarity during the mirror game or movement observation task (Figure 2). Further, we ensured that our participants had never met the confederates prior to the experiment, and that all sessions were run following the same script, maximising the likelihood that any change in perceived closeness within each dyad, over the course of the session, was a direct result of the synchronising mirror-game or movement observation activity. However, it is important to consider that differences in the overall amount of movement or solo vs. joint movements might contribute to our findings (this limitation is discussed further below).

We hypothesised that a synchronised observer could improve performance on a Go/NoGo task more than a non-synchronised observer in terms of both speed and accuracy. Our data demonstrated that a synchronised observer could indeed boost accuracy, but at the cost of speed. The trade-off is small (i.e., 3.66% fewer commission errors for 18.10 ms slower responses), but greater than trade-offs previously induced using non-social rewards (Padmala & Pessoa, 2010). Padmala & Pessoa (2010) suggest that the trade-off results from non-social reward-based motivation, which incurs greater self-monitoring, much like motor synchrony. Motor synchrony also incurs both reward processing and self-monitoring (Rauchbauer et al., 2020; Shamay-Tsoory et al., 2019; M. Zimmermann et al., 2022). As such, we attribute the speed-accuracy trade-off that occurs in the presence of the synchronised audience to greater behavioural motivation, which likely stems from stronger social alignment induced by the synchronising activity (Shamay-Tsoory et al., 2019). Moreover, maintaining social alignment requires continuous monitoring for gaps in alignment (Shamay-Tsoory et al., 2019) , and this continuous process may interfere with reaction speeds, resulting in slower reaction times. In light of the slower reaction times observed in this study, we propose that maintaining social alignment may outweigh the cost of slight reductions in behavioural performance (Kampis &

Southgate, 2020). The findings from our analyses of changes in cortical oxygenation offer additional insight into the neural mechanisms supporting response inhibition under observation by a synchronised audience.

4.2 Right IFG indexes more than inhibition in presence of an audience

Inhibition of motor responses has been pinpointed to right IFG using fMRI (Aron et al., 2004; Cai et al., 2014; Chevrier et al., 2007; Gavazzi et al., 2021; Schulz et al., 2009; R. Zhang et al., 2017). fNIRS studies have more consistently measured functional responses to tasks requiring inhibitory control, such as the Go/NoGo task used here, in right PFC (Ishii et al., 2017; Kaga et al., 2020; Monden et al., 2015; Nguyen et al., 2021). This difference may be related to the coarser spatial resolution of ~2-3 cm of fNIRS, compared to 3 mm in fMRI (Goense et al., 2016; Pinti et al., 2020). As we used fNIRS, our preregistered hypothesis was that we would observe increased right PFC activity during Mixed, relative to AllGo, blocks. This expected difference did not manifest in either group (Table 2 and Figure 5), nor was this difference present in right IFG when contrasting block types. The lack of a difference does not categorically imply that right IFG and PFC are inactive during the Go/NoGo task: In fact, substantial activation is observed both right IFG and PFC during both block types for the Synchronised group, with the Control group showing activation in both right IFG and PFC for AllGo blocks, and only in right IFG for Mixed blocks.

We delved further into right IFG activation in our exploratory analyses, revealing that slower reaction times and fewer commission errors correlated with greater cortical activity in right IFG in both groups (Table 4). The slope estimates for the Synchronised, relative to Control, group were greater for both behavioural measures, suggesting that right IFG may index processes related to the presence of the audience, in concert with inhibition itself. However, additional comparisons to performance without the presence of the audience would be needed to confirm this. It is plausible that the by-products of synchrony, including increased perceived closeness and self-other overlap, may drive the stronger association between behaviour and right IFG activity, as well as the speed-accuracy trade-off. Reaction times were strongly linked with cortical activation in right IFG for both block types, while commission errors were more closely linked with right IFG activity during Mixed than AllGo blocks (i.e., greater uncertainty for the latter). However, this difference between block types is not meaningful for the Synchronised group (Table 4), meaning that the positive association between slower, more accurate, responses and right IFG activity is unlikely to index increased inhibition per se. Instead, this difference may index increased attentional mechanisms (Padmala & Pessoa, 2010; Schulz et al., 2009), self-monitoring (Parthimos et al., 2019), and/or perceived closeness (Parkinson et al., 2014) related to maintenance of social alignment with the synchronised audience (Shamay-Tsoory et al., 2019). This final possibility is consistent with emerging findings from hyperscanning research, suggesting that shared right IFG activity is indicative of inter-personal coupling within interacting dyads (Czeszumski et al., 2020; Minagawa et al., 2018).

4.3 A synchronised audience increases self-monitoring

Previous fMRI studies investigating the neural correlates of an audience’s presence report increased haemodynamic activity in the dorso-medial prefrontal cortex and striatum (Chib et al., 2018; Finger et al., 2006; Izuma et al., 2010). These regions–which lie beyond the penetration depth of fNIRS–are known to be engaged in mentalising processes (Frith & Frith, 2006) and encode social network information associated with relationship value (Krienen et al., 2010; Parkinson et al., 2017). They also support self-monitoring and motivation (Chevrier et al., 2007; van Noordt & Segalowitz, 2012; R. Zhang et al., 2017) and are the purported generators of the ‘medial frontal negativities’, electrophysiological responses indexing error monitoring and feedback integration (Ullsperger & von Cramon, 2001; van Noordt & Segalowitz, 2012). These negativities have been demonstrated to be greater when an individual is observed by a friend, as compared to a stranger (He et al., 2018; Kang et al., 2010), and when observed by peers of a similar age, relative to older peers (Ferguson et al., 2018). It is thus proposed that these electrophysiological responses index the perceived closeness between the observed individual and the audience. Kang et al. (2010) propose that self-other overlap may mediate this relationship, while Ferguson et al. (2018) posit in-group/out-group dynamics as a potential explanation. These findings from different modalities can be further enriched by Shamay-Tsoory et al.'s (2019) proposition that the ACC and medial PFC monitor for gaps in social alignment; another form of self-monitoring.

