The Collective Mind: An Experimental Analysis of Imitation and Self-organization in Humans

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MASTER OF SCIENCE

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Abstract

I present an experimental paradigm to explore the interpersonal dynamics generating a collective mind. I hypothesized that collective organization among humans is based on dual interpersonal modes: (1) symmetrical and (2) anti-symmetrical. I specified these modes by detecting spatiotemporal patterns that embed cooperative agents in a three-dimensional (invariant) matrix. Within this spatiotemporal matrix, I found that the symmetrical mode is executed automatically and without guidance. Conversely, the anti-symmetrical mode required explicit direction and recruited attention for execution. I demonstrate that interpersonal symmetry stabilized group dynamics, enabled fast and efficient imitation that optimized information transmission, whereas anti-symmetrical imitation was comparatively slow, inefficient, and unstable. I determined that the anti-symmetrical mode spontaneously transitioned to the symmetrical mode under perturbations. Crucially, this renormalizing behaviour never transitioned from symmetrical to anti-symmetrical. This self-organizing group mechanism speaks to symmetry-breaking in cooperation dynamics. In the present work, spontaneous group choice mandated that agents align action-perception cycles in symmetrical space under internal or external perturbations. I provide examples to illustrate that this group behaviour manifests in invertebrates and vertebrates alike. I conclude by suggesting that inter-agent symmetry provides the social stability in which attention driven interactions enable intrapersonal and interpersonal change. Future researchers may employ the methods I provide here to explore the emergent brain activity that gives rise to interpersonal symmetry-breaking and renormalization. Research in this area may offer insight into the patterns of neural activity (i.e., intrapersonal dynamics) that predict interpersonal symmetry-breaking, thus enabling the analysis of the neurological mechanisms underlying collective organization and social cognition.
Chapter 1

The Collective Mind

General Introduction

The processes by which individuals cooperate is the focus of my thesis. In particular, my investigations provide evidence that cooperating individuals are comparable to a living system capable of information processing and generating automatic responses when perturbed. These system dynamics rely on coordination between self and others to maintain the perceptual architecture that underlies interconnected brains across space and time. I propose that these interconnections enable the nervous system to integrate the observer and the observed by encoding interpersonal symmetries that facilitate prosocial responsivity. With these underpinnings, I experimentally demonstrate that spatially symmetrical associative links between individuals are at the core of fast and efficient cooperation. In other words, the perceptual interconnectedness that enables cooperative activity requires individuals to represent a shared model based on symmetrical alignments between the observer and the observed. I suggest that these mirror-symmetries function as the underpinning of a stable collective whose dynamic structure enables perceptions about the self to emerge from cooperative interactions with others.

The implication here is that perceptual stability about self develops through exchanges with topographically symmetrical others. My experimental findings support this view by providing evidence demonstrating cooperation relies on mirror-reflected associations that maximize the spatiotemporal correspondence between individuals while concurrently optimizing information processing. To examine these dynamics, I employ the synergetics approach (Haken, 1983) to discern the mirror-symmetrical features of cooperative imitation, which in this context denotes the spatiotemporal correlations overlapping the observer and the observed. In the present
research, I specify this system’s cooperative structure by orienting dyads face-to-face and measuring the temporal responses generated during spatially-symmetrical exchanges. To demonstrate that these spatial symmetries underlie both fast and efficient cooperative dynamics, I present an experimental framework that utilizes mirrored reference frames to investigate symmetrical interaction effects on information processing and transmission during cooperative imitation.

To accomplish the above, I draw on the Markov blanket formalism (Kirchhoff et al., 2018) of the variational free-energy principle (Friston, 2012) to describe the stable-state architecture of coupled human brains embedded within a collective matrix (Badcock et al., 2019; Veissière et al., 2020). I leverage this description to test the hypothesis that imitation encodes a collective (generative) model through regulation of perception-action cycles via cooperation (Ashby, 1947; Haken, 1983; Heyes, 2018; Tschacher & Haken, 2007; Kelso, 2009). In systems neuroscience and statistical physics, theoretical and experimental works that conform to these behavioural postulates reveal that order at higher (group) scales are formed based on coordination at lower (individual) scales (Hesse & Gross, 2014; Keslo, 2009). This multiscale organization's maintenance relies on spatiotemporal connectivity to align scale-invariant dynamics at criticality (Bak et al., 1988). Criticality is an emergent property of self-organizing systems that undergo phase transitions and spontaneous realignment when perturbed (Bak et al., 1987; Bak et al., 1988; Haken et al., 1985; Kelso, 1984). My experiments evaluate these scale-invariant dynamics via the analysis of cognitive demand induced perceptual symmetry-breaking (Bak et al., 1987; Ovchinnikov, 2016) during cooperative imitation (Heyes, 2011; Heyes, 2018; Kelso, 2009; Tschacher & Haken, 2007). Here, I task research subjects to engage in face-to-face bilateral coordination. This mirror-symmetrical reference frame enables
the investigation of perceptual (phase) transitions (Friston et al., 2012) and group
renormalization (Schwabl, 2002) during perturbations. Ultimately, this experimental approach
demonstrates that cooperative imitation induces a collective matrix in which individuals bind
perceptually through spatiotemporal symmetries that generate a shared model of
interpersonal expectations.

The remainder of this introduction comprises three sections; the first articulates the
Markov blanket formalism conveyed through the variational free-energy principle and its
corollary, active inference. This explanatory framework provides a formal description of the
non-equilibrium steady-state dynamics of coupled brains that jointly exploit Bayesian mechanics
to self-organize through the assembly of a collective matrix. In the second section, synergetics
and imitation are applied to this network structure to specify the spatiotemporal associations that
influence macroscopic (group) controls of microscopic (individual) coordination. Here, the
spatiotemporal alignments that connect self to others during action-perception cycles are
specified conceptually. The final section employs these specifications to frame an experimental
design that leverages the physics and geometry of collective motion to test interpersonal
symmetry and group renormalization during cooperative imitation. In summary, these sections
reveal the psychophysical architecture in which self-other integration across spatiotemporal
scales gives rise to a collective mind generating interpersonal matrices.

**Markov Blankets of a Collective Mind**

A Markov Blanket (Kirchhoff et al., 2018) permits one to distinguish the internal states of a
living organism from the external states surrounding it in a statistical sense. This separation
presumes conditional independence between the internal and external states, where the Markov
blanket itself comprises active and sensory states. The blanket states follow a partitioning rule,
whereby internal states influence external states via active states and external states influence internal states via sensory states. This partitioning enables the internal and external states to couple reciprocally via recursive sensory and active state dynamics. Consequently, these demarcation rules permit assessment of the spatiotemporal coupling between blanketed internal states at multiple scales of biological organization (Palacios et al., 2020). This self-organizing structure suggests a Markov blanket induces a partition in which multidimensional experimentation can capture the spatiotemporal conditional dependencies encoding coupled brain dynamics by examining sensorimotor integration during collective interactions.

The description above proposes that a collective self-organizes across spatiotemporal scales via coupling conditioned on sensorimotor integration. This proposition allows one to exploit the variational free-energy principle (Friston, 2012) to identify the steady-state sensorimotor dynamics that guide collective motion at the group and individual scales. The free-energy principle provides a formal description of the expected behaviours that maintain an organism’s order across space and time. This formulation casts organisms as multiscale statistical objects that counter entropic dispersion by limiting the states that they occupy across their lifespan. In this permutation, free-energy embodies an information-theoretic quantity conceptually termed surprise (Bialek et al., 2001; Friston, 2010; Shannon, 1948). Surprise measures how unexpected a sensory state is given expectations about sensory data. The implication here is that interconnected brains cannot estimate surprise directly because doing so would require access to every possible cause of sensory input. However, given a generative model of interpersonal expectations, brains and their blanket states can evaluate variational free-energy by jointly approximating surprise, a hidden quantity, whose joint estimation refines interpersonal action-perception cycles. Crucially, by mathematical construction, free-energy is
always greater than surprise, which means coupled brains that work together to minimize free-energy concurrently minimize the surprise associated with interpersonal interactions. This multiscale interpersonal dynamic exposes the causal form in which a collective organism generates and maintains itself (Friston, 2012; Kelso, 2009). It demonstrates that collective self-organization emerges from cooperative processes built upon coupled brains that actively reduce an upper bound on surprise by jointly minimizing free-energy.

The machinery of Markov Blankets allows the implementation of active inferential dynamics (i.e., action-perception cycles) to identify the psychophysics of this collective behaviour, which involves interpersonal finessing of perceptual (or internal state) approximations to surprise through coordinated actions. Underpinning this behavioural capacity is a Bayesian optimization scheme (Knill & Pouget, 2004) encoding a generative model from which active inference operates to minimize free-energy (Friston, 2009). In this context, log model evidence and negative free-energy are equivalent quantities, which means minimizing the surprise induced by sensory input entails optimizing self-information through prediction error minimization (i.e., self-evidencing) (Hohwy, 2014). Thus, the existence of a mind operationally defined in terms of a multiscale network of interconnected nervous systems means a causal form (i.e., a collective matrix) is realized by cooperation via prediction error minimizing interpersonal exchanges.

