Exploring agency and self-other processing: an FMRI study of dynamic cooperation using an adaptively paced finger tapping task with variable auditory feedback

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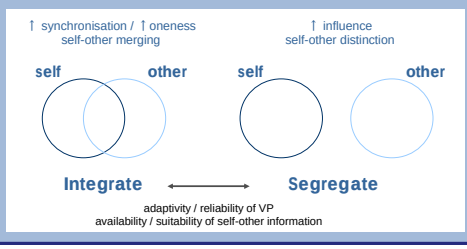
Introduction

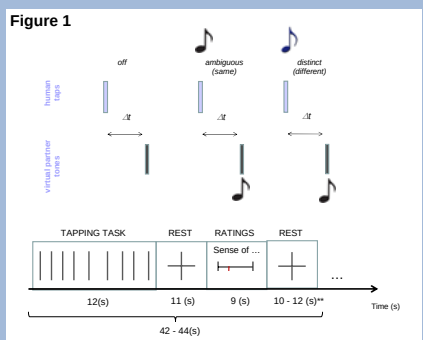
Ensemble musicians must be flexible and learn to adapt their performance to that of their partners and do so appropriately based on available sensory information streams. To further describe this type of dynamic joint action, we present a functional MRI study of sensorimotor synchronization with an adaptive "virtual partner" (VP). In particular, we investigate the behavioural and neural effects of variable auditory feedback associated with finger tapping performance across varying degrees of VP adaptivity (α). We predict that auditory feedback will bias the system to either i) integrate or ii) segregate information regarding "self" or the VP ("other").



Methods

Sixteen healthy, right handed individuals with finger tapping experience participated in an FMRI study. Subjects were instructed to i) tap in synchrony with the VP and ii) maintain tempo. The pacing signal was programmed to maintain the overall pulse while still adapting its timing to reduce asynchronies between human taps and computer tones. The degree of VP adaptivity varied across three conditions of phase (α) correction (non-adaptive α=0, minimally adaptive α=0.25 and completely adaptive α=1). Based on previous work using this paradigm, we posit that individuals will prioritize either (i) the interaction/synchronization task, reliant on integrating self and other information or (ii) maintenance of the tempo based on his/her internal time keeper (autonomy). To test this further we manipulate auditory feedback providing more or less useful information to distinguish self from other temporally. Participants' tapping either produced no tone (off), the same tone as the VP (ambiguous) or a different tone (distinct) (Figure 1). Using trial-by-trial visual analogue scale (VAS) ratings we further explore the manipulation's effect on perceived agency ("influence") and perceived "oneness".

Figure 1

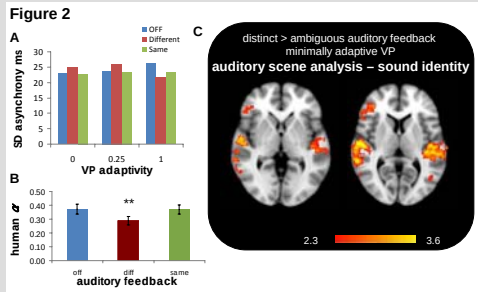


Study design. Each block started with two isochronous 50 ms pacing tones (inter-onset interval of 500 ms). With the third tone, subjects were instructed to tap in synchrony with the then variably adaptive pacing signal and received three types of auditory feedback (off, ambiguous-same as VP tones, or distinct-different to VP tones) After each task block of 22 tone/tap pairs, subjective ratings of "influence over the pulse", "oneness" and "difficulty" were acquired using a visual analogue scale (VAS).

Results

Behavioural tapping data show a significant interaction effect of auditory feedback and VP adaptivity on task performance such that distinctive ("different") self-other auditory information results in improvements in synchronization relative to both "off" and ambiguous "same" conditions, especially at higher levels of α (Fig. 1A). An estimation of human $_{\alpha}$ reveals that both the "off" and "same" auditory conditions show higher levels of employed error correction (Fig. 1B). Comparing behavioural effects of distinct or ambiguous feedback, when the VP is minimally adaptive, distinct self information produces marginally significant improvements in task performance. At a neural level, this same comparison reveals differences in activity in both the ventrolateral prefrontal cortex and auditory cortex (Fig. 1C).