Middle, and to a lesser extent, left PFC activity and reaction times were correlated for the Synchronised group only, whereby greater activation was observed for slower response times. Dorso-medial frontal activity has previously been reported to increase under social observation, purportedly serving the functional role of regulating of behavioural motivation (Chib et al., 2018; Finger et al., 2006; Izuma et al., 2010). From this perspective, individuals in the Synchronised group who responded more slowly and accurately may have experienced a greater degree of behavioural motivation because of their motor synchrony with their audience. Alternatively, the increased middle PFC activation could index the sustained self-monitoring required to ensure continued social alignment with the synchronised audience (Shamay-Tsoory et al., 2019). Another possible explanation comes from Hester et al. (2004), who reported that individuals who responded more slowly on a Go/NoGo task showed greater midline activity and higher self-reported absent-mindedness scores. Individuals who responded more slowly may have been mildly distracted by the presence of their synchronised partner. This explanation is improbable, as we did not observe reduced accuracy as well as slower response times. Considering our findings and the proliferation of research corroborating that both an audience and motor synchrony can improve cognitive performance, we propose that the association between reaction times and middle PFC activity observed in the Synchronised group, and not the Control group, points to increased behavioural motivation and/or increased self-monitoring to maintain social alignment with the audience.

In the Control group, we observed a group-level inverted BOLD response in left IFG during Mixed blocks (Figure 5), as well as a trend wherein individuals who sacrificed accuracy for speed exhibited stronger inverted BOLD responses (Table 4). The Synchronised group showed the same association in left IFG for reaction times, but with steeper slopes, relative to the Control group, for both Mixed and AllGo blocks. Closer examination showed a greater number of inverted BOLD responses in left IFG for Mixed blocks for Control group (84.61 % of negatively-correlated HbO-HbR pairs) than for the Synchronised group (70.37 %), which were also more pronounced in the Control group (Figure 5). Padmala & Pessoa (2010) also report inverted BOLD responses in left IFG, which lessen in amplitude with the introduction of non-social reward-based motivation. From this, we interpret that social motivation induced by an observer may potentially be analogous to reward motivation and functionally reduce the amplitude of inverted BOLD responses in a similar fashion. We also observed enhancement of left IFG activity with increasing errors for the Synchronised group during AllGo blocks: This may nuance the explanation above in that perhaps the enhanced social motivation experienced by Synchronised group was lessened during the AllGo blocks but remained constant across both block types for the Control group.

4.4 Implications for clinicians and future directions

These findings suggest that synchronising activities have the potential to improve self-monitoring while inhibiting motor responses. This could be particularly beneficial for individuals who have known difficulties in response inhibition and spontaneous mirroring, which has been documented in several psychological, neurodevelopmental, and psychiatric conditions such as ADHD, social anxiety, autism, and schizophrenia (Altmann et al., 2020; Dean et al., 2021; Ramseyer & Tschacher, 2011; Reinecke et al., 2022; Wright et al., 2014). For instance, a prior synchronising activity between the clinician and patient has potential to improve supervised response inhibition. Further research undertaken in clinical setting is needed and is supported by mounting evidence that response inhibition can be improved through training (Allom et al., 2016; Hartmann et al., 2016; Meyer et al., 2020; Schroder et al., 2020). However, further research is also needed to understand the influence of a dyad's social relationship (i.e., peers, strangers, patient-clinician, parent-child) on response inhibition in the presence of an audience.

In addition to exploring the dynamics of varying social relationships, future studies should further consider including measures relating to the change in perceived closeness and self-other overlap to verify whether these factors mediate the increased attentional mechanism and self-monitoring that appear to underpin the speed-accuracy trade-off reported here. To do this, another control condition where both members of the dyad move at the same time, but not in synchrony and without temporal contingencies, could be implemented, where possible with the experimenter in another room. Ideally, the overall amount of movement would be accounted for during analysis. Together, these methodological improvements could help disentangle the effects of synchrony per se from the overall amount of movement and the experience of joint movement vs. solo movement, which may also contribute to the group-level differences observed in the present study. Moreover, future research could delve into the relationship between the degree of synchrony per dyad and Go/NoGo performance, during the task itself, as this might yield more fine-grain insight into the mechanisms through which synchrony impacts cognition.

Further insight into the network underpinnings of the speed-accuracy trade-off could also be gained from examining connectivity within frontal brain regions (Ayaz et al., 2022; Nguyen et al., 2021). The inclusion of additional brain regions in such connectivity analyses, including the temporal parietal junction, inferior parietal lobule, and premotor areas involved in maintenance of motor, and more generally, social alignment (Bardi et al., 2017; Shamay-Tsoory et al., 2019; Sowden & Catmur, 2015; Spengler et al., 2009, 2010) would also be beneficial. Moreover, concurrent recording of neural activity (i.e., hyperscanning using fNIRS) from both the observed individual engaging in response inhibition and a genuinely interested audience, such as a clinician, could also provide valuable insight into the socially-mediated cognitive processes discussed here (Hamilton, 2021; Moffat, Casale, et al., 2023; Shamay-Tsoory et al., 2019).

5 Conclusions

This study demonstrated that the presence of a synchronised peer-audience can improve accuracy on a Go/NoGo task probing inhibitory control, at the cost of reaction speed. Further, this study demonstrated that increased cortical activity in bilateral IFG and middle PFC measured using fNIRS was associated with slower reaction times and fewer errors in the presence of a synchronised partner. We propose that this relationship reflects increased self-monitoring that helps maintain social alignment.

Supplementary materials

Supplementary materials can be found in *Supplementary_materials* file.

Data and code availability

The data and all code used to run experiment, as well as the preregistration and parameters for the cleaning and analysis of the data described in this study are available at https://osf.io/87xnj/.

Declaration of competing interest

None of authors disclose any potential conflict of interest.

Credit authorship contribution statement

RM: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Roles/Writing - original draft; Writing - review & editing.

NC: Conceptualization; Writing - review & editing.

EC: Conceptualization; Resources; Supervision; Writing - review & editing.