**Synergetic imitation and the matrix of minds**

Parameterizing a collective matrix requires the experimental manipulation of a group's spatiotemporal symmetries to identify the multiscale coupling dynamics between interconnected brains during interpersonal perceptual transitions and bilateral coordination at criticality. As I mentioned above, systems at criticality are characterized by non-equilibrium steady-state
dynamics that impose spatiotemporal order on higher (group) scales via behavioural integration at lower (individual) scales (Bak et al., 1988; Hesse & Gross, 2014). These integrative processes rely on scale-invariant associations to maintain the whole system's multiscale (Bayes-optimal) form at low entropy (or free-energy minima) across spatiotemporal scales. Given this view, the scale-invariant dynamics that integrate sensorimotor cycles enable the multiscale analysis of spontaneous symmetry-breaking during perceptual (phase) transitions involving cooperative bilateral action-selection. In terms of psychophysical relations, this perspective suggests that scale-invariant alignments organize humans such that their multiscale sensorimotor symmetries exhibit system-wide optimal memory and information processing capacities. This multiscale self-organizing form encodes interconnected brains with response sensitivity to sensory data that elicit reciprocal prediction error minimizing cycles that induce spontaneous coalignment under sensory perturbations. These behavioural mechanics automatically optimize the perceptual patterns that generate and maintain a collective model comprising expectations about self-other interrelations.

Exploring the self-other correlations encoding a collective model of interpersonal expectations necessitates the analysis of imitation. The leading theory of imitation offers the associative sequence learning (ASL) model, which provides a framework to parameterize the spatiotemporal associations integrating self and others (Catmur et al., 2009). The ASL model proposes a mechanistic account of the interpersonal capacity to “connect the felt but unseen movements of the self with the seen but unfelt movements of the other” (Meltzoff & Moore, 1997: 179). The ASL model claims that the nervous system acquires this inferential capacity through matching vertical associations (see Figure 1) that link a sensory representation of an observed action to a motor representation of the same action (Catmur et al., 2016; Catmur et al.,
Excitation of either representation is bidirectional, which means activation of one increases the other's probability of activation. The key here is that excitatory links between matching vertical associations increase the probability of bidirectional activation and subsequent imitation. The history of interpersonal contingencies defined in terms of contiguous sensorimotor experience determines the resulting imitative form. In other words, matching vertical associations are encoded primarily through social learning (Tunçgenç & Cohen, 2016; Wiltermuth & Heath, 2009), via enculturation (Hove & Risen, 2009; Tarr et al., 2015) and are activated during interpersonal sensorimotor exchanges (Heyes, 2011). This means the execution of imitative behaviour possesses a causal directionality that flows from sensory to motor experience. This experiential trajectory exists because human brains must predict others' actions before imitation can unfold. Therefore, imitation must align the associative links between sensory and motor representations by establishing an interpersonal matrix that underpins an observer’s capacity to perform observed actions (Heyes, 2011). This behavioural patterning suggests that matching (interpersonal) associations guide observational learning during the sensorimotor integration of observer and observed (Heyes, 2018). This organizational architecture mandates perceptual and motor sequence learning to work concurrently to encode a model comprising self-other associative interplay. Consequently, the mechanisms that operate on imitation are context dependent (Cook et al., 2012) and modifiable through sensorimotor learning that varies with contingency (Cook et al., 2010; Cooper et al., 2013). In light of this view, it is reasonable to hypothesize that imitation enables cooperative dynamics by maintaining scale-invariant connectivity generating a collective model built upon matching topographical symmetries (i.e., a shared neural encoding based on geometric self-similarities).
Figure 1. “Matching vertical associations are acquired through sensorimotor learning. In the simplest case, self-observation (a), activation of a motor representation contributes to performance of an action (e.g., flattening the hand; dotted arrow), and observation of the performed action produces correlated activation of a corresponding visual representation (dashed arrow). Correlated activation strengthens the excitatory link between the sensory and motor representations, establishing a matching vertical association (solid vertical line). Optical mirrors (b), being imitated by others (c), and synchronous activities (d) provide correlated sensorimotor experience for perceptually opaque actions, such as facial gestures and whole-body movements” (Heyes, 2018: 123). Reproduced with permission from Heyes (2018).

As expressed above, there is a considerable body of evidence suggesting that motor and perceptual sequence learning work concurrently to develop the capacity to imitate. Research indicates imitation arises from social learning processes that encode motor representations of observed actions (Heyes, 2018). These representations spatially overlap the observer and the observed, enabling the nervous system to link the topographical similarity between self and
others. Functional Magnetic Resonance Imaging (fMRI) studies have shown that these shared representations induce overlapping activation in the anterior medial frontal cortex (aFMC) and the temporoparietal junction (TPJ) of the brain (Brass et al. 2009). The TPJ is important for the separation of one’s actions from others. The aFMC enforces self-intentions when conflicting others elicit imitation. This interpersonal (control) mapping relies on stimulus-response compatibilities to guide imitative behaviour across space and time (Hove & Risen, 2009; Tarr et al., 2015; Wiltermuth & Heath, 2009). I suggest that these self-other compatibilities develop through mirror-symmetrical associative links that embed the mind in a collective matrix. Detection of this matrix is possible using the dual-route model of stimulus-response compatibility applied to automatic imitation (Heyes, 2011; Kornblum et al., 1990). The dual-route model provides a method to differentiate the short and long-term associations between a stimulus and a response, where automatic imitation develops from long-term associations. This form of imitation is operationally defined by fast and efficient actions that follow the same protocols as Stroop and Simon effects (Simon, 1969; Stroop, 1935). Like these classical effects, modulation of behavioural performance depends on the relationship between the topographies of observed action-stimuli and observer responses. I propose that automatic imitation arises when self-other symmetries coalesce around interpersonal compatibilities that give rise to fast actions and efficient cognition. This experiential dynamic implies that the mind comprises self-other compatibilities organized through behavioural symmetries that activate automatic imitation effects. In other words, social learning encodes a collective model, which subsumes self and others by linking mirror-symmetric perceptions through automatic behavioural replication of observed actions.
A collective model’s existence implies that mirror-symmetric interactions are essential for social development because they constitute the fundamental patterns that coordinate the observer and observed. Thus, the present work may advance research on neurodevelopmental disorders, such as autism, for example, a developmental disability characterized by social deficits, including an inability to interpret others’ intentions (5th ed.; DSM–5; American Psychiatric Association, 2013). Further, other examples like, research on ataxia (Akbar & Ashizawa, 2015), a neurodegenerative disease affecting coordinated movements, and hemispatial neglect (Kerkhoff, 2001; Vallar, 1998), a condition resulting from cerebral lesions that leads to an inability to deploy attention to contralateral body parts or space, may also benefit from the inclusion of the current paradigm. Furthermore, testing those who have personality disorders for behavioural deviations from the expected interpersonal symmetries established in this work may provide new perspectives on the effects of social connection and disconnection on the nervous system. Thus, it is conceivable in a clinical setting to implement the methods specified in this thesis as diagnostic tools or protocols for developmental intervention or psychosocial treatment. Beyond the clinic, the beneficial impact of interpersonal symmetry on brain function suggests rapid encoding of training regimes requiring complex motor skill acquisition is possible given an appreciation of a collective model's dynamics. In general, the information processing efficiency and automaticity associated with mirror-symmetric imitation speaks to its essential role in self-other integration. In that sense, my research provides a solid foundation to establish efficacious social learning paradigms, including strategies for maintaining group cohesion and techniques for prosocial engagement.
Experimental Paradigm

Here, I present an experimental paradigm to identify a collective model’s scale-invariant parameters. I accomplish this by evaluating spatiotemporal correlations during cooperative imitation. All experiments exploit the mirror-symmetries of face-to-face exchanges to partition dyadic sensory perceptions bilaterally and self-other integration medially. This four-quadrant geometric paradigm leverages the dual-route model (Kornblum et al., 1990) and the human body's anatomical symmetry to assess interpersonal phase transitions during cooperative spatial action-selection. These perceptual (phase) transitions organize spatiotemporal scales that give rise to binary sensorimotor configurations: (1) in-phase (ipsilateral) and (2) anti-phase (contralateral). These configurations embody divergent interpersonal matrices: (1) symmetrical and (2) anti-symmetrical. These relational contexts enable the quantitative analysis of symmetrical and anti-symmetrical perception-action cycles under perturbations. Given this framework, the measurement of the stable-state collective matrix guiding cooperative imitation is experimentally plausible. To this end, research subjects are paired, oriented as mirror-reflections, and tasked to engage in symmetrical and anti-symmetrical imitation. In this experiential setting, cooperative predictions of sensorimotor inputs are overlapping, which assures the associations driving interpersonal precision is self-reflected. This self-other form permits the assessment of the sociocognitive processing differences between symmetrical and anti-symmetrical connections and the interpersonal geometries facilitating fast and efficient cooperative dynamics.

The three experiments that follow subsume the framework above to manipulate attentional tasks involving interpersonal symmetry enacted through cooperative imitation. These experimental manipulations employ perceptual-switching and group renormalization to specify the scale-invariant regularities inducing a collective mind. Consequently, this experimental
paradigm provides a method that solidly embeds the mind and its neural architecture in a collective matrix specified by interpersonal (spatiotemporal) symmetries. This matrix of minds links the mechanics of cooperative human dynamics to the classical behaviours of objects in motion and the statistical predictions inherent to Bayesian communication systems. Suffice to say; this research sheds light on how human brains work together to predict the external world's unknown variables while simultaneously inducing self-other stability through cooperation.

