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Effects of Focused-Attention and Loving-Kindness Meditation Inductions on Tacit Coordination Performance

An Experimental and Cognitive Modeling Approach

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ABSTRACT

Tacit coordination describes the social process of coordinating without being able to communicate. It requires the use of focal points: mutually recognized obvious options or rules. Tacit coordination has been suggested to depend on Theory of Mind, and therefore should require executive functions such as working memory, attention and inhibition. These cognitive functions, as well as the process of perspective-taking, are hypothesized to be improved by meditation practice. More specifically, focused-attention meditation (FAM) has been found to improve attentional control and prosocial behavior, and loving-kindness meditation (LKM) has been shown to increase social perspective-taking. The current work investigated the effects of FAM and LKM inductions on thoughts and performance during a tacit coordination task. Both meditation inductions were assumed to improve task performance through increases in on-task thought and other-focused thought, respectively. In addition, trait levels of empathy and mindfulness were hypothesized to predict the aforementioned measures.

An experiment was conducted in which dyads performed a task with the objective of repeatedly selecting the same out of four abstract images without communicating. In this task, successful coordination is the result of the emergence of focal points over time. Task performance was compared before and after a ten-minute meditation induction. Results show no significant effects of FAM or LKM on task performance, or on-task and other-focused thought, compared to the control intervention. Trait levels of empathy and mindfulness were not found to be predictive of these measures either. Explanations are offered for these results, and limitations of the experiment are discussed.

Additionally, a cognitive model was created to examine the cognitive processes underlying tacit coordination. An instance-based learning (IBL) model played the task described above with a computer agent. Model behavior approximated human behavior only when randomness was added to its decision-making process. IBL is concluded to be insufficient in explaining human behavior during a tacit coordination task.

All in all, this work has made new connections between research areas, and can be considered a starting point for more extensive research on tacit coordination, meditation, and the modeling of social cognition.

CONTENTS

1 INTRODUCTION **3**

2 THEORETICAL BACKGROUND **4**
2.1 Tacit coordination 4
2.2 Meditation 6
2.3 Research questions 9

3 EXPERIMENT **11**
3.1 Methods 11
3.2 Results 15
3.3 Discussion 18

4 COGNITIVE MODEL **22**
4.1 Methods 22
4.2 Results 24
4.3 Discussion 25

5 GENERAL DISCUSSION **29**

REFERENCES **30**

A ACKNOWLEDGEMENTS **38**

B FIGURES **38**

1 INTRODUCTION

Many situations in daily life require coordinating with another person without being able to communicate: merging on the highway, reconvening with a lost companion whose phone is out of battery, or dancing with a partner. This process is referred to as tacit coordination, and has been a topic of interest within the field of social cognition since the 1960s. Tacit coordination problems can be solved through the use of focal points: decision conventions that are deemed obvious by those who are involved. Focal points may be based on a salient property inherent to the solution, or they may emerge spontaneously over time if similar coordination problems are encountered multiple times.

This Master's Thesis focuses on the emergence of focal points over time in a tacit coordination game. In particular, it questions whether this emergence is aided by practicing two types of meditation: focused-attention meditation and loving-kindness meditation. These have been hypothesized to improve certain cognitive processes that are also thought to be involved with tacit coordination. Additionally, a cognitive model is created in an attempt to explain the cognitive mechanisms underlying tacit coordination.

The next section will provide theoretical background on the two topics of interest: tacit coordination and meditation practice. Research questions and hypotheses are presented, after which the experimental study on meditation and tacit coordination is discussed. Next, the cognitive modeling study is presented, ending with a general discussion.

2 THEORETICAL BACKGROUND

2.1 Tacit coordination

Consider two spouses losing each other in a department store. How will they coordinate where to meet if they are unable to communicate with each other? This is a classic example of a tacit coordination problem, introduced by Schelling in his 1960 book *The Strategy of Conflict*. In situations like these, people must coordinate their behavior based on their predictions and expectations of one another. This often involves the use of a *focal point* (Mehta, Starmer, & Sugden, 1994b): a mutually recognized "obvious option" or "rule" allowing the two parties to socially coordinate (for a review of focal point theory, see Van der Rijt, 2019). For example, the spouses may both decide to go to the "lost and found" department and reunite there (Schelling, 1960). The following section will discuss how tacit coordination and focal points have been investigated, and which cognitive processes have been suggested to be involved in it.

2.1.1 Coordination games

Tacit coordination is often investigated using coordination games. A specific type of tacit coordination game is of interest to the present study: repeated pure coordination games with two players. The choice of this type of game will be explained by discussion of its three facets (pure coordination, two players, repetition) and their relation to the concepts of focal points and coordination.

Firstly, in *pure coordination games* players share a common goal with equal payoff for any chosen solution. It is therefore in the players' best interest to cooperate, and it does not matter in which way they do so (Mehta, Starmer, & Sugden, 1994a; Schelling, 1960). In contrast, divergent interest coordination games involve dissimilar payoffs for particular solutions, requiring players to balance cooperation and the pursuit of their own interests (Mizrahi, Laufer, & Zuckerman, 2021b). Such a tradeoff negatively impacts coordination (Crawford, Gneezy, & Rottenstreich, 2008), making this type of game less suitable for studying the dynamics of cooperation. A classic example of a pure coordination game concerns players answering questions with the goal of providing the same answer as a partner. An experiment suggested by Schelling (1960) and first carried out by Mehta et al. (1994a) shows that many players are able to coordinate in this way. For example, upon the instruction "Name any mountain", Mehta et al. (1994a) demonstrate 89% of players answering "Everest". Mount Everest evidently is a focal point for many players, "perhaps because Everest ranks first on an obvious scale of comparison for mountains, namely height" (Mehta et al., 1994a, p. 180). As a more abstract example, consider the "Assign Circles" game (Mehta et al., 1994a, 1994b; Mizrahi, Laufer, & Zuckerman, 2019, 2020, 2022). Players need to assign a number of circles to one of two squares on a grid, with the goal of creating the same assignment as another player. Results show that the rule of proximity acts as a focal point for most players. Depending on the type of pure coordination game, other sources of focal points may include social norms such as fairness (De Kwaadsteniet & Van Dijk, 2012) or social information about the other player (Abele, Stasser, & Chartier, 2014).