References

Abraham, A., Pedregosa, F., Eickenberg, M., Gervais, P., Mueller, A., Kossaifi, J., Gramfort, A., Thirion, B., & Varoquaux, G. (2014). Machine learning for neuroimaging with scikit-learn. *Frontiers in Neuroinformatics*, *8*, 14. https://doi.org/10.3389/fninf.2014.00014

Allom, V., Mullan, B., & Hagger, M. (2016). Does inhibitory control training improve health behaviour? A meta-analysis. *Health Psychology Review*, *10*(2), 168–186. https://doi.org/10.1080/17437199.2015.1051078

Altmann, U., Schoenherr, D., Paulick, J., Deisenhofer, A.-K., Schwartz, B., Rubel, J. A., Stangier, U., Lutz, W., & Strauss, B. (2020). Associations between movement synchrony and outcome in patients with social anxiety disorder: Evidence for treatment specific effects. *Psychotherapy Research*, *30*(5), 574–590. https://doi.org/10.1080/10503307.2019.1630779

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, *8*(4), 170–177. https://doi.org/10.1016/j.tics.2004.02.010

Asher, M., Kauffmann, A., & Aderka, I. M. (2020). Out of sync: Nonverbal synchrony in social anxiety disorder. *Clinical Psychological Science*, *8*(2), 280–294. https://doi.org/10.1177/2167702619894566

Ayaz, H., Baker, W. B., Blaney, G., Boas, D. A., Bortfeld, H., Brady, K., Brake, J., Brigadoi, S., Buckley, E. M., Carp, S. A., Cooper, R. J., Cowdrick, K. R., Culver, J. P., Dan, I., Dehghani, H., Devor, A., Durduran, T., Eggebrecht, A. T., Emberson, L. L., … Zhou, W. (2022). Optical imaging and spectroscopy for the study of the human brain: Status report. *Neurophotonics*, *9*(S2). https://doi.org/10.1117/1.NPh.9.S2.S24001

Bardi, L., Six, P., & Brass, M. (2017). Repetitive TMS of the temporo-parietal junction disrupts participant's expectations in a spontaneous Theory of Mind task. *Social Cognitive and Affective Neuroscience*, *12*(11), 1775–1782. https://doi.org/10.1093/scan/nsx109

Barnett, M. D., Parsons, T. D., Reynolds, B. L., & Bedford, L. A. (2018). Impact of rapport on neuropsychological test performance. *Applied Neuropsychology: Adult*, *25*(3), 258–265. https://doi.org/10.1080/23279095.2017.1293671

Barnett, M. D., Sawyer, J., & Moore, J. (2022). An experimental investigation of the impact of rapport on Stroop test performance. *Applied Neuropsychology: Adult*, *29*(5), 941–945. https://doi.org/10.1080/23279095.2020.1828081

Barr, D. J. (2013). Random effects structure for testing interactions in linear mixed-effects models. *Frontiers in Psychology*, *4*(June), 3–4. https://doi.org/10.3389/fpsyg.2013.00328

Belletier, C., Davranche, K., Tellier, I. S., Dumas, F., Vidal, F., Hasbroucq, T., & Huguet, P. (2015). Choking under monitoring pressure: Being watched by the experimenter reduces executive attention. *Psychonomic Bulletin & Review*, *22*(5), 1410–1416. https://doi.org/10.3758/s13423-015-0804-9

Bernieri, F. J. (1988). Coordinated movement and rapport in teacher-student interactions. *Journal of Nonverbal Behavior*, *12*, 120–138. https://doi.org/10.1007/BF00986930

Bogdanova, O. V., Bogdanov, V. B., Dureux, A., Farnè, A., & Hadj-Bouziane, F. (2021). The peripersonal space in a social world. *Cortex*, *142*, 28–46. https://doi.org/10.1016/j.cortex.2021.05.005

Bond, C. F., & Titus, L. J. (1983). Social facilitation: A meta-analysis of 241 studies. *Psychological Bulletin*, *94*(2), 265–292. https://doi.org/10.1037/0033-2909.94.2.265

Brigadoi, S., & Cooper, R. J. (2015). How short is short? Optimum source–detector distance for short-separation channels in functional near-infrared spectroscopy. *Neurophotonics*, *2*(2), 025005. https://doi.org/10.1117/1.nph.2.2.025005

Broadwell, P., & Tangherlini, T. R. (2021). Comparative K-Pop choreography analysis through deep-learning pose estimation across a large video corpus. *Digital Humanities Quarterly*, *15*(1). http://www.digitalhumanities.org/dhq/vol/15/1/000506/000506.html

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1). https://doi.org/10.18637/jss.v080.i01

Cai, W., Ryali, S., Chen, T., Li, C.-S. R., & Menon, V. (2014). Dissociable roles of right inferior frontal cortex and anterior insula in inhibitory control: Evidence from intrinsic and task-related functional parcellation, connectivity, and response profile analyses across multiple datasets. *Journal of Neuroscience*, *34*(44), 14652–14667. https://doi.org/10.1523/JNEUROSCI.3048-14.2014

Cao, Z., Hidalgo, G., Simon, T., Wei, S.-E., & Sheikh, Y. (2019). Openpose: Realtime multi-person 2D pose estimation using part affinity fields. *arXiv:1812.08008 [Cs]*. http://arxiv.org/abs/1812.08008

Chevrier, A. D., Noseworthy, M. D., & Schachar, R. (2007). Dissociation of response inhibition and performance monitoring in the stop signal task using event-related fMRI. *Human Brain Mapping*, *28*(12), 1347–1358. https://doi.org/10.1002/hbm.20355

Chib, V. S., Adachi, R., & O'Doherty, J. P. (2018). Neural substrates of social facilitation effects on incentive-based performance. *Social Cognitive and Affective Neuroscience*, *13*(4), 391–403. https://doi.org/10.1093/scan/nsy024

Czeszumski, A., Eustergerling, S., Lang, A., Menrath, D., Gerstenberger, M., Schuberth, S., Schreiber, F., Rendon, Z. Z., & König, P. (2020). Hyperscanning: A valid method to study neural inter-brain underpinnings of social interaction. *Frontiers in Human Neuroscience*, *14*, 39. https://doi.org/10.3389/fnhum.2020.00039

Dean, D. J., Scott, J., & Park, S. (2021). Interpersonal coordination in schizophrenia: A scoping review of the literature. *Schizophrenia Bulletin*, *47*(6), 1544–1556. https://doi.org/10.1093/schbul/sbab072