In summary, I present an experimental paradigm that explores the cooperative structure underpinning social organization. This experiential structure suggests that imitation relies upon behavioural symmetries that overlap the observer's topographical features with the observed. This self-other mapping draws on a collective model to embody the interpersonal symmetries that guide perceptions and actions through space and time. In this mirrored social context, cooperative exchanges are automatic, and mutual information is effectively transmitted. The realization of these perceptual efficiencies has important implications for research on human behaviour because they tell the story of social organization in terms of prediction error minimization through self-other mirror-symmetry seeking. In this paradigm, cooperative processes enlist automatic imitation to embed the mind in a collective matrix. The chapters that follow explore this matrix of minds by testing social cognition and cooperative action under various experimental conditions.
Chapter 2

Abstract

In this experiment, I specify the spatial and temporal invariances enabling the organization of a collective mind. I hypothesized that cooperative dynamics automatically aligned agents symmetrically (or ipsilaterally) in space and time. I provide evidence for this notion by demonstrating that symmetrical imitation enabled rapid integration of interpersonal perceptions and actions without depleting attentional resources. I found the opposite was true for anti-symmetrical (or contralateral) imitation, which drew heavily from attentional resources. This interpersonal divergence rooted imitating agents within a collective matrix that operated based on a three-dimensional grid that was self-reflected at its midline. This means symmetrical imitation arranged agents as mirror-reflections, and anti-symmetrical imitation did not. This interpersonal duality split the collective mind into integrated and segregated forms. The integrated form was defined by automatic mirror-symmetrical imitation, which provided fast and stable interactions that optimized information transmission. Conversely, anti-symmetrical imitation produced the segregated form, which was comparatively slow, unstable, and nonoptimal. I conclude by proposing that these dual interpersonal modes control the levers of social cognition. Consequently, they enabled the identification of the self-organizing dynamics that gives rise to a collective mind, a self-regulating dualistic entity embedded within a multiscale matrix.
Experiment 1

The effects of symmetrical and anti-symmetrical coordination on social cognition

Introduction

This experiment aims to demonstrate that the fundamental patterns of coordination arise spontaneously from self-organizing dynamics. I propose that these emergent patterns arrange agents mirror-symmetrically across space and time by linking self-other perceptions about cooperative intentions. Encoding these intentions is a collective mind embedded within a three-dimensional matrix that overlaps the observer and the observed. I suggest that this self-other overlap enables the observer to embody observed actions through interpersonal symmetry-seeking. In this sociocognitive context, (1) information transmission is at optimal efficiency, (2) actions are fast, and (3) group member interactions renormalize in symmetrical space. I propose that symmetrical imitation facilitates the cooperative behaviours underlying the stability enabling these interpersonal dynamics. This finding would suggest that self-other symmetry-seeking tunes the nervous system to preferentially engage in mirrored interactions that develop spatiotemporal associations between the observer and the observed.

To quantify the spatial and temporal associative links that integrate cooperative agents, I employ the dual-route model. This model allows the implementation of reaction time procedures to measure the long-term associative effects of symmetrical and anti-symmetrical imitation on social cognition. For this, subjects are oriented face-to-face to induce a self-other overlapping pair. In this self-reflected context, the observer and the observed are nested within a three-dimensional matrix characterized by divergent self-other cooperative dynamics: (1) symmetrical and (2) anti-symmetrical. This experiential dualism implies cooperative perceptions can only fulfill expectations within ipsilateral (symmetrical) or contralateral (anti-symmetrical)
space. Therefore, it is reasonable to suspect that cooperation relies on interpersonal symmetries to sustain coordination across spatial and temporal scales. This dualistic paradigm allows the reaction time analyses of interpersonal symmetry effects on cooperative imitation. I hypothesize that the associative links that enable coordination between self and others develop through symmetric alignments that maintain self-other connectivity through automatic imitation.

Automatic imitation is a stimulus-response compatibility effect “in which the speed and/or accuracy of behavioural performance is modulated by the relationship between the topographic features of task-irrelevant action stimuli and the [subjects] responses” (Heyes, 2011: 464). Therefore, I claim that symmetrical imitation is an automatic behaviour activated by long-term associative links between self and others. This means it must be demonstrated that observation of symmetrical (compatible) and not anti-symmetrical (incompatible) imitation facilitates responding despite its function as a task-irrelevant cue. For this, task-relevant visual stimuli are used to assess the attentional effects of compatible and incompatible action observation on cooperation.

**Subjects and Methods**

**Subjects**

Sixty-four subjects (age range 18 to 40; mean age = 20.8; 41 females, 23 males; 5 left-handed) were recruited from within the Department of Psychology, University of Manitoba, and received research participation credits. All subjects were enrolled in Introduction to Psychology at the University of Manitoba. From this subject pool, thirty-two (age range 18 to 30; mean age = 20.5; 23 females, 9 males; 2 left-handed) participated in Experiment 1a and thirty-two (age range 18 to 40; mean age = 21; 18 females, 14 males; 3 left-handed) participated in Experiment 1b. All subjects had normal or corrected-to-normal vision and were not made
aware of the experiment’s purpose (see Appendix A). The Psychology/Sociology Research Approval Board provided approval for this study (Protocol HS19206 (P2015:153)).

**Task-relevant and task-irrelevant stimuli**

In Experiments 1a and 1b, both the stimuli and task instructions were displayed on a Dell computer monitor with a diagonal screen measurement of 60 cm. The monitor was oriented toward and positioned in the action initiator’s peripheral vision (see Figure 2a). The subjects assigned to the role of initiator were instructed to lead action selection during cooperative exchanges. The initiators’ stimulus set was either a 25 x 25 cm blue or red square positioned in the computer monitor's center (see Figures 1b & c). These visual stimuli are displayed randomly and served as the initiator’s task-relevant cues, which in Experiment (1a) initiators respond to after a delay and in Experiment (1b) simultaneously. The subjects assigned to respond to the initiator's actions operate in this context as task-irrelevant stimuli that produce social cues in the initiator's direct field of vision during task execution. These stimulus-response dynamics allow the subject responses to perform separate relevance functions depending on the assigned role. Here, initiators generate responses that are the task-relevant sensory cues activating cooperative imitation in followers. On the other hand, followers respond to initiators by generating action stimuli that are task-irrelevant to the initiators’ responses but are salient signals of cooperative intentions. Ultimately, this stimulus-response setup enables the response time analysis of cooperative action observation effects on task performance.
Figure 2. An illustration of the setup for Experiments 1a and b. Here, the response time differences between symmetrical (R2 leader actions $\rightarrow$ L2 follower responses or L2 leader actions $\rightarrow$ R2 follower responses) and anti-symmetrical (R2 leader actions $\rightarrow$ R2 follower responses or L2 leader actions $\rightarrow$ L2 follower responses) cooperation in the Z-dimension were evaluated during divided attention manipulations. Leaders were tasked to pay attention to a blue (b) or red (c) square presented on a computer monitor and respond by selecting the corresponding (L2 or R2) trigger on the controller (d) on-stimulus or after a 1-second delay. Simultaneous with this task, Leaders were required to monitor the Followers’ responses to ensure cooperative actions were fulfilled. Followers were tasked to respond to Leaders by engaging the (L2 or R2) triggers on the controller (d) by imitating the Leaders symmetrically or anti-symmetrically.

Data recording

PlayStation 4© controllers (SONY Corporation, Minto, Japan) were used as the interface through which response times (RTs) were measured. E-Prime 2.0 Professional© (Psychology
Software Tools, Inc, 2012) was used to record RTs in milliseconds. In Experiment 1a, completion of a 1-second stimulus presentation marked the beginning, and the initiator’s response marked the end of the initiator’s response time interval. In Experiment 1b, stimulus presentation marked the beginning, and the initiator’s response marked the end of the initiator’s response time interval. In both experiments, the initiator’s response marked the beginning, and the follower’s reactive response marked the end of the follower’s response time interval.

**Methods and analysis**

Subjects were assessed in groups of two. Each group member was assigned to the role of (1) *leader* or (2) *follower*. The leader (i.e., action initiator) and follower were oriented face-to-face across a table; each was provided with a controller (see Figure 2a). The pair were instructed to hold their controller while positioning the index and middle fingers of their right and left hands on the controller’s R1, L1, R2, and L2 triggers, respectively (see Figure 2d). A computer monitor was positioned to the follower's right so that the stimulus set and instructions were displayed to the leader without obstructing the leader’s view of the follower’s responses. At the experiment's midpoint, the subjects switched roles and positions. Experiments 1a and 1b comprise two stimulus-response conditions: (1) *symmetrical* and (2) *anti-symmetrical*. The symmetrical condition involved the imitation of action feedback within ipsilateral hemispace (e.g., right-side action observation followed by left-side responses or left-side action observation followed by right-side responses). In contrast, the anti-symmetrical condition involves imitation of action feedback within contralateral hemispace (e.g., right-side action observation followed by right-side responses or left-side action observation followed by left-side responses). The symmetrical and anti-symmetrical conditions were presented in a 20 block procedure comprising 24 trials allocated to each block. Subjects switched roles and seating positions after 10
consecutive blocks. These 10 blocks were partitioned into 5 symmetrical blocks and 5 anti-symmetrical blocks that were counterbalanced. At the beginning and end of each 5 block condition, the computer monitor displayed text instructions (“Press R2 or L2 to begin mirroring” or “Press R2 or L2 to begin matching” or “Press R2 or L2 to continue”). Leaders were required to share the terms of the cooperative conditions and await an affirmative from followers before proceeding. Note, the “mirroring” and “matching” task instructions denote the symmetrical and anti-symmetrical conditions, respectively. In Experiment 1a, when the procedure begins, the leaders must select their controller’s R2 trigger as quickly as possible after a 1-second display of a blue square or the L2 trigger after a 1-second display of a red square. In Experiment 1b, the only procedural difference was the leaders must select as quickly as possible their controller’s R2 trigger immediately after the blue square is detected or the L2 trigger immediately after the red square is detected (see Figures 2b & c). Therefore, both experiments required the leaders to divide their visual attention between the task-relevant stimuli displayed on the monitor and the follower's task-irrelevant action stimuli. Followers were instructed to react to the leader’s actions by selecting as quickly as possible the R2 or L2 trigger on their controllers depending on the experimental condition: (1) symmetrical action observation followed by symmetrical responses or (2) anti-symmetrical action observation followed by anti-symmetrical responses. For the event chain (i.e., stimulus-response feedback cycle) to proceed uninterrupted, subjects must engage the correct trigger. For example, in the leaders' case, a R2 trigger response must follow blue stimulus observation, and a L2 trigger response must follow red stimulus observation. Concerning followers, the experimental condition dictates the correct response. This means the correct action executed in the symmetrical condition was always symmetrical, likewise for the anti-symmetrical condition. Crucially, in all conditions, an incorrect trigger response slowed a
subject's RTs; this was due to the procedural rule that the correct response must be selected to advance the cooperative exercise. Subjects were provided with training before the experimental procedure commenced. Training consisted of 20 blocks, where each block contained 12 trials. The partitioning of trials, event chain sequences, and task instructions unfolded in the same way as those outlined in the Methods section above.