Secondly, two-player games are considered because they offer theoretical and methodological simplicity compared to the complexity of group coordination. They allow studying tacit coordination in its purest form, since group coordination involves intra-group *explicit* communication (e.g. Sitzia & Zheng, 2019; Van Elten & Penczynski, 2020).

Thirdly and finally, the current work focuses on repeated games. Often, the study of tacit coordination considers one-shot games such as the Assign Circles game discussed above. In these types of unrepeated games, focal points are the result of some inherent salience of a solution. Alberti, Sugden, and Tsutsui (2012) introduce a difference source of salience, namely spontaneous emergence over time through learning. They employ a repeated two-player tacit pure coordination game in which players are shown four abstract images and are instructed to choose the same image as they think the other player will choose (see Alberti, Heap, & Sugden, 2011). This singular game is repeated many times with similar images. Alberti et al. (2012) demonstrate that this game leads to the emergence of focal points in the shape of conventions or decision rules. This phenomenon could be explained by Crawford and Haller (1990)'s theory of repeated coordination: "In each case, players begin by searching for a pair of actions to serve as a coordination precedent and then use this precedent to maintain coordination." (p. 577). This explanation is echoed by Sugden (2011), who writes that "arbitrary asymmetries between players tend to precipitate the evolution of correspondingly arbitrary conventions" (p. 39). However, these theories have not yet been supported by experimental evidence. In summary, a repeated two-player pure coordination game is chosen because it allows studying the emergence of focal points in a cooperation effort between two individuals.

2.1.2 Tacit coordination and cognition

In a pure coordination game, "the best choice for either [player] depends on what he expects the other to do, knowing that the other is similarly guided, so that each is aware that each must try to guess what the second guesses the first will guess the second to guess and so on" (Schelling, 1960, p. 87). Tacit coordination must therefore involve cognitive perspective-taking (De Kwaadsteniet & Van Dijk, 2012) which falls under Theory of Mind (ToM; Barnes-Holmes, McHugh, & Barnes-Holmes, 2004). The concept of ToM was first introduced by Premack and Woodruff (1978) who define it as imputing mental states to oneself and to others, which facilitates the prediction of other people's or one's own behavior. The link between ToM and tacit coordination is supported by a growing body of literature (e.g. De Weerd, Verbrugge, & Verheij, 2015; McMillan, Rascovsky, Khella, Clark, & Grossman, 2011; Yoshida, Dolan, & Friston, 2008). The following discussion of the cognitive processes involved with tacit coordination will therefore mainly focus on ToM.

In the past, researchers have theorized that ToM occurs spontaneously, involuntarily, and without effort (such as Samson, Apperly, Braithwaite, Andrews, and Scott (2010); see Cole & Millett, 2019). However, dual-task paradigms have shown over the years that ToM and perspective-taking do require mental effort and cognitive resources. More specifically, ToM is associated with executive functions such as working memory, attention and inhibition (Bull, Phillips, & Conway, 2008; McKinnon & Moscovitch, 2007; Qureshi & Monk, 2018). Studies by Fizke, Barthel, Peters, and Rakoczy (2014) and Maehara and Saito (2011) suggest that these functions are particularly involved in the coordination of one's own and another's perspective. Their explanations focus on different facets of executive functions. Fizke et al. (2014) attribute the coordination of perspectives to the inhibition of one's own perspective based on a correlational study in children. Maehara and Saito (2011) on the other hand declare it to depend on working memory based on a dual-task paradigm in adults.

Having discussed possible cognitive underpinnings of ToM, the next step is to consider what these studies can predict about tacit coordination in a pure coordination game. Importantly, all previously mentioned ToM studies are single-participant paradigms in which participants are tasked with considering the hypothetical perspective of a fictional individual. In these situations, participants are detached spectators who are not actively engaging with another person, limiting the conclusions that can be drawn about mechanisms in social cognition (Schilbach et al., 2013). As of yet, there have been only two studies centering around the cognitive processes involved in pure coordination. Mizrahi et al. (2020) demonstrate that coordination ability in a one-shot word selection task correlates with an electrophysiological marker of cognitive load. Newman, Cao, Täuber, and Van Vugt (2021) employed a dual-task paradigm, combining Alberti et al. (2012)'s repeated coordination image selection task with an *n*-back task. They found working memory load to impair pure coordination performance. In conclusion, while research is severely lacking in this area, tacit coordination is suggested to rely on executive functions: working memory, attention and inhibition.

A question of interest, then, is whether tacit coordination performance can be improved. Based on the literature discussed above, any factor that aids executive functions should be expected to also enhance coordination. Furthermore, coordination could be improved by increasing ToM and perspective-taking directly. Both of these mechanisms have been shown to be impacted by meditation, which may therefore improve tacit coordination performance.

2.2 Meditation

Around fifty years ago, meditation practices from traditions such as Zen, Buddhism and Yoga, separated from their cultural and spiritual format, started to gain scientific interest related to their psychotherapeutic and physiological (Shapiro, 1982) and behavioral effects (Kabat-Zinn, Lipworth, & Burney, 1985). As mentioned before, the current study focuses on the effects of meditation on both executive functions and prosocial and perspective-taking behavior. More specifically, focused-attention meditation and loving-kindness meditation practices are considered.

2.2.1 Focused-attention meditation

Focused-attention meditation (FAM) is aimed at training the focusing and sustaining of attention. It involves directing attention to one particular object or sensation, most often one's own breathing, and upon distraction, shifting attention back to it (Lippelt, Hommel, & Colzato, 2014). As Lutz, Slagter, Dunne, and Davidson (2008) describe, FAM improves three skills associated with attentional regulation: directing and sustaining attention towards an object; monitoring the quality of attention and detecting distractors; and disengaging attention from distractors and shifting it toward the initial object. Additionally, meditators are encouraged to observe the event of getting distracted in a nonjudgmental manner, relating to the concept of mindfulness (see Kabat-Zinn, 2003). Many studies use the term "mindfulness meditation" to refer to focused-attention meditation (e.g. Baranski, 2021; Berry et al., 2023).

A number of neuroimaging studies have been dedicated to investigating FAM and executive functions as a whole. Ganesan et al. (2022) conclude from their meta-analysis of 28 fMRI studies that executive functions are invoked when practicing FAM. The three facets of executive functions (working memory, attention and inhibition) will now be considered individually in their relationship to FAM.