Delpy, D. T., Cope, M., Van Der Zee, P., Arridge, S., Wray, S., & Wyatt, J. (1988). Estimation of optical pathlength through tissue from direct time of flight measurement. *Physics in Medicine and Biology*, *33*(12), 1433–1442. https://doi.org/10.1088/0031-9155/33/12/008

Eastvold, A. D., Belanger, H. G., & Vanderploeg, R. D. (2012). Does a third party observer affect neuropsychological test performance? It depends. *The Clinical Neuropsychologist*, *26*(3), 520–541. https://doi.org/10.1080/13854046.2012.663000

Feniger-Schaal, R., Schönherr, D., Altmann, U., & Strauss, B. (2021). Movement Synchrony in the Mirror Game. *Journal of Nonverbal Behavior*, *45*(1), 107–126. https://doi.org/10.1007/s10919-020-00341-3

Ferguson, H. J., Brunsdon, V. E. A., & Bradford, E. E. F. (2018). Age of avatar modulates the altercentric bias in a visual perspective-taking task: ERP and behavioral evidence. *Cognitive, Affective, & Behavioral Neuroscience*, *18*(6), 1298–1319. https://doi.org/10.3758/s13415-018-0641-1

Finger, E. C., Marsh, A. A., Kamel, N., Mitchell, D. G. V., & Blair, J. R. (2006). Caught in the act: The impact of audience on the neural response to morally and socially inappropriate behavior. *NeuroImage*, *33*(1), 414–421. https://doi.org/10.1016/j.neuroimage.2006.06.011

Fitzpatrick, P., Romero, V., Amaral, J. L., Duncan, A., Barnard, H., Richardson, M. J., & Schmidt, R. C. (2017). Social motor synchronization: Insights for understanding social behavior in autism. *Journal of Autism and Developmental Disorders*, *47*(7), 2092–2107. https://doi.org/10.1007/s10803-017-3124-2

Frith, C. D., & Frith, U. (2006). The neural basis of mentalizing. *Neuron*, *50*(4), 531–534. https://doi.org/10.1016/j.neuron.2006.05.001

Gagnon, L., Cooper, R. J., Yücel, M. A., Perdue, K. L., Greve, D. N., & Boas, D. A. (2012). Short separation channel location impacts the performance of short channel regression in NIRS. *NeuroImage*, *59*(3), 2518–2528. https://doi.org/10.1016/j.neuroimage.2011.08.095

Gavazzi, G., Giovannelli, F., Currò, T., Mascalchi, M., & Viggiano, M. P. (2021). Contiguity of proactive and reactive inhibitory brain areas: A cognitive model based on ALE meta-analyses. *Brain Imaging and Behavior*, *15*(4), 2199–2214. https://doi.org/10.1007/s11682-020-00369-5

Gelman, A. (2006). Prior distributions for variance parameters in hierarchical models (comment on article by Browne and Draper). *Bayesian Analysis*, *1*(3). https://doi.org/10.1214/06-BA117A

Glover, G. H. (1999). Deconvolution of impulse response in event-related BOLD fMRI. *NeuroImage*, *9*(4), 416–429. https://doi.org/10.1006/nimg.1998.0419

Goense, J., Bohraus, Y., & Logothetis, N. K. (2016). fMRI at High Spatial Resolution: Implications for BOLD-Models. *Frontiers in Computational Neuroscience*, *10*. https://doi.org/10.3389/fncom.2016.00066

Goldberg, L. (1992). The development of markers for the Big-Five factor structure. *Psychological Assessment*, *4*(1), 26–42. https://doi.org/10.1037/1040-3590.4.1.26

Gramfort, A., Luessi, M., Larson, E., Engemann, D. A., Strohmeier, D., Brodbeck, C., Goj, R., Jas, M., Brooks, T., Parkkonen, L., & Hämäläinen, M. (2013). MEG and EEG data analysis with MNE-Python. *Frontiers in Neuroscience*, *7*, 1–13. https://doi.org/10.3389/fnins.2013.00267

Guenole, N., & Chernyshenko, O. S. (2005). The suitability of Goldberg's big five IPIP personality markers in new zealand: A dimensionality, bias, and criterion validity evaluation. *New Zealand Journal of Psychology*, *34*(2), 86–96.

Hamilton, A. (2021). Hyperscanning: Beyond the hype. *Neuron*, *109*(3), 404–407. https://doi.org/10.1016/j.neuron.2020.11.008

Hamilton, A., & Lind, F. (2016). Audience effects: What can they tell us about social neuroscience, theory of mind and autism? *Culture and Brain*, *4*(2), 159–177. https://doi.org/10.1007/s40167-016-0044-5

Hartmann, L., Sallard, E., & Spierer, L. (2016). Enhancing frontal top-down inhibitory control with Go/NoGo training. *Brain Structure and Function*, *221*(7), 3835–3842. https://doi.org/10.1007/s00429-015-1131-7

He, Q., Sun, Q., Shi, Z., Zhang, X., & Hu, F. (2018). Effect of social distance on outcome evaluation in self–other decision-making: Evidence from event-related potentials. *NeuroReport*, *29*(17), 1499–1503. https://doi.org/10.1097/WNR.0000000000001141

Hester, R., Fassbender, C., & Garavan, H. (2004). Individual differences in error processing: A review and reanalysis of three event-related fmri studies using the GO/NOGO task. *Cerebral Cortex*, *14*(9), 986–994. https://doi.org/10.1093/cercor/bhh059

Huguet, P., Galvaing, M. P., Monteil, J. M., & Dumas, F. (1999). Social presence effects in the Stroop task: Further evidence for an attentional view of social facilitation. *Journal of Personality and Social Psychology*, *77*(5), 1011–1025. https://doi.org/10.1037/0022-3514.77.5.1011

Huppert, T. J. (2016). Commentary on the statistical properties of noise and its implication on general linear models in functional near-infrared spectroscopy. *Neurophotonics*, *3*(1), 010401. https://doi.org/10.1117/1.nph.3.1.010401

Ishii, S., Kaga, Y., Tando, T., Aoyagi, K., Sano, F., Kanemura, H., Sugita, K., & Aihara, M. (2017). Disinhibition in children with attention-deficit/hyperactivity disorder: Changes in [oxy-Hb] on near-infrared spectroscopy during “rock, paper, scissors” task. *Brain and Development*, *39*(5), 395–402. https://doi.org/10.1016/j.braindev.2016.12.005