In summary, this experimental framework enabled the evaluation of the modulatory capacities of symmetrical and anti-symmetrical action observation on behavioural performance in terms of speed and efficiency. I leverage this framework to measure RTs during task-irrelevant action observation. This was done to determine the compatible and incompatible interpersonal forms encoding long-term associative links. Here, incompatible associations impede task-performance (i.e., slowing responses), whereas compatible associations play a facilitatory role (i.e., hastening responses). Finally, followers’ RTs serve as the baseline measure for comparing the effects of symmetrical and anti-symmetrical imitation in the absence of attentional manipulation.

No trials were excluded from the analyzed dataset. However, to reduce the influence of outliers, each subject's median RT was used as a measure of central tendency (Ratcliff, 1993). To avoid violations of the sphericity assumption, I employed a two-way repeated measures analyses of variance (ANOVA) for all reported ANOVA statistics. All pairwise comparisons were performed using paired-samples t-tests in which a Bonferroni adjusted alpha of 0.0025 was employed to control for inflation of Type 1 error.
Results

Experiment 1a: Task-relevant delayed response manipulation

The results revealed a significant main effect for IMITATION STATE with faster responses in the symmetrical condition than in the anti-symmetrical condition, $F(1, 31) = 51.7, p < 0.001$. Furthermore, a significant main effect of ROLE was found, $F(1, 31) = 99.9, p < 0.001$. Subjects were faster in the role of the leader than in the role of follower. Consequently, a significant interaction effect between IMITATION STATE by ROLE was detected, $F(1, 31) = 51.7, p < 0.001$. To expose the nature of this interaction, a post hoc analysis was conducted. In the role of leader, response times were significantly faster when observed actions were symmetrical (207 ms) compared with anti-symmetrical (245 ms), $t(31) = 3.47, p < 0.002$, $d = 0.613$. This behavioural pattern was repeated in followers; here, reaction times were significantly faster in the symmetrical (323 ms) compared with the anti-symmetrical condition (397 ms), $t(31) = 7.86, p < 0.001$, $d = 1.389$ (see Figure 3 and Table 1). The IMITATION STATE effect in the symmetrical condition indicates that subjects produce faster responses in the task-relevant dimension when cooperative actions are generated in the ipsilateral and not the contralateral hemispace. All but one follower produced faster baseline responses in the symmetrical condition (see Appendix B1). Here, subject 15 generated marginally faster anti-symmetrical (225 ms) than symmetrical (229 ms) responses.
Figure 3. Response time (mean± SEM) difference between symmetrical and anti-symmetrical cooperation are compared. *p < 0.0025.

<table>
<thead>
<tr>
<th>Pairwise Comparison</th>
<th>95% Confidence interval Lower vs. Upper</th>
<th>t-statistic</th>
<th>df</th>
<th>P-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leader: symmetry vs anti-symmetry</td>
<td>[-59.54, -15.43]</td>
<td>3.47</td>
<td>31</td>
<td>0.002*</td>
<td>0.613</td>
</tr>
<tr>
<td>Follower: symmetry vs anti-symmetry</td>
<td>[93.75, -55.12]</td>
<td>7.86</td>
<td>31</td>
<td>0.000*</td>
<td>1.389</td>
</tr>
</tbody>
</table>

Table 1. *p < 0.0025.
Experiment 1b: Task-relevant on-stimulus response manipulation

The results show a significant main effect for IMITATION STATE with faster responses in the symmetrical than in the anti-symmetrical condition, $F(1, 31) = 51.9, p < 0.001$. Furthermore, a significant main effect of ROLE was found, $F(1, 31) = 23.3, p < 0.001$. Subjects were faster in the role of the follower than in the role of the leader. Consequently, a significant interaction effect between IMITATION STATE by ROLE was detected, $F(1, 31) = 34.6, p < 0.001$. A post hoc analysis was conducted to evaluate this interaction. In the role of leader, response times were not significantly different when observed actions were symmetrical (422 ms) compared with anti-symmetrical (431 ms), $t(31) = 1.38, p < 0.179, d = 0.24$. This behavioural pattern was not repeated by followers; instead, response times were significantly faster in the symmetrical (306 ms) compared with the anti-symmetrical condition (383 ms), $t(31) = 7.39, p < 0.001, d = 1.389$ (see Figure 4 and Table 2). The IMITATION STATE effect in the symmetrical condition indicates that subjects show behavioural interference in the task-relevant dimension when cooperative actions are generated in the anti-symmetrical hemispace. Interference also emerged when the subject’s responses to task-relevant stimuli were elicited on-stimulus instead of after a 1-second delay like in Experiment 1a. Here, the on-stimulus response manipulation abolished the response speed difference between the symmetrical and anti-symmetrical conditions. All followers produced faster baseline responses in the symmetrical than anti-symmetrical condition (see Appendix B2).
Figure 4. Response time (mean ± SEM) difference between symmetrical and anti-symmetrical cooperation are compared. *p < 0.0025.

Table 2. *p < 0.0025.

<table>
<thead>
<tr>
<th>Pairwise Comparison</th>
<th>95% Confidence interval</th>
<th>t-statistic</th>
<th>df</th>
<th>P-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leader: symmetry vs anti-symmetry</td>
<td>[21.79, 4.23]</td>
<td>1.38</td>
<td>31</td>
<td>0.179</td>
<td>0.24</td>
</tr>
<tr>
<td>Follower: symmetry vs anti-symmetry</td>
<td>[96.25, -56.50]</td>
<td>7.39</td>
<td>31</td>
<td>0.000*</td>
<td>1.389</td>
</tr>
</tbody>
</table>
**Discussion**

These data conform to the hypothesis that symmetrical imitation is generated automatically during cooperative action selection. The present design demonstrates interpersonal expectations of symmetrical exchange enhances task performance by reducing response times and attentional resource demands. Experiments 1a and b reveal that the followers’ baseline measures indicate that cooperative motor plan execution in symmetrical hemispace is faster and more efficient than execution in the anti-symmetrical hemispace. This result replicates previous research by Brass et al. (2009), in which they report overlapping brain activation in the anterior medial frontal cortex (aFMC) and the temporoparietal junction (TPJ) enable neural processes that inhibit automatic imitation (Heyes, 2011). It is suggested that this inhibition mechanism allows the nervous system to decouple the self from others by incurring a resource cost to recruit the aFMC to counter automatic imitation. In simultaneous operation with the aFMC, the TPJ generates a separation between self and others, which underpins the shared representation (Brass and Heyes, 2005) that enable the sociocognitive capacity to infer others' mental states (i.e., mentalization). These overlapping brain dynamics imply that cognition flows with little resistance during automatic imitation, a social behaviour that is selectively inhibited by the nervous system through attentional control. Experiment 1a shows that the inhibition of symmetrical imitation slows response speeds during actions and perceptions that are anti-symmetrical. The results of Experiment 1b support this claim by demonstrating divided attention involving simultaneous responses abolished the response speed advantage of symmetrical imitation, which indicates its function as the automatic state of cooperative exchange. The logic here is that when leaders encountered the response cue and responded after a delay, as in Experiment 1a, both the response and social cues were processed sequentially. This
sequence of events enabled the leaders' behavioural patterns to recapitulate those of the followers (i.e., faster symmetrical than anti-symmetrical imitation). By contrast, in Experiment 1b, when leaders encountered the response cue and must respond on stimulus, this task required simultaneous processing of both response and social cue, which reduced the speed of symmetrical imitation when compared to the followers. Based on these outcomes, I suggest that anti-symmetrical imitation slows response times because the nervous system must recruit attentional resources to inhibit automatic imitation in the ipsilateral hemispace. This interpretation is supported by past research that suggests imitative response slowing is due to attentional competition between motor intentions and socially triggered response tendencies (Brass et al., 2009). In other words, anti-symmetrical action observation impedes responsivity to the short-term associative links established by the task-relevant dimension. Conversely, symmetrical actions and perceptions represent long-term connections activated automatically via social controls that reduce attentional resource demands by eliminating the processing cost incurred during the inhibition of actions. Therefore, the elimination of the response speed difference reported in Experiment 1b indicates attentional resources are available for use when cooperative exchanges arise within the symmetrical and not the anti-symmetrical hemispace. These findings provide strong evidence that symmetry is the expected state of social interaction for the human brain (Brass et al., 2009; Friston, 2009; Hove & Risen, 2009; Knill & Pouget, 2004). They indicate that cognitive resources are subject to modulation under the symmetrical and not the anti-symmetrical state of perception and action.
In summary, this chapter demonstrates that observation of symmetrical and anti-symmetrical imitation produces an appreciable difference in responsivity and cognitive resource demands. Experiment 1a shows interpersonal perceptions of symmetrical actions induce automatic imitation effects that enable fast and efficient coordinated responses. Experiment 1b reveals that these symmetrical perceptions not only improve task performance, but they also liberate attentional resources and allow multitasking. These outcomes suggest that self-other symmetry functions as the normative mechanism minimizing the prediction error of cooperative behaviours. In other words, the spatiotemporal invariance specifying the geometric symmetry of self-other dynamics encodes a collective model of interpersonal expectations. These shared expectations guide the collective mind of collaborative agents by maintaining sociocognitive stability across space and time.