Firstly, evidence on the effects of FAM on working memory (WM) has been mixed. Ma, Deng, and Hommel (2021) suggest that FAM improves WM performance as measured by an *n*-back task, but only if task demand is neither too low nor too high. Yamaya et al. (2021) found FAM to increase WM capacity, a finding that is in contrast with Baranski and Was (2018) who did not find an increase in WM capacity. Additionally, a meta-analysis by Yakobi, Smilek, and Danckert (2021) (8 studies) shows no WM improvement after mindfulness meditation practice.

Next, evidence for focused-attention meditation strengthening attentional mechanisms is robust. Meta-analyses by Chiesa, Calati, and Serretti (2011) (15 studies), Sumantry and Stewart (2021) (78 studies) and Yakobi et al. (2021) (14 studies) show significant effects of FAM practice on a range of facets of attention, such as executive control, general attention and selective attention.

Lastly, findings regarding the effects of focused-attention meditation on inhibition are inconclusive. A review by Gallant (2016) (6 studies) shows positive effects of mindfulness meditation on inhibitory control as measured by the Stroop task (Stroop, 1935) among other tests. In contrast, a more recent study by Baranski (2021) does not show FAM practice to influence inhibition.

All in all, results on the effects of FAM on executive functions are quite mixed. Positive effects for attentional processes are evident, but there is no strong evidence for effects on working memory or inhibition. A tentative prediction is therefore that FAM could affect tacit coordination through improving Theory of Mind due to its reliance on executive functions.

In addition to executive functions, focused-attention meditation has also been linked to prosocial behavior, defined by Eisenberg, Fabes, and Spinrad (2007) as "voluntary behavior intended to benefit another" (p. 646). For example, Condon, Desbordes, Miller, and DeSteno (2013) and Lim, Condon, and DeSteno (2015) found that participants that completed a mindfulness training were more likely to offer their seat to a disabled individual. Additionally, a meta-analysis by Donald et al. (2018) (21 studies) shows mindfulness interventions to have a moderate positive effect on prosocial behavior. In the same vein, Berry et al. (2023) found that an FAM intervention increased participants' empathetic concern and helping behavior towards an ostracized racial outgroup member. Taken together, these results suggest that focused-attention meditation could positively influence coordination through an increase in prosocial behavior.

The skills and attitudes that are trained in focused-attention meditation are associated with mindfulness. Trait mindfulness can be assessed through self-reports via the Five Facet Mindfulness Questionnaire (FFMQ; see Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Baer et al., 2008). In order to measure mindfulness across different dimensions, the FFMQ consists of five subscales: *Act with Awareness*, *Describe*, *Nonjudge*, *Nonreact*, and *Observe*. Items are presented as a statement to which a participant responds using a five-point Likert scale (1 = *Never or very rarely true*, 5 = *Very often or always true*). Since the original FFMQ consists of 39 questions (Baer et al., 2006), it is often shortened to lower response burden. Medvedev, Titkova, Siegert, Hwang, and Krägeloh (2018) recommend using an 18-item modified FFMQ.

2.2.2 Loving-kindness meditation

Loving-kindness meditation (LKM) may impact tacit coordination through an increase in ToM and perspective-taking. Instead of being related to attentional modulation like FAM, LKM is concerned with the cultivation of positive affective thoughts toward other individuals, resulting in feelings of kindness or compassion (Dahl, Lutz, & Davidson, 2015). All LKM practices have the goal of directing kindness to others as one would to oneself, though they might differ in their specific approaches. Traditionally, the extension of compassion is progressively broadened from oneself, to a loved one, then to a neutral person or stranger, toward a difficult person, and finally to the whole universe (Galante, Galante, Bekkers, & Gallacher, 2014; Vago & Silbersweig, 2012). In directing kindness to a person one has negative feelings toward, the meditator is encouraged to replace these with positive feelings such as empathic concern (Lippelt et al., 2014). Generally, the target is first visualized, after which compassion is directed to them by for example repeating mantra-like phrases ("may you be happy, may you be healthy, may you be free from all pain" in Seppala, Hutcherson, Nguyen, Doty, & Gross, 2014), or visualizing a light flowing from oneself to the target (Galante et al., 2014).

The benefits of loving-kindness meditation are related to emotions more so than to general cognitive resources such as attention. In meta-analyses focused on self-reports, Reilly and Stuyvenberg (2022) found LKM practice to have a moderate positive effect on self-compassion across seven studies, and Zeng, Chiu, Wang, Oei, and Leung (2015) found LKM to increase positive emotions in general across 24 studies. Additionally, in an empirical study Leppma and Young (2016) report LKM positively influencing self-reported perspective-taking. All findings above are corroborated by a meta-analysis of 22 studies by Galante et al. (2014), who present an important caveat to self-reports in this context: LKM being quite explicitly connected to compassion and empathy invites a social desirability bias in reporting. However, Galante et al. (2014)'s analysis also shows implicit measures of the effects of LKM unlikely to be influenced by social biases, such as a positive shift in affective learning. Using implicit measures as well, Seppala et al. (2014) showed LKM to decrease self-focus in a pronoun-choice task by Wegner and Giuliano (1980). For the current purposes, the benefits related to perspective-taking are most relevant. They predict that LKM may improve coordination performance.

Loving-kindness meditation has been related to the cultivation of empathy and compassion (Bibeau, Dionne, & Leblanc, 2015; Galante et al., 2014) which can be seen as personal traits with a baseline level for each individual. In measuring this level, the Interpersonal Reactivity Index (IRI; see Davis, 1980, 1983) has been the most used scale of empathy in social situations (Leppma & Young, 2016), measuring both cognitive and emotional facets of empathy. It consists of the four subscales *Perspective-taking*, *Fantasy*, *Empathetic Concern* and *Personal Distress*. The 28 items are presented as statements, and answers are given in a five-point scale format (1 = *Does not describe me well*, 5 = *Describes me very well*).

2.2.3 Meditation in research

Studies on the effects of meditation practice vary greatly in their methodology. Administration of meditation interventions can occur over multiple days or even weeks (Heppner & Shirk, 2018). These interventions often intend to elicit a long-lasting effect. In contrast, many experimental studies are aimed at inducing a temporary state of mindfulness. These short meditation inductions (5–45 minutes) are particularly useful in experimental research since they separate specific meditation practices from other possibly therapeutic elements of meditation sessions (Gill, Renault, Campbell, Rainville, & Khoury, 2020), such as a social aspect. Additionally, they allow for proper randomized control trials. As a result of these methodological benefits "the momentary cognitive impact of specific mindfulness instructions can be evaluated with high confidence" (Gill et al., 2020, p. 2).