Izuma, K., Saito, D. N., & Sadato, N. (2010). Processing of the incentive for social approval in the ventral striatum during charitable donation. *Journal of Cognitive Neuroscience*, *22*(4), 621–631. https://doi.org/10.1162/jocn.2009.21228

Julien, C. (2006). The enigma of Mayer waves: Facts and models. *Cardiovascular Research*, *70*(1), 12–21. https://doi.org/10.1016/j.cardiores.2005.11.008

Kaga, Y., Ueda, R., Tanaka, M., Kita, Y., Suzuki, K., Okumura, Y., Egashira, Y., Shirakawa, Y., Mitsuhashi, S., Kitamura, Y., Nakagawa, E., Yamashita, Y., & Inagaki, M. (2020). Executive dysfunction in medication-naïve children with ADHD: A multi-modal fNIRS and EEG study. *Brain and Development*, *42*(8), 555–563. https://doi.org/10.1016/j.braindev.2020.05.007

Kampis, D., & Southgate, V. (2020). Altercentric cognition: How others influence our cognitive processing. *Trends in Cognitive Sciences*, *24*(11), 945–959. https://doi.org/10.1016/j.tics.2020.09.003

Kang, S. K., Hirsh, J. B., & Chasteen, A. L. (2010). Your mistakes are mine: Self-other overlap predicts neural response to observed errors. *Journal of Experimental Social Psychology*, *46*(1), 229–232. https://doi.org/10.1016/j.jesp.2009.09.012

Kaynezhad, P., Mitra, S., Bale, G., Bauer, C., Lingam, I., Meehan, C., Avdic-Belltheus, A., Martinello, K. A., Bainbridge, A., Robertson, N. J., & Tachtsidis, I. (2019). Quantification of the severity of hypoxic-ischemic brain injury in a neonatal preclinical model using measurements of cytochrome-c-oxidase from a miniature broadband-near-infrared spectroscopy system. *Neurophotonics*, *6*(04), 1. https://doi.org/10.1117/1.NPh.6.4.045009

Keisari, S., Feniger-Schaal, R., Palgi, Y., Golland, Y., Gesser-Edelsburg, A., & Ben-David, B. (2020). Synchrony in old age: Playing the mirror game improves cognitive performance. *Clinical Gerontologist*, *45*(2), 312–326. https://doi.org/10.1080/07317115.2020.1799131

Klein, H. J., Lount, R. B., Park, H. M., & Linford, B. J. (2020). When goals are known: The effects of audience relative status on goal commitment and performance. *Journal of Applied Psychology*, *105*(4), 372–389. https://doi.org/10.1037/apl0000441

Kocsis, L., Herman, P., & Eke, A. (2006). The modified Beer-Lambert law revisited. *Physics in Medicine and Biology*, *51*(5), N91–N98. https://doi.org/10.1088/0031-9155/51/5/N02

Koehne, S., Behrends, A., Fairhurst, M. T., & Dziobek, I. (2016). Fostering social cognition through an imitation- and synchronization-based dance/movement intervention in adults with autism spectrum disorder: A controlled proof-of-concept study. *Psychotherapy and Psychosomatics*, *85*(1), 27–35. https://doi.org/10.1159/000441111

Kolyva, C., Ghosh, A., Tachtsidis, I., Highton, D., Cooper, C. E., Smith, M., & Elwell, C. E. (2014). Cytochrome c oxidase response to changes in cerebral oxygen delivery in the adult brain shows higher brain-specificity than haemoglobin. *NeuroImage*, *85*, 234–244. https://doi.org/10.1016/j.neuroimage.2013.05.070

König, N., Steber, S., Borowski, A., Bliem, H., & Rossi, S. (2021). Neural processing of cognitive control in an emotionally neutral context in anxiety patients. *Brain Sciences*, *11*(5), 543. https://doi.org/10.3390/brainsci11050543

Krienen, F. M., Tu, P.-C., & Buckner, R. L. (2010). Clan mentality: Evidence that the medial prefrontal cortex responds to close others. *Journal of Neuroscience*, *30*(41), 13906–13915. https://doi.org/10.1523/JNEUROSCI.2180-10.2010

Kruschke, J. K., & Liddell, T. M. (2018). The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychonomic Bulletin & Review*, *25*(1), 178–206. https://doi.org/10.3758/s13423-016-1221-4

Kupper, Z., Ramseyer, F., Hoffmann, H., & Tschacher, W. (2015). Nonverbal synchrony in social interactions of patients with schizophrenia indicates socio-communicative deficits. *PLOS ONE*, *10*(12), e0145882. https://doi.org/10.1371/journal.pone.0145882

Lakin, J. L., Jefferis, V. E., Cheng, C. M., & Chartrand, T. L. (2003). The chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *Journal of Nonverbal Behavior*, *27*, 145–162. https://doi.org/10.1023/A:1025389814290

Landa, R. J., Holman, K. C., O'Neill, A. H., & Stuart, E. A. (2011). Intervention targeting development of socially synchronous engagement in toddlers with autism spectrum disorder: A randomized controlled trial: RCT of social intervention for toddlers with ASD. *Journal of Child Psychology and Psychiatry*, *52*(1), 13–21. https://doi.org/10.1111/j.1469-7610.2010.02288.x

Lee, R. W. Y., Jacobson, L. A., Pritchard, A. E., Ryan, M. S., Yu, Q., Denckla, M. B., Mostofsky, S., & Mahone, E. M. (2015). Jitter Reduces Response-Time Variability in ADHD: An Ex-Gaussian Analysis. *Journal of Attention Disorders*, *19*(9), 794–804. https://doi.org/10.1177/1087054712464269

Lemoine, N. P. (2019). Moving beyond noninformative priors: Why and how to choose weakly informative priors in Bayesian analyses. *Oikos*, *128*(7), 912–928. https://doi.org/10.1111/oik.05985

Lenth, R. V. (2021). *emmeans: Estimated marginal means, aka least-squares means* [Computer software].