**Conclusion**

I have briefly summarized evidence for the assumption that symmetrical imitation gives rise to the fundamental patterns of self-organization among humans. I suggest that underpinning this organizational pattern is a shared model that serves as the social template for cooperation. I refer to this model as the collective mind, a system of nested subsystems specified by spatial and temporal invariance that maintains interpersonal connectivity and perceptual stability. Here, I argued that symmetrical imitation attenuates response times, optimizes information transmission, and normalizes group behaviours. The results of the experiment presented in this chapter support these postulates; however, additional investigation is required. Thus, in the following chapter, I conduct an experiment that induces interpersonal symmetry-breaking and group renormalization during cooperative synchrony. This examination is conducted to test the effects of attentional resource demands on action selection. My hypothesis here is that symmetrical interconnection
provides the perceptual architecture that brains rely upon to coordinate interpersonal action selection. If correct, attentional resource depletion during symmetrical and anti-symmetrical synchrony should induce criticality and spontaneous coalignment in ipsilateral and not contralateral hemispase. Chapter 3 examines this postulate by detecting spontaneous symmetry-breaking during cooperative dynamics.
Chapter 3

Abstract

In this experiment, I examine interpersonal symmetry-breaking and renormalization in human coordination dynamics. I hypothesized that perceptions of symmetrical actions functioned as the automatic and normative states of coordinated exchange. I provide evidence for these functional relationships by revealing spontaneous symmetry-breaking and renormalization during interpersonal synchrony under perturbations. I achieved this end by tasking subjects to synchronize their arm movements over a 2-minute duration that required the repeated transition between dual interpersonal forms: (1) symmetrical and (2) anti-symmetrical. This manipulation required cooperation that was both mentally and physically taxing, which enabled the video analysis of symmetry-breaking and renormalization induced by perceptual instability. In this exploratory paradigm, perceptual instability arose from the demand that subjects pay attention to their own movements while simultaneously monitoring the position of their partners’ movements over time. I report that coordination dynamics spontaneously transitioned from the anti-symmetrical to the symmetrical form when synchronized perceptions of actions destabilized. Crucially, this group normalization function never transitioned from the symmetrical back to the anti-symmetrical unless mediated by attention. These outcomes strongly suggest that cooperation dynamics are regulated automatically through interpersonal symmetry-breaking that spontaneously aligns perceptions and actions in symmetrical space under perturbations. I conclude by proposing that this dynamic behaviour reveals the underlying mechanism driving group renormalization.
Experiment 2

Interpersonal symmetry-breaking and renormalization in humans

Introduction

In this chapter, I postulate that the nervous system's self-other connections are conserved across space and time by encoding shared representations based on dual interpersonal modes: (1) symmetrical and (2) anti-symmetrical. Chapter 2 demonstrated that the symmetrical mode supplies stable connections that serve as the sensorimotor template for fast and efficient coordinated movements. Conversely, the anti-symmetrical mode draws from neural resources to inhibit symmetrical imitation effects and is, therefore, a collective capacity modulated by attentional processes. These findings replicate those established in Coordination Dynamics (CD) literature, which encompasses a line of scientific inquiry dedicated to understanding “how the parts and processes of living things come together and break apart in space and time” (Kelso, 2014: 67). From the CD perspective, a living system possesses two complementary aspects in which integration and segregation exist concurrently (Kelso, 2009). The integrative aspect arises from self-organizing collective variables whose dynamics emerge from undirected coordination between parts. The segregation aspect emerges from goal-directed coordination that enables novel information to be accumulated through intentions that rely on the integrative aspect to guide the whole system’s functional order across space and time. These coordination dynamics activate spatiotemporal patterns of behaviour that evolve and change based on phase transitions that result from spontaneous choice, where the whole system preferentially selects one behavioural pattern over another (Haken et al., 1985; Kelso, 1984; Kelso, 2000a). This dualism captures the dynamics of cooperative stability in terms of integration and segregation. The capacity to switch between these coexisting states is referred to as metastable coordination.
(Kelso, 2001), evidenced by spontaneous symmetry-breaking in the brain (Kelso, 2014). Here, metastable coordination emerges from cooperation within locally segregated neural areas and between cortical and subcortical neural areas (Kelso, 2012). This symmetry-breaking in neural dynamics enables the brain to “exhibit a far more variable, plastic and fluid form of coordination in which integration and segregation coexist” (Kelso, 2000b: 11). Given this account of coordination, I aim to test the hypothesis that group members exhibit symmetry-breaking and renormalization within symmetrical space when attentional resources are depleted or redirected. I propose that the complementary symmetrical and anti-symmetrical modes of cooperation represent the coexisting integration and segregation aspects of a metastable collective mind.

In the experiment that follows, I instructed dyads to engage in in-phase (symmetrical) and anti-phase (anti-symmetrical) synchrony during perceptual-switching involving coordination dynamics. In this manipulation, subjects were required to repeatedly switch between perceptions about interpersonal actions. This means, subjects were tasked to pay attention to their own movements while simultaneously tracking the changing spatial positions of their partner's movements. This cooperative dynamic overlapped intentions and demanded that subjects focus their energies on synchronizing two interpersonal transformations: (1) symmetrical cycles that involved homologous muscle groups contracting synchronously and (2) anti-symmetrical cycles that involved homologous muscle groups contracting in an alternating fashion. These spatiotemporal constraints on cooperation enabled the analysis of the interpersonal configurations inducing perceptual stability under perturbations. In other words, restricting cooperative arm movements to the vertical plane allowed perceptual-switching and attentional manipulations to be employed to identify the stable (spatiotemporal) states of self-other
integration. I aim to demonstrate that coordinated actions seek stability in symmetrical and not anti-symmetrical space during symmetry-breaking induced by perceptual instability.

**Subjects and methods**

**Subjects**

Thirty-two subjects (age range 17 to 25; mean age = 20.4 years; 20 females, 12 males) were recruited from within the Department of Psychology, University of Manitoba, and received research participation credits. Subjects were enrolled in Introduction to Psychology at the University of Manitoba. Subjects had normal or corrected-to-normal vision and were not made aware of the experiment’s purpose (see Appendix A). The Psychology/Sociology Research Approval Board provided approval for this study (Protocol HS19206 (P2015:153)).

**Data recording**

Canon’s EOS Rebel© T6i and EF-S 18-55 mm f/3.5-5.6 IS STM camera lens (Canon Incorporated, Ōta, Tokyo, Japan) were used to record the experimental sessions. The recording equipment was placed on a tripod oriented toward the subjects and positioned 5 m from where the sessions occurred. This was done to ensure the video camera captured the subject’s full range of motion.

**Methods and analysis**

Subjects were assessed in groups of two. Group members were positioned 2-meters apart and oriented face-to-face. The pair were instructed to synchronize vertical arm movements based on four interpersonal configurations: (1) Together, (2) Apart, (3) Split Together, and (4) Split Apart. Together involved coordination in which each subject was tasked to hold their left and right arms parallel to each other during in-phase synchronization (see Figure 5a). Apart involved the same arm positioning as the Together configuration; however, subjects were tasked to
coordinate anti-phase synchronization (see Figure 5b). Split Together involved in-phase synchrony where subjects decouple their arms so that when the right arm of one subject was at the lowest vertical position (0°), their partner's left arm was also at its lowest (0°). The same rule applied to the subject’s left and right arm alignment at their highest point (180°) (see Figure 5c). Split Apart involved anti-phase synchrony where subjects decouple their arms so that the right arm of one subject was at the highest vertical position (180°) when the left arm of their partner was at its lowest (0°) and vice versa (see Figure 5d). The experimental session comprised two cooperative conditions. Condition one involved cooperation in which subjects synchronize perceptual cycles according to the following action sequence: Together, Apart, Split Together, Apart, Together, and Split Apart. Condition two’s sequence was as follows: Together, Apart, Split Apart, Apart, Together, and Split Together. These conditions were presented in a 2 block procedure comprising 2 trials allocated to each block. These trials were partitioned into CONDITION ONE and CONDITION TWO, which were counterbalanced across blocks. At the onset of the first block, the subjects raised their arms to the starting position. A 2-minute timer was then activated simultaneously with a verbal prompt indicating the interpersonal configuration to be performed. Thus, the verbal prompts were presented at the beginning of the first block and at 5-second intervals until the 2-minutes elapsed. Consequently, each trial lasted 30-seconds and was presented in continuous order (e.g., CONDITION ONE → CONDITION TWO → CONDITION TWO → CONDITION ONE). Subjects were provided training before the experimental session commenced. The training involved a demonstration of the behaviours the subjects were expected to perform, followed by a practice session. Practice consisted of 2 blocks, where each block contained 2 trials. The partitioning of trials, action sequences, and task
instructions unfolded in the same way as those outlined in the Methods section above, except the length of the sessions were 4-minutes, which means each trial lasted 60, not 30-seconds.