2.3 Research questions

A number of research questions emerge from the theoretical background outlined above. The first relate to the influence of meditation inductions on thoughts and performance during a tacit coordination task. Associated hypothesis are provided.

RQ1: *Do meditation inductions affect the frequency of on- vs. off-task thought and/or self- vs. other-focused thought during coordination?* Based on findings regarding mindfulness and executive functions, it is hypothesized that an FAM meditation induction increases the frequency of on-task thought during a coordination task. An LKM induction may increase the frequency of other-focused thought based on its link to perspective-taking.

RQ2: *Do meditation inductions affect coordination performance through changes in thought content?* Both FAM and LKM meditation inductions are expected to improve coordination performance compared to a control intervention. These improvements are hypothesized to be mediated by the increases in on-task thought (FAM) and other-focused thought (LKM) that are described in RQ1.

As previously mentioned, the meditation practices are associated with trait levels of mindfulness and empathy which differ per individual. The following questions consider what these levels (as measured by the FFMQ and IRI questionnaires) can predict about tacit coordination.

RQ3: *Do levels of mindfulness and/or empathy predict the frequency of on- vs. off-task thought and/or self- vs. other-focused thought during coordination?* Mindfulness levels are expected to predict the frequency of on- vs. off-task thought and empathy levels are expected to predict self- vs. other-focused thought.

RQ4: *Do levels of mindfulness and/or empathy predict coordination performance?* It is hypothesized that coordination performance is predicted by frequency of on-task and/or other-focused thought. Combining this with RQ3, trait levels of mindfulness and/or empathy are expected to correlate positively with tacit coordination performance.

These four questions will be explored in the experimental study that follows. Additionally, a cognitive model will be created in an attempt to shed more light on the emergence of focal points in a tacit coordination game. In particular, the theory of instance-based learning (IBL; see Gonzalez, Lerch, & Lebiere, 2003) will be employed, leading to the last research question:

RQ5: *Can the emergence of focal points in a coordination game be predicted by a cognitive model of instance-based learning?* The theory of instance-based learning is expected to be applicable to a Theory of Mind task such as a tacit coordination game. Human performance in such a game should therefore be predictable using an IBL model.

3 EXPERIMENT

3.1 Methods

3.1.1 Participants

A total of 112 volunteers aged 17–33 ($M = 21.2$; $SD = 2.78$) participated in this experiment. Participants were divided into 56 dyads: 16 male dyads, 37 female dyads and 3 mixed dyads. Same-sex dyads were preferred since, as Cheng, Li, and Hu (2015) suggest, different neural processes underly cooperation in same-sex versus mixed-sex dyads. Prior to the experiment it was ensured that dyad members did not know each other such that there was no pre-existing social knowledge (see Chartier & Abele, 2015). All participants had normal or corrected-to-normal color vision and did not have any neurological injury or illness. Participants received monetary compensation for their time. The experiment was approved by the Research Ethics Committee (CETO).

3.1.2 Design

This experiment employed both a within-subject and between-subject design. Within subjects, tacit coordination performance before the meditation induction was regarded as the baseline performance, to which performance after the induction could be compared. The differential effects of the two meditation types relative to the control intervention were compared between dyads.

The experiment consisted of two blocks of ninety trials each. One block involved stimuli varying across color while the other varied across shape. The block order was counterbalanced across dyads. The order of the stimuli within a block was randomized across dyads. One-sixth of trials (fifteen per block) were followed by a thought probe to explore participants' thought content (see Section 3.1.4). These trials were determined using a random seed and were therefore random but fixed across all participants.

Participants were subjected to a ten-minute meditation induction between the two blocks. The inductions varied across three conditions: focused attention meditation, loving-kindness meditation and a neutral control intervention (see Section 3.1.5).

3.1.3 Experimental procedure

After being welcomed by the experimenter, participants sat down at separate desks with a bookcase in between, preventing them from seeing each other. Participants were asked to briefly introduce themselves to each other, such that all dyads were approximately equally familiar with each other. Before starting the task, participants answered the IRI and FFMQ-18 questionnaires through an online form (see Section 3.1.6). Instructions to the task were provided as written text on the monitors. These instructions started with information on the general aim of the task – that is: selecting the same image as the other person without communicating. The task was then explained in more detail by through the description of a trial sequence. Participants were explicitly

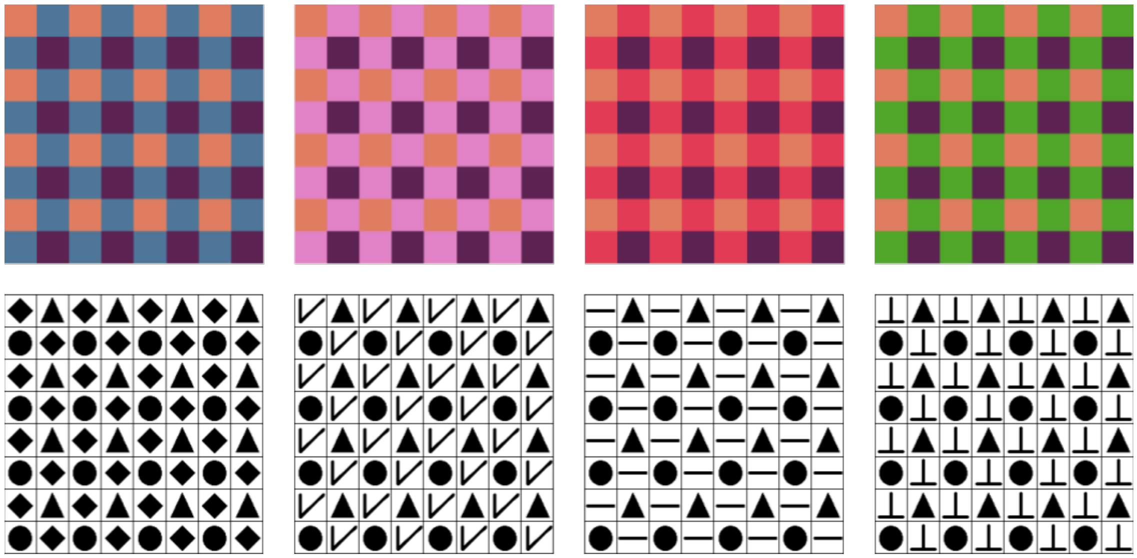


Figure 1: Example of stimuli used in the experiment. The four abstract images shown to dyads differed across either color (top) or shape (bottom). From Newman et al. (2021)

instructed to not choose an image based on position on the screen as these were different for both participants. They also received instructions about the thought probe.