Luke, R., Larson, E., Shader, M. J., Innes-Brown, H., Van Yper, L., Lee, A. K. C., Sowman, P. F., & McAlpine, D. (2021). Analysis methods for measuring passive auditory fNIRS responses generated by a block-design paradigm. *Neurophotonics*, *8*(2), 025008. https://doi.org/10.1117/1.nph.8.2.025008

Luke, R., Shader, M. J., & McAlpine, D. (2021). Characterization of Mayer-wave oscillations in functional near-infrared spectroscopy using a physiologically informed model of the neural power spectra. *Neurophotonics*, *8*(04), 041001. https://doi.org/10.1117/1.NPh.8.4.041001

McElreath, R. (2020). *Statistical Rethinking; A Bayesian Course with Examples in R and Stan* (2nd Edition).

Menglu, S., Ruiwen, L., Suyong, Y., & Dong, Z. (2021). Effects of Tai Chi on the executive function and physical fitness of female methamphetamine dependents: A randomized controlled trial. *Frontiers in Psychiatry*, *12*, 653229. https://doi.org/10.3389/fpsyt.2021.653229

Meyer, K. N., Santillana, R., Miller, B., Clapp, W., Way, M., Bridgman-Goines, K., & Sheridan, M. A. (2020). Computer-based inhibitory control training in children with Attention-Deficit/Hyperactivity Disorder (ADHD): Evidence for behavioral and neural impact. *PLOS ONE*, *15*(11), e0241352. https://doi.org/10.1371/journal.pone.0241352

Miles, L. K., Nind, L. K., Henderson, Z., & Macrae, C. N. (2010). Moving memories: Behavioral synchrony and memory for self and others. *Journal of Experimental Social Psychology*, *46*(2), 457–460. https://doi.org/10.1016/j.jesp.2009.12.006

Miles, L. K., Nind, L. K., & Macrae, C. N. (2009). The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of Experimental Social Psychology*, 5.

Minagawa, Y., Xu, M., & Morimoto, S. (2018). Toward interactive social neuroscience: Neuroimaging real-world interactions in various populations. *Japanese Psychological Research*, *60*(4), 196–224. https://doi.org/10.1111/jpr.12207

Moffat, R., Başkent, D., Luke, R., McAlpine, D., & Van Yper, L. (2023). Cortical haemodynamic responses predict individual ability to recognise vocal emotions with uninformative pitch cues but do not distinguish different emotions. *Human Brain Mapping*, *44*(9), 3684–3705. https://doi.org/10.1002/hbm.26305

Moffat, R., Casale, C., & Cross, E. S. (2023). *Mobile fNIRS for exploring inter-brain synchrony across generations and time* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/3kmux

Moffat, R., & Cross, E. S. (in prep). *Awareness of embodiment maximises enjoyment and engages sensorimotor cortices*. https://osf.io/e7w4v/

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. https://doi.org/10.1016/j.jesp.2017.03.009

Monden, Y., Dan, I., Nagashima, M., Dan, H., Uga, M., Ikeda, T., Tsuzuki, D., Kyutoku, Y., Gunji, Y., Hirano, D., Taniguchi, T., Shimoizumi, H., Watanabe, E., & Yamagata, T. (2015). Individual classification of ADHD children by right prefrontal hemodynamic responses during a go/no-go task as assessed by fNIRS. *NeuroImage: Clinical*, *9*, 1–12. https://doi.org/10.1016/j.nicl.2015.06.011

Morris, P., Hope, E., Foulsham, T., & Mills, J. P. (2021). The effectiveness of mirroring- and rhythm-based interventions for children with autism spectrum disorder: A systematic review. *Review Journal of Autism and Developmental Disorders*, *8*(4), 541–561. https://doi.org/10.1007/s40489-021-00236-z

Nahardiya, G., Markus, A., Bennet, R., & Shamay-Tsoory, S. G. (2022). The benefits of learning movement sequences in social interactions. *Frontiers in Psychology*, *13*, 901900. https://doi.org/10.3389/fpsyg.2022.901900

National Institute of Mental Health. (2017). *An Experimental Therapeutic Approach to Psychosocial Interventions*. National Institute of Mental Health (NIMH). https://www.nimh.nih.gov/about/director/messages/2017/an-experimental-therapeutic-approach-to-psychosocial-interventions

Nguyen, T., Condy, E. E., Park, S., Friedman, B. H., & Gandjbakhche, A. (2021). Comparison of functional connectivity in the prefrontal cortex during a simple and an emotional go/no-go task in female versus male groups: An fnirs study. *Brain Sciences*, *11*(7), 909. https://doi.org/10.3390/brainsci11070909

Padmala, S., & Pessoa, L. (2010). Interactions between cognition and motivation during response inhibition. *Neuropsychologia*, *48*(2), 558–565. https://doi.org/10.1016/j.neuropsychologia.2009.10.017

Paladino, M.-P., Mazzurega, M., Pavani, F., & Schubert, T. W. (2010). Synchronous multisensory stimulation blurs self-other boundaries. *Psychological Science*, *21*(9), 1202–1207. https://doi.org/10.1177/0956797610379234

Parkinson, C., Kleinbaum, A. M., & Wheatley, T. (2017). Spontaneous neural encoding of social network position. *Nature Human Behaviour*, *1*(5), 0072. https://doi.org/10.1038/s41562-017-0072

Parkinson, C., Liu, S., & Wheatley, T. (2014). A common cortical metric for spatial, temporal, and social distance. *Journal of Neuroscience*, *34*(5), 1979–1987. https://doi.org/10.1523/JNEUROSCI.2159-13.2014

Pärnamets, P., Espinosa, L., & Olsson, A. (2020). Physiological synchrony predicts observational threat learning in humans. *Proceedings of the Royal Society B: Biological Sciences*, *287*, 20192779. https://doi.org/10.1098/rspb.2019.2779

Parthimos, T. P., Karavasilis, E., Rankin, K. P., Seimenis, I., Leftherioti, K., Papanicolaou, A. C., Miller, B., Papageorgiou, S. G., & Papatriantafyllou, J. D. (2019). The neural correlates of impaired self-monitoring among individuals with neurodegenerative dementias. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *31*(3), 201–209. https://doi.org/10.1176/appi.neuropsych.17120349