In summary, this experiment enabled the identification of interpersonal symmetry-breaking and renormalization in coordination dynamics. I leverage perceptual switching to evaluate the effects of in-phase and anti-phase synchrony on social cognition. These perceptual switching manipulations impose demands on mental processing by shifting attention between symmetrical and anti-symmetrical perceptions and actions. In this context, spontaneous symmetry-breaking arises when demands on attentional resources induce perceptual instability, which results in an incongruity between the instructed and observed configuration executed by the coordinating group. In other words, group members will spontaneously select one of the binary interpersonal configurations (in-phase or anti-phase) when criticality is induced through perceptual instability. This spontaneous group choice should result in coordinated action selection within symmetrical and never anti-symmetrical space regardless of task instruction.

**Coding criteria**

No trials were excluded from the analyzed dataset. Data collection involved tabulating interpersonal symmetry-breaking through the evaluation of video recordings of the experimental sessions. These video recordings were analyzed at half playback speed. Symmetry-breaking was defined as an incongruence between the instructed and the executed configuration generated by the group. For example, if the task instruction prompted in-phase symmetry and anti-phase symmetry was generated, this incongruence was tabulated as a symmetry-breaking event. This same rule was applied to prompted anti-phase symmetry that resulted in the group generating in-phase coordination. Whether symmetry-breaking occurs or does not occur per session and the direction of the break (in-phase to anti-phase or anti-phase to in-phase) were the only data
Coding was performed by the experimenter. Video recordings with participant’s individual identities obscured are available upon request.

<table>
<thead>
<tr>
<th>(In-phase)</th>
<th>(Anti-phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symmetrical configurations</strong></td>
<td><strong>Anti-symmetrical Configuration</strong></td>
</tr>
<tr>
<td><img src="image1.png" alt="Image of configurations" /></td>
<td><img src="image2.png" alt="Image of configurations" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Mirror" /></td>
<td><img src="image4.png" alt="Match" /></td>
</tr>
</tbody>
</table>

**Figure 5.** These illustrations depict four interpersonal configurations: (a) Together, (b) Apart, (c) Split Together, and (d) Split Apart. The subjects are tasked to switch between these configurations while synchronizing perceptions and actions in the Y-dimension.

**Results**

The results reveal that coordinated movements transition automatically from anti-phase to in-phase synchrony under cognitive perturbations. Anti-phase to in-phase symmetry-breaking emerged spontaneously in 16 out of 16 sessions, whereas in-phase to anti-phase symmetry-breaking did not occur in a single session. In other words, synchronized movements spontaneously transitioned from (b) to (a) and (b) to (c) and never (a) to (b) or (c) to (b) (see
Figure 5). Furthermore, synchronized movements spontaneously transitioned from (d) to (a) and (d) to (c) and never (a) to (d) or (c) to (d) (see Figure 5).

**Discussion**

The present experiment examined spontaneous symmetry-breaking in interpersonal dynamics. The data collected here support the claim that cooperative action patterns renormalize in symmetrical space when perceptual cycles are unstable (Bak et al., 1987; Friston et al., 2012; Haken, 1985; Kelso, 1984; Schwabl, 2002). I demonstrate that anti-symmetrical interactions induce symmetry-breaking and symmetrical normalization when cognitive demands are high or attention divided. The results show that in-phase to anti-phase transitions arose only when directed and never through symmetry-breaking. In contrast, anti-phase to in-phase transitions emerged spontaneously and without direction in every session. These findings provide strong evidence that collective dynamics operate based on dual (symmetrical and anti-symmetrical) modes of interaction characterized by coexisting integration (undirected) and segregation (directed) aspects in the framework of Coordinated Dynamics (Kelso, 2009). These dual aspects achieve stability through interpersonal symmetry-seeking evinced by spontaneous symmetry-breaking, where perceptual instability results in renormalization in symmetrical space. The undirected (integrative) aspect connects spatiotemporal dynamics by automatically aligning observed actions mirror-symmetrically with self-perceptions when perturbed. This sociocognitive mechanism suggests that collectives enlist self-organizing processes to minimize interpersonal prediction error through automatic imitation that induces perceptual stability. Here, symmetrical actions support and sustain themselves across individual and group scales through undirected self-other integration. This multi-level stability enables the collective’s segregation aspect to recruit cognitive resources to engage anti-symmetrically. These propositions support
the idea that the segregation aspect of coordination dynamics reveals “how information is created [ anew] and how information guides, directs and is modulated by [undirected] self-organizing dynamics” (Kelso, 2000b: 3). Given this context, it is reasonable to suspect that symmetrical and anti-symmetrical interactions allow the brain to perform parallel processing, where symmetrical processing gives rise to self-organizing dynamics that manifest automatically during cooperation. Conversely, anti-symmetrical processing occupies one’s attention and relies on symmetrical interactions to normalize when disturbed by external variables.

I claim that metastable coordination dynamics emerge from these coexisting interpersonal modes. Here, the symmetrical form is undirected and automatic, whereas the anti-symmetrical form is directed and always intentional. I suggest that these dual interpersonal modes operate in parallel. This means that symmetrical interactions sustain a shared (collective) model that integrates new knowledge through the segregation induced by anti-symmetrical exchanges. This collective behaviour coincides with those reported in ants (Atta insularis), where an experiment conducted by Altshuler et al. (2005) found that high-panic induced herding resulted in nonsymmetrical use of two identical doors (i.e., symmetry-breaking). In contrast, in the low panic condition, the doors were used equally as often. Saloma et al. (2003) studied group escape panic in ICR mice (Mus musculus) and found that the diffusive flow at exits follows self-organizing queuing and scale-free dynamics. Here, exponential and power-law distributions define the rate of escape. In other words, group-panic induced predictive spatiotemporal patterns in which group movements towards egresses fluctuated in size depending on exit width.

Computer simulations by Helbing et al. (2000) modelling collective human escape behaviours demonstrated that spontaneous group choice is induced under perturbations. In their simulations, group choice consistently aligned the whole system’s normative trajectory such that
interpersonal movements flowed unidirectionally. These examples suggest that spontaneous symmetry-breaking and renormalization are emergent properties of group interactions under duress. Consequently, the experimental paradigm I present provides a naturalistic setting in which theoretical and applied questions about interpersonal dynamics can be tested empirically and modelled accurately. Moreover, the realization of dual interpersonal modes in which the symmetrical form automatically aligns the organization of group behaviours under stress provides a paradigm to explore the underlying cooperative mechanisms inducing multiple social phenomena, e.g., conformity (Cialdini & Goldstein, 2004), groupthink (Schmidt, 2016), silo effects (Bevs et al., 2015), among others. Lastly, the capacity to internally inhibit these group behaviours and segregate oneself from others by harnessing attention may offer insights into the discordant interpersonal processes involved in social change.

Conclusion

In this chapter, I have provided evidence that the collective mind is embedded within a spatiotemporal matrix comprising self-other symmetries defined by dual interpersonal modes. The next chapter focuses on this multimodal dynamic by posing the question, “how should I be, given the position of you, given the position of me?” In the final experiment, I task subjects to select between spatial integration (symmetry) and segregation (anti-symmetry) in the absence of explicit direction. I hypothesize that in this social context, subjects will preferentially select integration over segregation unless otherwise directed.
Chapter 4

Abstract

In this final experiment, I explored a social paradigm in which subjects were tasked to make binary spatial judgments about where to align themselves given the alignment of an observed other. This manipulation required that subjects select between divergent self-other forms: (1) integration and (2) segregation. Integration involved spatial actions that align subjects together in (symmetrical) space, whereas segregation split subjects apart (anti-symmetrically). I hypothesized that these self-other forms coordinate based on dual interpersonal modes: (1) undirected and (2) directed. The undirected (or integrative) mode activates automatic imitation that unfolds spontaneously in symmetrical space. The directed (or segregative) mode suppresses the undirected mode by recruiting attentional resources to imitate in anti-symmetrical space. I provide evidence for this hypothesis by demonstrating that subjects automatically aligned together and never split apart when the only salient signals were an observed other's actions. In contrast, subjects split apart only when explicitly instructed and never automatically. These dual interpersonal modes speak to a collective mind comprising integrative and segregative aspects that operate in parallel during cooperative interactions. I conclude by arguing that the undirected mode gives rise to interpersonal symmetry-seeking, a reflexive social behaviour that aligns agents together and affords interpersonal stability. Conversely, I argue that the directed mode enables segregation via inhibitory neural mechanisms that promote intrapersonal change via perceptual instability.
Experiment 3