Both blocks started with the aforementioned instructions, followed a practice round in order to get participants familiar with the stimuli and the task. A practice round consisted of three trials followed by one thought probe. Afterward, on-screen instructions reminded participants to not communicate during the task and to pay attention to the other person's choice. Participants were able to ask the experimenter questions at this stage, after which the experiment began.

After the first block, participants could take a self-paced break. They were then subjected to a ten-minute meditation induction. In the instructions before and during the experiment, this induction was referred to as "an intermission to help [the participant] relax" to obscure the goal of the intervention from the participant, which otherwise might have affected their performance. After the intervention, participants completed the second block of trials. Altogether, the experiment lasted around 60 minutes. Participants were compensated €10 per hour for their time, plus a performance bonus of up to €4.

3.1.4 Task

The tacit coordination game that was used was designed by Alberti and colleagues to investigate experiential learning and the resulting emergence of conventions (see Alberti et al., 2011, 2012). The goal of the task was for dyad members to choose the same image out of four abstract images without communicating in any way.

An example of the stimuli, which were adapted from Newman et al. (2021), is shown in Figure 1. An image contained three distinct items (colors or shapes) arranged in a grid. Two of these items were fixed across the four images (e.g., orange and mauve in the top row of Figure 1). One item differed across images, and its location was randomized between trials.

Following Newman et al. (2021) a trial sequence consisted of the following. A fixation dot was shown to both participants with a duration between 1000 and 3500 ms that was randomly determined at intervals of 500 ms. The four images were then presented to the participants simultaneously and in a random order. Participants had to select an image through a key press, to which there was no time limit. After both participants responded feedback was provided for 3000 ms as "YOUR CHOICE" displayed above and "OTHER'S CHOICE" below the respective images, after which a new trial started. The trial sequence is illustrated in Figure B.1.

Thought probes were inserted after one-sixth of the trials. The thought probe ("What were you thinking about before you chose an image?") and answer options, which are shown in Table 1, were largely based on previous work (Huijser, Van Vugt, & Taatgen, 2018; Jin, Borst, & Van Vugt, 2019) with one modification: the option for task-related thought could either include consideration of the other player's choice process or not.

	Answer option	**Coded as**
(1)	I thought about which image to choose based on what the other person would choose	On-task; other-focused
(2)	I thought about which image to choose without basing my decision on what the other person would choose	On-task; self-focused
(3)	I was evaluating aspects of the task (e.g., my performance, how long it takes, difficulty of the task)	Off-task
(4)	I was distracted by my environment (sound/temperature, etc.) or by my physical state (hungry/thirsty)	Off-task
(5)	I was daydreaming/I thought about task-unrelated things	Off-task
(6)	I was not paying attention, but I did not think about anything specific	Off-task

Table 1: Response options for the thought probe "What were you thinking about before you chose an image?" and their respective interpretations.

The instructions for the thought probe included the request for participants to be as honest and accurate as possible with their answers. This is based on work by Robison, Miller, and Unsworth (2019) who warn against participants being hesitant to report off-task thought due to a social desirability bias. Participants responded to the thought probe via key press, and there was no response time limit. The next trial commenced when both participants responded.

The experiment was written in OpenSesame (Mathôt, Schreij, & Theeuwes, 2012) and presented to dyads on two separate computer monitors. Participants responded using two separate keyboards.

3.1.5 Meditation induction

All meditation inductions were recorded by the same speaker and were administered to participants through a pair of headphones. They all lasted for approximately ten minutes.

One third of participants performed a focused attention meditation (FAM) which centers around bodily experiences. Participants were instructed to solely pay attention to the rhythm of their breath. If they noticed they were distracted they were to return their focus to their breath. The content of this meditation induction was based on a FAM induction by Baas, Nevicka, and Ten Velden (2014), which Ma et al. (2021) utilized to show that mindfulness training promotes working memory performance.

Another third of participants was subjected to a loving-kindness meditation (LKM) induction, which generally involved wishing wellbeing to others as one would to themself. Participants imagined extending feelings of love and compassion first toward loved ones, then acquaintances, and then to the whole world. The content of the meditation was based on work by Seppala et al. (2014) who found it to improve feelings of social connectedness, and decrease self-focus.

The remaining third of participants were in the control group. They performed a neutral visualization exercise designed by Seppala et al. (2014), requiring them to visualize locations such as a drugstore or laundry room in as much detail as possible. This control intervention was chosen due to it being similar to the meditation interventions in terms of visualization, but unrelated to modulating attention or compassion.

3.1.6 Questionnaires

The positive effects of FAM and LKM are associated with a baseline level differing per individual. Questionnaires were therefore used to gain insight into participants' general level of mindfulness and empathy. Mindfulness level was examined using the Five Facet Mindfulness Questionnaire (FFMQ), which includes the subscales Act with Awareness, Describe, Nonjudge, Nonreact, and Observe. Instead of the original 39-item version (see Baer et al., 2006), a shortened version (FFMQ-18) was used as recommended by Medvedev et al. (2018) in order to save time. Empathy level was probed using the 28-item Interpersonal Reactivity Index (IRI; Davis, 1983), which includes the subscales Perspective-Taking, Fantasy, Empathic Concern, and Personal Distress.

3.1.7 Data analysis

All data were analyzed using the R programming language (R Core Team, 2021). Three dependent variables of interest emerge from the research questions described in Section 2.3: on-task thought as proportion of total thought, other-focused thought as proportion of total thought, and tacit coordination performance (i.e., accuracy). The effects of meditation intervention, as well as trait levels of empathy and mindfulness on these dependent variables, were analyzed using linear mixed-effects (LME) models from the `lme4` package (Bates, Mächler, Bolker, & Walker, 2015). More specifically, null models were compared with full models. Null models included fixed effects of stimulus type and block number, and session number as a random intercept. Full models included these variables and the predictor of interest (e.g., mindfulness level). Model comparisons were performed using chi-square tests. Moreover, Bayes factors (from the `BayesFactor` package; Morey & Rouder, 2022) were computed for these model comparisons to quantify evidence for the null hypothesis. In this context, BF_{01} refers to the likelihood of the null model relative to the full model, and vice versa for BF_{10}. In estimating the strength of the evidence M. Lee and Wagenmakers (2013)'s scale is used in which $BF = 1$ corresponds to no evidence, $1 < BF < 3$ corresponds to anecdotal evidence, and $3 < BF < 10$ corresponds to moderate evidence.