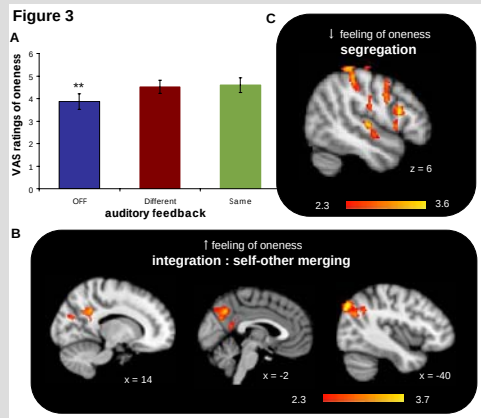
Figure 2



Effect of auditory feedback. A) Performance in a synchronized tapping task as a function of SD of asynchronies between pacing signal tones and participant taps (low SD Asynchrony = high performance) across three conditions of variable VP adaptivity and three conditions of auditory feedback, blue – off, red – different and green – same. B) Estimate of human $_{\alpha}$ (implemented error correction) per condition of auditory feedback. C) Group mean activation map (mixed effects, p<0.05) contrasting tapping with a minimally adaptive VP with either distinct or ambiguous auditory feedback.

Trial-by-trial VAS ratings show that in tapping blocks where greater synchronization was achieved (low SD asynchrony), individuals expressed greater perceived oneness. These oneness ratings grouped by condition of auditory feedback highlight a significant difference in perceived oneness between auditory feedback on and "off" conditions at α=0.25 (Fig. 3A). Contrasting imaging data at this level of VP α and covariance with greater perceived oneness, we identify midline activity in the precuneus and posterior cingulate (Fig. 3B). A reverse contrast reveals that less perceived oneness correlates with activation of a primarily right lateralized pattern of activity in areas including the inferior and superior frontal gyri (Fig. 3C). Interestingly at higher levels of VP α, oneness in the "same" condition is rated significantly lower suggesting that some differences or degree of autonomy between self and other must exist to feel part of a whole

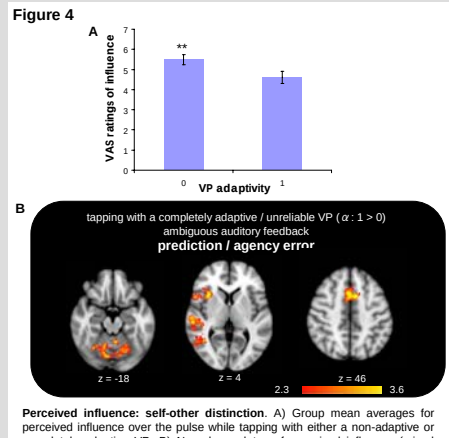
Figure 3



Perceived oneness: self-other merging. A) Group mean subjective ratings of perceived oneness when tapping with a minimally adaptive VP by condition of auditory feedback. Correlated neural activity (group mean: mixed effects, p<0.05) with B) greater perceived oneness and C) less feeling of oneness (reverse contrast) across auditory feedback conditions.

To explore self-other distinction, we acquired ratings of influence: an assessment which we posit requires an increased awareness of self as distinct from other. Overall our data show a significant effect of adaptivity but no significant effect of auditory feedback on influence ratings. However in the condition where individuals tapped with a completely adaptive VP (as compared to a non-adaptive VP) receiving "same" auditory feedback, we see not only less oneness (or "noneness") but also less perceived influence (p<0.05) (Fig. 4A) despite objectively cooperating with a more adaptive partner. We suggest that, with greater adaptivity comes greater variance and therefore perhaps greater ambiguity when predicting and assessing who tapped when – an effect heightened by ambiguous auditory feedback. As such an assessment of self influence is more difficult at high degrees of VP α. When contrasting the imaging data from these conditions we identify regions including the cerebellum, SMA, anterior insula and IFG (Fig. 4B). Together these areas have been associated with sensory prediction and agency error.

Figure 4



Perceived influence: self-other distinction. A) Group mean averages for perceived influence over the pulse while tapping with either a non-adaptive or completely adaptive VP. B) Neural correlates of perceived influence (mixed effects, Z = 2.3; p = 0.05)

Discussion

The present data suggest that depending on the level of VP α, auditory feedback can facilitate the integration or segregation processes necessary to synchronise. Our results show that across levels of VP adaptivity but especially at α=1, *different* self information enhances self-other distinction which may explain relative improvements in task performance. Based on the estimate of human $_{\alpha}$, we posit that less error may be being made and therefore less must be corrected in the "different" condition. Imaging data of distinct vs. ambiguous conditions shows that greater segregation results in greater activity in areas implicated in sound identity and auditory scene analysis. We see that integration, necessary for synchronization and correlated with oneness ratings, produces activation of midline structures involved in integration of external and self generated information and therefore perhaps greater self-other merging. By contrast, both a reverse oneness contrast and a subtraction of distinct>ambiguous reveal a more lateralised pattern of activation in areas related to self-other distinction necessary for agency processing. Additionally or alternatively, the influence analysis suggests these areas may be involved in agency error, in this case as a result of ambiguous feedback.

References:

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