Interpersonal symmetry-seeking: Directed versus undirected coordination

Introduction

Where should I align in space and time? In the following experiment, I demonstrate that the default response is to align “together.” Chapter 2 presented an exploratory paradigm that revealed that symmetrical actions are generated significantly faster than anti-symmetrical actions. In addition to superior responsivity, I show that information transmission between agents is optimal when perceptual cycles are symmetrical. Chapter 3 exposed a renormalization mechanism based on dual interpersonal modes in which perceptual instability resulted in spontaneous transitions from anti-symmetrical to symmetrical configurations. These findings support the notion that coexisting integration and segregation aspects operate in parallel during cooperation (Kelso, 2009). Here, the integration (or undirected) aspect provides the behavioural template from which the segregation (or directed) aspect operates. In other words, cooperative action selection that is symmetrical is automatic and undirected, whereas anti-symmetrical action selection is produced only when directed. A study by Ancel et al. (2015) on social thermoregulation in Emperor penguins (*Aptenodytes forsteri*) reported that aggregations of individuals fluctuated in size and density depending on air temperature, wind, and solar radiation. The key findings were that individuals' movements were directed from loose aggregations to huddles when air temperature decreased, wind speed rose, or solar radiation diminished. The researchers claimed that this grouping behaviour enabled individuals to band together to conserve energy when faced with inclement weather conditions. When energy dissipation was necessary, individuals were observed breaking from huddles through spontaneous disassembly. These cooperative movements together and apart unfolded through
synchronous actions (Gerum et al., 2013; Waters et al., 2012; Zitterbart et al., 2011) that minimized the heat loss of huddling groups and their members (Ancel et al., 1997; Gilbert et al., 2008). Research involving schooling fish (Hemelrijk et al., 2014) and flocking birds (Corcoran & Hedrick, 2019) suggests that these coordinated behaviours serve the same resource function as huddling in penguins. Here, hydrodynamic and aerodynamic efficiencies enable schooling fish and flocking birds to reduce individual-level energy consumption during collective motion. In contrast, separation from the group produced the opposite effect. These observations support the dual nature of group dynamics by demonstrating that the integrative (undirected) aspect conserves energy, whereas the segregative (directed) aspect dissipates energy.

To test for this behavioural dualism, I conduct a whole-body experiment in which paired subjects are tasked to make a binary spatial choice between symmetrical and anti-symmetrical coalignments without instruction. This manipulation tasked subjects to make a judgment about where to align themselves in space, given no indication about how to act except for the actions of an observed other. The logic here is that cooperative action selection operates based on coexisting directed and undirected aspects. The undirected part enables self-other integration, and the directed part, segregation. Consequently, coordinating groups should automatically align (together) symmetrically in the absence of instruction and (segregate) anti-symmetrically only when instructed explicitly.

Subjects and methods

Subjects

Thirty-two subjects (age range 17 to 40; mean age = 20.88 years; 19 females, 13 males) were recruited from within the Department of Psychology, University of Manitoba, and received research participation credits. Subjects were enrolled in Introduction to Psychology at the
University of Manitoba. Subjects had normal or corrected-to-normal vision and were not made aware of the experiment’s purpose (see Appendix A). The Psychology/Sociology Research Approval Board provided approval for this study (Protocol HS19206 (P2015:153)).

**Data recording**

Canon’s EOS Rebel© T6i and EF-S 18-55 mm f/3.5-5.6 IS STM camera lens (Canon Incorporated, Ōta, Tokyo, Japan) were used to record the experimental sessions. The recording equipment was placed on a tripod oriented toward the subjects and positioned 5 m from where the sessions occurred. This was done to ensure the video camera captured the subject’s full range of motion.

**Methods and analysis**

Subjects were assessed in groups of two. The pair were positioned 2m apart and aligned face-to-face. Each was assigned to the role of (1) LEADER or (2) FOLLOWER. However, the participants were not referred to by these titles; instead, they were referred to as “subject one” and “subject two,” respectively (Figure 6). Before the procedure began, the leader and follower were taken to separate rooms and provided instructions by the experimenter on the sequence of actions they were tasked to perform. In the first experimental condition, the leader was told to take one step to the left when verbally prompted and await their partner's response. Once the partner’s response was selected, the leader was told to return to the starting position by taking one-step to their right when prompted. This cooperative pattern was repeated on the right side. The follower was not made aware of the instructions provided to the leader. Instead, the follower was instructed to respond to the leader’s action by taking one-step to either their left or right, followed by a return to the starting position when verbally prompted. Immediately after this behavioural sequence was completed, the procedure was repeated. In this condition, the leader
began the trial by taking one-step to the right instead of the left. On the other hand, the follower was instructed to select actions that align anti-symmetrically with the leader (e.g., when the leader takes one step to the left, the follower takes one-step to the left and vice versa). The procedure comprised two conditions: (1) UNDIRECTED and (2) DIRECTED. In the undirected condition, the leader was instructed to (1) take a prespecified step to the right or left, (2) allow the follower to select their spatial action, and (3) return to their original position. The follower was tasked to respond to the leader by inferring which spatial location to select given the leader's action. Importantly, the follower’s selected action emerged without the aid of specific instructions about which of the binary actions to select. In the directed condition, the leader moved in the opposite direction (e.g., if they initially shifted left, they would now shift to the right and vice versa). In this condition, followers were provided instructions indicating which action to select (e.g., “if the initiator shifts to their left, you must shift to your left,” and vice versa for a shift to the right). The directed and undirected conditions were presented in a 2 block procedure comprising 2 trials allocated to each block. These two blocks were partitioned into 1 directed block and 1 undirected block that was counterbalanced. No training was provided before the experiment began.
Figure 6. The illustration above depicts the binary choice associated with directed and undirected spatial action selection in the X-dimension. Column (a) represents the leader and follower starting positions. Column (b) depicts the two spatial positions the leader can select. Column (c) illustrates the follower's symmetrical responses, and column (d) the follower's anti-symmetrical responses.

In summary, this experiment evaluated the undirected states of cooperative action in the absence of external instruction. In this paradigm, the leader-follower alignments that draw subjects together in space are defined as symmetrical, and alignments that split subjects apart are identified as anti-symmetrical.

Coding criteria

No trials were excluded from the analyzed dataset. Coding involved tabulating the locations selected by the followers in both the directed and undirected conditions. For example, whenever followers respond to leaders by aligning symmetrically in space (rightward leader actions resulting in leftward follower responses and vice versa for leftward leader actions and rightward follower responses), those events were tabulated. The same rule applied to follower responses that resulted in anti-symmetrical spatial alignments (rightward leader actions result in rightward follower responses and vice versa for leftward leader actions and leftward follower
responses). Coding was performed by the experimenter. Video recordings with participant’s individual identities obscured are available upon request.

Results

The results reveal that in the undirected condition, followers aligned symmetrically with the leaders in every trial (see Table 3). Conversely, in the directed condition, followers aligned anti-symmetrically except for one trial, in which a subject incorrectly aligned symmetrically instead of anti-symmetrically (see Table 3).

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*Table 3.* Only follower responses are displayed.

Discussion

These data confirm that cooperation dynamics that align agents symmetrically are generated automatically and without direction (Kelso, 2009). The present experiment shows that cooperative agents align themselves within symmetrical space when no specific instruction about how to behave is provided. Only when agents were instructed to align anti-symmetrically did spatial segregation occur. These behaviours are consistent with studies examining group-panic (Altshuler et al., 2005; Helbing et al., 2000; Saloma et al., 2003), which found agents aggregated and moved together in space when under duress. Here, information about where and how to move is extracted from the social milieu and executed spontaneously. In essence, environmental perturbations activated inter-agent alignments that flow with a unified directionality across space and time. Additional evidence from studies examining social thermoregulation found that agents aggregate through coordinated movements that operationally adjust group size and density to
counter energy dissipation under environmental stress (Ancel et al., 2015; Gerum et al., 2013; Waters et al., 2012; Zitterbart et al., 2011). Here, agents separate from the aggregation to expel energy and return to the aggregation to conserve it (Ancel et al., 1997; Gilbert et al., 2008). This same resource function was shown to operate in flocking birds (Hemelrijk et al., 2014) and schooling fish (Corcoran & Hedrick, 2019). These examples support the existence of dual inter-agent modes that operate based on directed and undirected aspects constrained by a spatiotemporal matrix. Within the constraints of this matrix, movements together are undirected, whereas movements apart are not. These findings support my claim that in humans, symmetrical dynamics are automatic, energy-efficient, and function as the behavioural template from which anti-symmetry is enacted through energy costly applied attention. Here, cooperative interactions are specified by a three-dimensional matrix in which the observer and the observed integrate self and other when symmetrical and segregate when not.

The realization above implies that symmetry binds collectives and the agents that comprise them across multiple levels of biological organization. Binding together is automatic and functions to conserve energy and maximizes computational processing by synchronizing perceptions and actions in expected space. Separation from the collective is energy costly and is triggered through internal thermoregulatory constraints, as shown in Emperor penguins (Ancel et al. 2015) or external stimuli as demonstrated in the present work. This dynamic suggests that multiscale stability arises from the shared structure generated when agents are bound together through symmetry-seeking. In this context, agents engage anti-symmetrically as a behavioural change function triggered by salient sources.
Conclusion

In this chapter, I provide evidence that self-organization in human coordination is automatic and undirected. Here, undirected dynamics conform to symmetrical space during interaction and supply the shared model for social exchange. Cooperative interactions within anti-symmetrical space occupy one's attention and require goal-direction for activation. These divergent interpersonal modes regulate themselves through undirected symmetry-seeking, which provides the stable structure upon which social adaptation via directed anti-symmetry is enabled. I claim that from this paradigm emerges a multiscale system sustained by groups of agents bound together through automatic imitation across invariant spatial and temporal scales.
Chapter 5

General Discussion

In this thesis, I hypothesized that cooperating groups of humans embody a self-integrating system capable of information processing and automatic response modulation when perturbed. The experimental paradigm I put forward confirms this hypothesis by exposing dual interpersonal modes (symmetrical and anti-symmetrical) specified by a spatiotemporal matrix. From this geometric matrix arises a collective mind bound together by imitation based on metastable symmetrical and anti-symmetrical coordination dynamics. The symmetrical form emerges automatically and without attention, whereas the anti-symmetrical form consumes attentional resources. In this paradigm, symmetry serves as the cooperative architecture on which anti-symmetrical interactions modify social dynamics. In other words, a cooperating group and its members coexist as integrated (undirected) and segregated (directed) aspects of a scale-invariant system of minds maintained by interpersonal symmetry-seeking (i.e., self-evidencing).