In addition, the non-linear progression of performance across trials was analyzed using a generalized additive mixed-effects (GAM) model from the `mgcv` package (Wood, 2011). This model aimed to find whether intervention type influenced task performance over time. It included three parametric slopes (block number, stimulus type and intervention type), one spline for trial number, and three splines across trial number (a random factor smooth per session and splines for block number and intervention type). A spline for stimulus type was not included to prevent overfitting, and because a non-linear effect of stimulus type was not expected. Both block number and intervention type were considered as ordered factors, such that performance post-intervention was compared to pre-intervention, and that the two meditation interventions were compared to the control intervention.

3.2 Results

Participants were able to cooperate rather successfully in the tacit coordination game: mean accuracy across the whole task was 0.76 ± 0.014. This accuracy was significantly affected by block number ($\chi^2(1) = 25.3$, $p < 0.001$; $BF_{10} > 100$), with an estimated post-intervention increase in accuracy of 0.11 ± 0.020 (see Figure 2).

As a GAM model showed (see Figure 3a), task performance progressed non-linearly over time. In this model, block number is significant both as a parametric slope (estimate = 0.47 ± 0.037; $z = 12.5$, $p < 0.001$) and as a spline over trial ($\chi^2 = 10.7$, edf[1] = 3.08, $p = 0.021$). In other words, performance is increased in the second compared to the first block in not only a linear, but also a non-linear fashion.

Thought probe answers showed participants being on-task nearly constantly with an average frequency of on-task thought of $92.2\% \pm 0.9\%$. This frequency did not differ between blocks ($\chi^2(1) = 0.55$, $p = 0.46$; $BF_{01} = 4.68 \pm 12.7\%$). Similarly, other-focused thought occurred with an average frequency of $81.3\% \pm 1.5\%$, and also did not differ between blocks ($\chi^2(1) = 0.17$, $p = 0.68$; $BF_{01} = 5.53 \pm 12.6\%$). Results will now be discussed in order of the research questions that they are linked to (see Section 2.3).

3.2.1 Meditation inductions and thoughts

It is first asked whether meditation inductions had an effect on thought content. Results do not indicate that intervention type had an effect on frequency of on-/off-task thought ($\chi^2(2) = 0.089$, $p = 0.96$). Bayes factor analysis confirms that intervention type likely did not influence on-task frequency ($BF_{01} = 6.33 \pm 13.6\%$). The same is true for frequency of self-/other-focused thought: in-

[1] edf = estimated degrees of freedom.

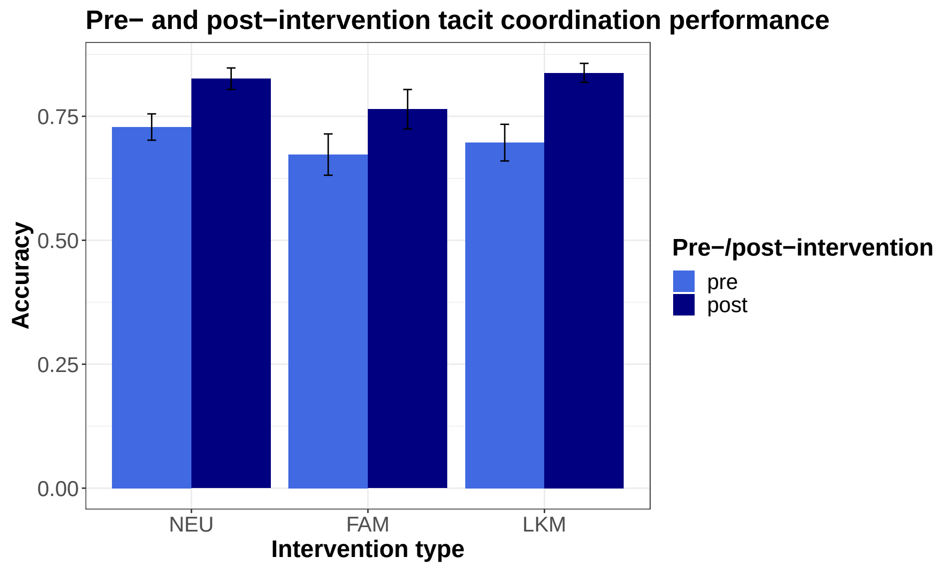


Figure 2: Overall task performance split by block number and intervention type (NEU = neutral visualization exercise, FAM = focused-attention meditation, LKM = loving-kindness meditation). Error bars represent standard error from the mean.

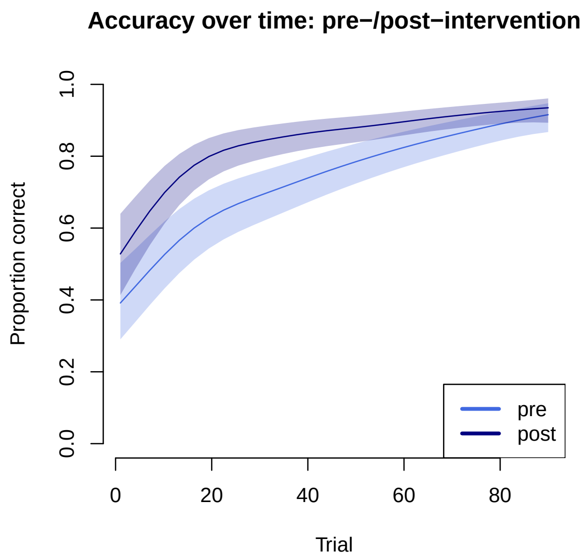
tervention type is not a significant predictor ($\chi^2(2) = 0.30,\ p = 0.86$) and there is sufficient evidence for the null model ($BF_{01} = 8.78 \pm 15.8\%$).