Peirce, J. W., Hirst, R. J., & MacAskill, M. R. (2022). *Building Experiments in PsychoPy* (2nd ed.). Sage. https://uk.sagepub.com/en-gb/eur/building-experiments-in-psychopy/book273700

Pinti, P., Tachtsidis, I., Hamilton, A., Hirsch, J., Aichelburg, C., Gilbert, S., & Burgess, P. W. (2020). The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience. *Annals of the New York Academy of Sciences*, *1464*, 5–29. https://doi.org/10.1111/nyas.13948

R Core Team. (2022). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. http://www.r-project.org/

Ramseyer, F., & Tschacher, W. (2011). Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology*, *79*(3), 284–295. https://doi.org/10.1037/a0023419

Rauchbauer, B., Dunbar, R. I. M., & Lamm, C. (2020). Being mimicked affects inhibitory mechanisms of imitation. *Acta Psychologica*, *209*, 103132. https://doi.org/10.1016/j.actpsy.2020.103132

Rauchbauer, B., & Grosbras, M.-H. (2020). Developmental trajectory of interpersonal motor alignment: Positive social effects and link to social cognition. *Neuroscience & Biobehavioral Reviews*, *118*, 411–425. https://doi.org/10.1016/j.neubiorev.2020.07.032

Ravreby, I., Shilat, Y., & Yeshurun, Y. (2022). Liking as a balance between synchronization, complexity and novelty. *Scientific Reports*, *12*(1), 3181. https://doi.org/10.1038/s41598-022-06610-z

Reinecke, K. C. H., Joraschky, P., & Lausberg, H. (2022). Hand movements that change during psychotherapy and their relation to therapeutic outcome: An analysis of individual and simultaneous movements. *Psychotherapy Research*, *32*(1), 104–114. https://doi.org/10.1080/10503307.2021.1925989

Rennung, M., & Göritz, A. S. (2016). Prosocial consequences of interpersonal synchrony: A meta-analysis. *Zeitschrift Für Psychologie*, *224*(3), 168. https://doi.org/10.1027/2151-2604/a000252

Rolls, E. T., Joliot, M., & Tzourio-Mazoyer, N. (2015). Implementation of a new parcellation of the orbitofrontal cortex in the automated anatomical labeling atlas. *NeuroImage*, *122*, 1–5. https://doi.org/10.1016/j.neuroimage.2015.07.075

Rosenberg, M. (1965). *Society and the adolescent self-image*. Princeton University Press.

RStudio Team. (2020). *RStudio: Integrated Development for R* [Computer software]. RStudio, Inc. http://www.rstudio.com/

Santosa, H., Huppert, T. J., Fishburn, F., & Zhai, X. (2019). Investigation of the sensitivity-specificity of canonical- and deconvolution-based linear models in evoked functional near-infrared spectroscopy. *Neurophotonics*, *6*(2), 1–10. https://doi.org/10.1117/1.NPh.6.2.025009

Santosa, H., Zhai, X., Fishburn, F., & Huppert, T. J. (2018). The NIRS Brain AnalyzIR Toolbox. *Algorithms*, *11*(5), 73. https://doi.org/10.3390/a11050073

Schroder, E., Dubuson, M., Dousset, C., Mortier, E., Kornreich, C., & Campanella, S. (2020). Training inhibitory control induced robust neural changes when behavior is affected: A follow-up study using cognitive event-related potentials. *Clinical EEG and Neuroscience*, *51*(5), 303–316. https://doi.org/10.1177/1550059419895146

Schulz, K. P., Clerkin, S. M., Halperin, J. M., Newcorn, J. H., Tang, C. Y., & Fan, J. (2009). Dissociable neural effects of stimulus valence and preceding context during the inhibition of responses to emotional faces. *Human Brain Mapping*, *30*(9), 2821–2833. https://doi.org/10.1002/hbm.20706

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences*, *10*(2), 70–76. https://doi.org/10.1016/j.tics.2005.12.009

Shamay-Tsoory, S. G., Saporta, N., Marton-Alper, I. Z., & Gvirts, H. Z. (2019). Herding brains: A core neural mechanism for social alignment. *Trends in Cognitive Sciences*, *23*(3), 174–186. https://doi.org/10.1016/j.tics.2019.01.002

Sharon-David, H., Mizrahi, M., Rinott, M., Golland, Y., & Birnbaum, G. E. (2019). Being on the same wavelength: Behavioral synchrony between partners and its influence on the experience of intimacy. *Journal of Social and Personal Relationships*, *36*(10), 2983–3008. https://doi.org/10.1177/0265407518809478

signal developers. (2014). *signal: Signal processing* [Computer software]. http://r-forge.r-project.org/projects/signal/

Sinclair, S. J., Blais, M. A., Gansler, D. A., Sandberg, E., Bistis, K., & LoCicero, A. (2010). Psychometric Properties of the Rosenberg Self-Esteem Scale: Overall and Across Demographic Groups Living Within the United States. *Evaluation & the Health Professions*, *33*(1), 56–80. https://doi.org/10.1177/0163278709356187

Somerville, L. H., Jones, R. M., Ruberry, E. J., Dyke, J. P., Glover, G., & Casey, B. J. (2013). The Medial Prefrontal Cortex and the Emergence of Self-Conscious Emotion in Adolescence. *Psychological Science*, *24*(8), 1554–1562. https://doi.org/10.1177/0956797613475633

Sowden, S., & Catmur, C. (2015). The role of the right temporoparietal junction in the control of imitation. *Cerebral Cortex*, *25*(4), 1107–1113. https://doi.org/10.1093/cercor/bht306

Spengler, S., Brass, M., Kühn, S., & Schütz-Bosbach, S. (2010). Minimizing motor mimicry by myself: Self-focus enhances online action-control mechanisms during motor contagion. *Consciousness and Cognition*, *19*(1), 98–106. https://doi.org/10.1016/j.concog.2009.12.014

Spengler, S., von Cramon, D. Y., & Brass, M. (2009). Control of shared representations relies on key processes involved in mental state attribution. *Human Brain Mapping*, *30*(11), 3704–3718. https://doi.org/10.1002/hbm.20800