The existence of an internally generated spatiotemporal matrix is supported by research on hippocampal grid cells, i.e., cells that specify an agent’s environmental location by exhibiting spatially localized firing in response to internal and external geometric associations (O’Keefe & Dostrovsky 1971; O’Keefe & Nadel 1978). Here, each grid cell activates slightly different x, y-coordinates in the environment, which enable aggregations of grid cells to collectively organize using theta fluctuations to map the entire receptive field. These cells work in coordination with place cells, i.e., cells that detect environmental features based on their associative qualities and allocentric direction (O’Keefe, 1991). Both grid and place cells operate together to orient the nervous system within three-dimensional space specified by time (O’Keefe
& Burgess, 1996; Stensola & Moser, 2016). Functional magnetic resonance imaging (fMRI) and positron emission tomography studies revealed that working together with place and grid cells is a mirror neuron system, which researchers claim mediate automatic imitation effects by overlapping observed and executed actions (Aziz-Zadeh et al., 2006; Dinstein et al., 2007; Kilner et al., 2010; Gazzola et al., 2006; Gazzola et al., 2007). This mirror mechanism’s integrative function suggests that automatic imitation effects underpin the coordination of self-other integration and segregation. In other words, it is plausible that the symmetrical and anti-symmetrical modes of interaction give rise to the mirror neuron system (i.e., a self-regulating neural network generating a collective model embedded in a spatiotemporal matrix).

This plausibility finds credence given hemispatial neglect, a neurological condition characterized by sensory-attention deficits to intrapersonal and extrapersonal space on the contralesional side (Bisiach et al., 1979; Buxbaum et al., 2004). This link between behavioural and neuroanatomical features speaks to a strict bilateral partitioning of the nervous system’s internal and external space. Allochiria is a phenomenon in which some patients with hemispatial neglect incorrectly perceive contralateral stimuli as occurring in ipsilateral space (Grossi et al., 2004). In the example represented in Figure 7, a patient tasked to write the numbers 1 to 12 on a clock from memory wrote all twelve digits on the clock’s ipsilateral side while failing to notice the contralateral side of space. This transposition of contralateral stimuli to ipsilateral space during a task requiring attention supports the resource attenuation hypothesis of symmetrical (i.e., ipsilateral) interactions as described in this thesis. This implies that the high attentional resource costs associated with anti-symmetrical (i.e., contralateral) information processing resulted in a perceptual disconnection of contralateral space. This hemispatial disconnection
partitioned space bilaterally, which resulted in the content of the entire visual field outputting on the ipsilateral side of space. This neurological condition supports my claim that the nervous system constructs social reality by internally generating a spatiotemporal matrix that partitions the interpersonal world three-dimensionally. From here, inter-manual conflict, a neurological condition resulting from lesions to the frontal lobe and corpus callosum supports the dual nature of mind embedded in a matrix (Brainin et al., 2008; Nishikaw et al., 2001). Patients with inter-manual conflict exhibit inhibitory motor behaviours that execute without awareness. In a study by Nishikaw et al. (2001), a patient reported opening a sliding door with his right hand intending on going outside, when in quick succession, his left hand closed the door, preventing his exit. The patient reported that this conflict with his own left hand repeated over and over until he eventually called his wife for help. In an experiment by Brainin et al. (2008), a patient with inter-manual conflict was observed having a “tug of war between hands.” In a task requiring coordination between the left and right hands, the patient maintained motor control over the left hand; however, this resulted in the right hand operating autonomously and in direct opposition to the goal. Brainin et al. (2008) suggested that this behaviour can “be understood as sequences of complex inhibitory motor programmes that have become isolated from normal motor planning, which usually suppresses them via the contralateral cortico-subcortical prefrontal circuits and the corpus callosum” (Brainin et al., 2008: 246). Therefore, it is plausible that inter-manual conflict reveals the bilateral segregation of the mind and body into dual intrapersonal forms. Because these patients cannot inhibit the undirected form, actions of the right hand appears to operate autonomously when attention is occupied by the left hand’s use of the directed form. In a normal functioning brain, inhibition suppresses the undirected (automatic) form while the directed
(intentional) form occupies attention. Thus, the oppositional behaviours observed in inter-manual conflict could be these dual intrapersonal forms operating independently.

Figure 7. “In drawing a clock from memory, [patient 1] spontaneously started writing numbers clockwise and showed right allochiria (left panel), but when he was required to write numbers in an anti-clockwise direction, he located all digits in the left half of the clock (right panel)” (Grossi et al., 2004: 512). Reproduced with permission from Grossi et al. (2004).

Conclusion

This thesis provides a methodological design that is ecologically sensitive to the nature of interpersonal coordination because of its use of real-life social interaction as the focus of analysis. Moreover, the three-dimensional design enables a group to be analyzed using multimodal coordination dynamics specified by spatial and temporal invariance. I’ve shown that this paradigm embeds a collective mind in a matrix that allows one to observe symmetry-breaking at criticality induced by self-organization that normalize agents in symmetrical space under internal or external perturbations. For this reason, I propose that neural criticality predicts interpersonal symmetry-breaking. If correct, future neuroimaging studies using the methods presented in this thesis should observe neural oscillations that generate
activity patterns recapitulated at multiple levels of biological order. This means activity patterns should emerge from brain states and propagate out to subsume interpersonal states in a scale-invariant wave. In other words, spatial and temporal patterns of activity should flow from intrapersonal to interpersonal and back in a recursive manner. Further, changes in the order of magnitude should correspond with predictable changes in the level of biological organization under observation. Consequently, symmetrical interactions should produce activity patterns that arise quickly and efficiently compared to the anti-symmetrical form. These activity patterns should emerge in brain regions that reliably predict interpersonal symmetry-breaking at criticality. The implication of this finding would indicate that symmetrical and anti-symmetrical interactions are fundamental states that define collective dynamics. I suggest this because they would demonstrate that interpersonal symmetry-seeking provides stability to groups and their members down to neural networks and cells, which would reveal the fractal-like architecture of collective dynamics at multiple levels of biological organization.
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https://doi.org/10.1037/a0022288


https://doi.org/10.1111/nous.12062


https://doi.org/10.1002/9783527651009


Appendix A: Consent Form

Research Project Title: Processes of Imitation
Principal Investigators: Emmanuel Olarewaju
Supervisor: Jason Leboe-McGowan
Contact Information:
P219 Duff Roblin, 1(204) 5989579
Department of Psychology
Duff Roblin Building, University of Manitoba
Winnipeg, MB R3T 2N2
umolaree@umanitoba.ca

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about, and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose: The general purpose of this research is to examine how the speed and efficiency with which participants imitating the actions of another individual. Gaining insights into these processes will be useful in better understanding how the processes that underlie cooperative behaviour.

Description: The experiment will be completed in two sessions. For each session, you will complete the procedure at a computing station with another participant. Each participant, will take turns fulfilling the role of 'imitator', in which you will either imitate or counter-imitate the actions of the other participant, and the role of 'model', in which you will generate responses that the other participant will either imitate or counter-imitate. Regardless of your role as 'imitator' or 'model', or whether your task will be to imitate or counter-imitate, your responses will simply involve pressing a button in response to either a prompt on the computer screen or the response generated by another participant. The sessions may be recorded on video if consent of both participants is given. The recorded video will be used to further examine behaviour and code responses. Note, you have the option to decline being videotaped.

Risks: There are no risks associated with the experiment.

Benefits: The benefit will be for better understanding the processes that underlie cooperative behaviour.

Confidentiality: Confidentiality will be respected. Data and video recordings will be kept in a secure office, P219 Duff Roblin, to which only the researchers will have access. No information that discloses your identity will be released or published. The data collected from this study will be destroyed five years after this research has been published. Data collected will include names from the consent forms, as well as your age, and gender of participants will potentially be
released or published: any other identifiers, such as your name, will not be used and will be destroyed a month after the experiments are completed.

Participation: Your participation in this study is completely voluntary. If you choose to participate, you have the right to discontinue your participation at any time during or after this experiment, even after signing this form. Should you choose not to participate or choose to stop once you have begun, you will still receive your experimental credits.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba Research Ethics Board(s) and a representative(s) of the University of Manitoba Research Quality Management/Assurance office may also require access to your research records for safety and quality assurance purposes.

This research has been approved by the Psychology/Sociology Research Ethics Board at the University of Manitoba. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122, or e-mail Margaret_bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Consent: I have read and understood the above information and agree to participate in this experiment. I understand that I may keep a copy of this form for my own records.

I consent to be recorded on video [place an X where appropriate]: Yes _____ or No _____

Participant's Signature __________________________ Date __________________

Name of Participant (Please Print) __________________________

Researcher's Signature __________________________
If you would like to receive information about the results of this study once it has been completed, please leave your email address on the line below, this however is entirely optional. You will be contacted by the Principal Investigator with a summary of the results in approximately 5 months’ time. Remember, analysis of the data for this experiment will not identify you or your results personally. Your email address will be kept strictly confidential. Thank you for your participation.

Email (optional)
## Appendix B1: Experiment 1a – Individual Response Measures

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| Mean (milliseconds) | 422 | 431 | 306 | 383 |