3.2.2 Meditation inductions and task performance

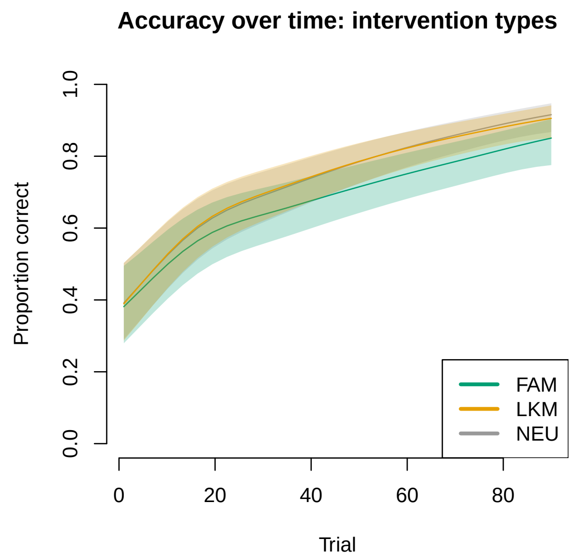
Next, it is considered whether meditation inductions affected performance on the tacit coordination task, and whether this was mediated by frequency of on-task and other-focused thought. Performance was analyzed both as overall task accuracy and as the progression of accuracy over time.

Overall task accuracy across different interventions is shown in Figure 2. There was no significant effect of intervention type on task accuracy ($\chi^2(2) = 3.09,\ p = 0.21$). Bayes factor analysis shows only anecdotal evidence for the null model ($BF_{01} = 2.08 \pm 2.59\%$). Results can therefore be regarded as inconclusive.

Task performance by intervention type over the course of a block was analyzed using a GAM (see Figure 3b). First considering focused-attention meditation, the parametric slope is nearly significant (estimate = 0.275 ± 0.154; $z = 1.79,\ p = 0.074$), and the spline over trial is non-significant ($\chi^2 = 2.33$, edf = 1.00, $p = 0.127$). Figure 3b shows that performance is lower for focused-attention meditation than for the neutral control intervention near the end of the block. This is supported by Figure 4a showing that performance is significantly worse for focused-attention meditation from around trial 60 onward. For loving-kindness meditation, generally no differences are found compared to the control group. Its parametric slope is non-significant ($z = -0.063,\ p = 0.95$), as well as its spline ($\chi^2 = 0.21$, edf = 1.42, $p = 0.81$). As can be seen in Figure 4b, there is no difference in performance compared to the control group at any point along the block.



(a) Split by block number (i.e., pre- and post-intervention).



(b) Split by intervention type where FAM = focused-attention meditation; LKM = loving-kindness meditation; NEU = neutral control intervention.

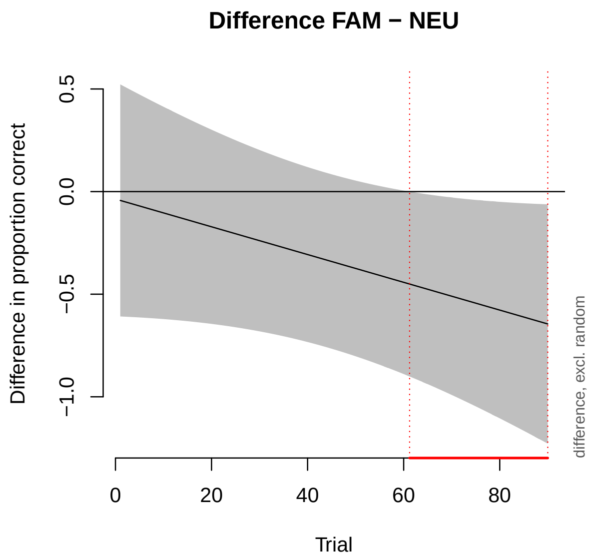
Figure 3: GAM model of task accuracy over time. The setup of the model is described in Section 3.1.7. Ribbons represent a 95% confidence interval around the mean.

Considering the effects of thought content on task performance, on-task thought was found to be unpredictive of coordination performance ($\chi^2(1) = 0.0026$, $p = 0.96$; $BF_{01} = 13.0 \pm 21.9\%$). On the other hand, a marginally significant positive effect of other-focused thought on coordination performance was found ($\chi^2(1) = 3.45$, $p = 0.063$). However, evidence for the full model is insufficient here ($BF_{10} = 0.94 \pm 8.35\%$).

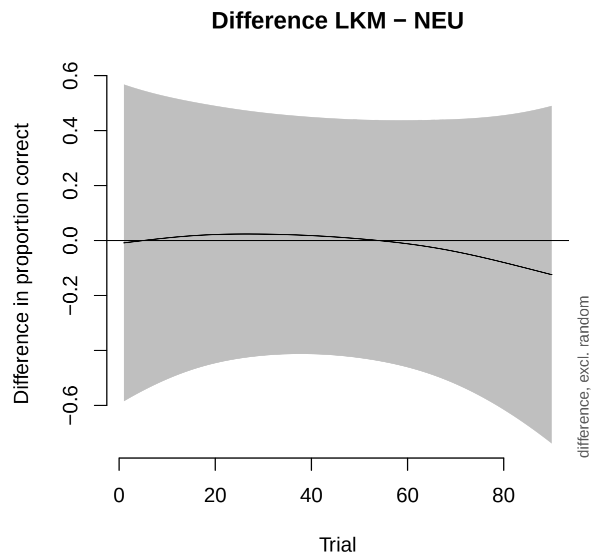
3.2.3 Empathy and mindfulness and thought

It is then asked whether an individual's levels of empathy and mindfulness predicted their thought content during the coordination task. A marginally significant effect of empathy levels on on-task thought was found ($\chi^2(1) = 3.88$, $p = 0.049$). However, evidence for the full model was insufficient ($BF_{10} = 1.57 \pm 9.58\%$). No effect of mindfulness levels on on-task thought was found ($\chi^2(1) = 0.87$, $p = 0.35$), although there was little evidence for the null model ($BF_{01} = 2.90 \pm 10.2\%$).

Other-focused thought was not found to be predicted by empathy levels ($\chi^2(1) = 0.053$, $p = 0.82$) with anecdotal to moderate evidence for the null model ($BF_{01} = 3.57 \pm 21.7\%$). It was not found to be predicted by mindfulness levels either ($\chi^2(1) = 1.04$, $p = 0.31$), though evidence for the null model was anecdotal ($BF_{01} = 2.18 \pm 20.4\%$).