Srinivasan, S. M., Kaur, M., Park, I. K., Gifford, T. D., Marsh, K. L., & Bhat, A. N. (2015). The Effects of Rhythm and Robotic Interventions on the Imitation/Praxis, Interpersonal Synchrony, and Motor Performance of Children with Autism Spectrum Disorder (ASD): A Pilot Randomized Controlled Trial. *Autism Research and Treatment*, *2015*, 1–18. https://doi.org/10.1155/2015/736516

Strangman, G. E., Franceschini, M. A., & Boas, D. A. (2003). Factors affecting the accuracy of near-infrared spectroscopy concentration calculations for focal changes in oxygenation parameters. *NeuroImage*, *18*(4), 865–879. https://doi.org/10.1016/S1053-8119(03)00021-1

Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Mazoyer, B., & Joliot, M. (2002). Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. *NeuroImage*, *15*(1), 273–289. https://doi.org/10.1006/nimg.2001.0978

Ullsperger, M., & von Cramon, D. Y. (2001). Subprocesses of performance monitoring: A dissociation of error processing and response competition revealed by event-related fMRI and ERPs. *NeuroImage*, *14*(6), 1387–1401. https://doi.org/10.1006/nimg.2001.0935

Uziel, L. (2007). Individual differences in the social facilitation effect: A review and meta-analysis. *Journal of Research in Personality*, *41*(3), 579–601. https://doi.org/10.1016/j.jrp.2006.06.008

van Noordt, S. J. R., & Segalowitz, S. J. (2012). Performance monitoring and the medial prefrontal cortex: A review of individual differences and context effects as a window on self-regulation. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00197

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, *27*(5), 1413–1432. https://doi.org/10.1007/s11222-016-9696-4

Vicaria, I. M., & Dickens, L. (2016). Meta-analyses of the intra- and interpersonal outcomes of interpersonal coordination. *Journal of Nonverbal Behavior*, *40*(4), 335–361. https://doi.org/10.1007/s10919-016-0238-8

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology*, *55*(3), e12871. https://doi.org/10.1111/psyp.12871

Wodka, E. L., Simmonds, D. J., Mahone, E. M., & Mostofsky, S. H. (2009). Moderate variability in stimulus presentation improves motor response control. *Journal of Clinical and Experimental Neuropsychology*, *31*(4), 483–488. https://doi.org/10.1080/13803390802272036

Wolf, M., Wolf, U., Toronov, V., Michalos, A., Paunescu, L. A., Choi, J. H., & Gratton, E. (2002). Different time evolution of oxyhemoglobin and deoxyhemoglobin concentration changes in the visual and motor cortices during functional stimulation: A near-infrared spectroscopy study. *NeuroImage*, *16*(3), 704–712. https://doi.org/10.1006/nimg.2002.1128

Wright, L., Lipszyc, J., Dupuis, A., Thayapararajah, S. W., & Schachar, R. (2014). Response inhibition and psychopathology: A meta-analysis of go/no-go task performance. *Journal of Abnormal Psychology*, *123*(2), 429–439. https://doi.org/10.1037/a0036295

Yang, Y., Chen, T., Shao, M., Yan, S., Yue, G. H., & Jiang, C. (2020). Effects of Tai Chi Chuan on inhibitory control in elderly women: An fNIRS study. *Frontiers in Human Neuroscience*, *13*, 476. https://doi.org/10.3389/fnhum.2019.00476

Young, M. E., Sutherland, S. C., & McCoy, A. W. (2018). Optimal go/no-go ratios to maximize false alarms. *Behavior Research Methods*, *50*(3), 1020–1029. https://doi.org/10.3758/s13428-017-0923-5

Yücel, M. A., Lühmann, A. v., Scholkmann, F., Gervain, J., Dan, I., Ayaz, H., Boas, D., Cooper, R. J., Culver, J., Elwell, C. E., Eggebrecht, A., Franceschini, M. A., Grova, C., Homae, F., Lesage, F., Obrig, H., Tachtsidis, I., Tak, S., Tong, Y., … Wolf, M. (2021). Best practices for fNIRS publications. *Neurophotonics*, *8*(1), 1–34. https://doi.org/10.1117/1.nph.8.1.012101

Zhang, R., Geng, X., & Lee, T. M. C. (2017). Large-scale functional neural network correlates of response inhibition: An fMRI meta-analysis. *Brain Structure and Function*, *222*(9), 3973–3990. https://doi.org/10.1007/s00429-017-1443-x

Zhang, Y., Tan, F., Xu, X., Duan, L., Liu, H., Tian, F., & Zhu, C.-Z. (2015). Multiregional functional near-infrared spectroscopy reveals globally symmetrical and frequency-specific patterns of superficial interference. *Biomedical Optics Express*, *6*(8), 2786. https://doi.org/10.1364/boe.6.002786

Zimeo Morais, G. A., Balardin, J. B., & Sato, J. R. (2018). FNIRS Optodes' Location Decider (fOLD): A toolbox for probe arrangement guided by brain regions-of-interest. *Scientific Reports*, *8*, 1–11. https://doi.org/10.1038/s41598-018-21716-z

Zimeo Morais, G. A., Scholkmann, F., Balardin, J. B., Furucho, R. A., de Paula, R. C. V., Biazoli, C. E., & Sato, J. R. (2017). Non-neuronal evoked and spontaneous hemodynamic changes in the anterior temporal region of the human head may lead to misinterpretations of functional near-infrared spectroscopy signals. *Neurophotonics*, *5*(01), 1. https://doi.org/10.1117/1.NPh.5.1.011002

Zimmermann, M., Lomoriello, A. S., & Konvalinka, I. (2022). Intra-individual behavioural and neural signatures of audience effects and interactions in a mirror-game paradigm. *Royal Society Open Science*, *9*(2), 211352. https://doi.org/10.1098/rsos.211352

Zimmermann, R., Fürer, L., Kleinbub, J. R., Ramseyer, F. T., Hütten, R., Steppan, M., & Schmeck, K. (2021). Movement synchrony in the psychotherapy of adolescents with borderline personality pathology – A dyadic trait marker for resilience? *Frontiers in Psychology*, *12*, 660516. https://doi.org/10.3389/fpsyg.2021.660516