(a) FAM = focused-attention meditation.



(b) LKM = loving-kindness meditation.

Figure 4: Comparison between the neutral control intervention (NEU) and the respective meditation inductions. Ribbons indicate a 95% confidence interval around the mean. A significant difference (i.e., difference $\neq 0$) is indicated by dashed vertical red lines.

3.2.4 Empathy and mindfulness and task performance

Finally, it is considered whether empathy and mindfulness levels were predictive of coordination performance. The effects of the trait levels on task accuracy were analyzed per individual. Therefore, the accuracy score for each dyad was predicted twice, using the trait levels of both individuals. Empathy levels were not found to be predictive of task performance ($\chi^2(1) = 0.29$, $p = 0.59$; $BF_{01} = 2.91 \pm 10.6\%$), and neither were mindfulness levels ($\chi^2(1) = 0.15$, $p = 0.70$; $BF_{01} = 3.01 \pm 10.9\%$). Evidence for the null model is considered anecdotal in both cases, meaning no strong conclusion can be drawn.

3.3 Discussion

The current work aims to answer a number of questions relating to the effect of meditation interventions on the process of tacit coordination. To this end, an experiment was conducted in which participants played a two-player repeated pure coordination game before and after a meditation induction. Thought content was sampled using thought probes and was coded as on-/off-task and self-/other-focused. Additionally, trait levels of mindfulness and empathy were measured.

3.3.1 Conclusions

It is quite clear that meditation inductions do not influence thought content as compared to the control intervention (RQ1). It is unclear whether they influence overall task performance as results are inconclusive (RQ2). However, for the last thirty trials of the block specifically, it was found that task performance for focused-attention meditation (FAM) decreased compared to the control intervention. Additionally, thought content was not found to be predictive of task performance. More specifically, frequency of on-task thought did not affect coordination performance, and evidence was insufficient for the effect of other-focused thought on performance.

Thought content was not found to be predicted by trait levels of mindfulness and empathy (RQ3). Furthermore, these trait levels were not found to predict task performance (RQ4). Evidence was generally weak for these results, meaning that it is not possible to conclude that there is no effect at all.

3.3.2 Explanations of results

Task performance There being no overall difference in task performance between the meditation inductions (RQ2) may be explained in two ways. Firstly, it is possible that the two meditation inductions had no effect on thought content or task performance. In that case, the reported improvement in performance after the intervention has to be attributed to a practice effect of the task. While task-specific information (i.e., the focal points that emerged) cannot be carried over between the two blocks, task-general information (e.g., the structure and goal of the task) can. Therefore, a practice effect was to be expected, and may be the only explanation for the increase in performance after the intervention.

A second explanation is also possible. It may be the case that the neutral control intervention had a similar positive effect on performance as the two meditation inductions had. The control intervention involved effortful visualization of neutral locations and was reproduced from Seppala et al. (2014) who used it as a control intervention for a study on LKM. Though the intervention did not involve *social* perspective-taking, it may still have induced some state of perspective-taking. This effect, combined with the effort required to perform the visualization task, may have lead to an increase in task performance that was comparable to effects of FAM and LKM.

The reported decrease in task performance near the end of the block for FAM as compared to NEU may be explained by a fatigue effect. During informal debriefing, many participants reported that the intervention made them feel sleepy. However, no conclusions can be drawn on this matter due to lack of objective measures.

Thought content Thought content not being predicted by intervention type (RQ1) or by trait levels of mindfulness and empathy (RQ4) may be explained by the ceiling effect. Frequency of on-task thought and other-focused thought was generally very high (92.2% and 81.3%, respectively). In comparison, consider results by Huijser et al. (2018) and Jin et al. (2019) who used thought probes that are similar to the current experiment. The former report an average frequency of on-task thought of 58.2% during a complex working memory task, and the latter a frequency of 30.0% during an SART and a visual search task. The image selection task was apparently very engaging to participants, leading to an almost negligible amount of off-task thought. Therefore, the ceiling effect can explain a lack of effect of meditation inductions or trait levels.

3.3.3 Limitations

One of the limitations of this study is that the effect of the meditation inductions was not measured by itself. Informal debriefing made clear that some participants did not particularly enjoy the intervention and were not engaged with their contents. However, it is not possible to draw conclusions on this without any formal measures. It is therefore recommended that future studies do employ checks of some kind. Checking for the effects of FAM and LKM may become quite extensive, seeing as they elicit effects in rather different domains. The checks that creators of the current FAM and LKM inductions employed are described below.

Baas et al. (2014), who created the FAM induction, check induction outcomes through a number of self-reported measures. Participants rated awareness of thoughts, feelings and sensations; they rated the extent to which they were able to follow the instructions; and they rated how motivated they were to perform the exercise. Beside these Likert scale questions, participants also indicated their pleasure and arousal levels using an affect grid (Russell, Weiss, & Mendelsohn, 1989).

Seppala et al. (2014) measured effects of their LKM induction in terms of self-reported feelings of social connection, and degree of self-focus. Social connection was measured through affect by the Positive and Negative Affect Scales (PANAS; Watson, Clark, & Tellegen, 1988) and through rating photos of strangers in terms of similarity, connectedness, familiarity, and attractiveness (see Hutcherson, Seppala, & Gross, 2008). Self-focus was measured implicitly through a pronoun-choice task (Wegner & Giuliano, 1980).

The issue for many of these checks, and the reason that they were not included in this study in the first place, is the risk of an expectancy effect in self-reports. Based on work by Ghanbari Noshari, Kempton, and Kreplin (2022) and Day et al. (2023) it was predicted that participants' expectations of FAM and LKM effects would inflate self-reported measures of these effects, limiting their use. Implicit measures of the effects (such as a cognitive measure of attention for FAM (Ghanbari Noshari et al., 2022), or the pronoun-choice task for LKM) would therefore be more reliable.

An additional limitation concerns the lack of passive control group. As discussed in the previous section, it may be the case that the neutral visualization task had a positive impact on task performance. It is recommended that future studies employ a passive control intervention (i.e., mind-wandering) in order to separate the effects of the active control intervention from by-products of the passage of time (Heppner & Shirk, 2018).

3.3.4 Future directions

The effects of meditation inductions on tacit coordination, or possible lack thereof, could be investigated using neuroimaging in the future. This could shed more light on whether there is a link between the cognitive functions trained by meditation practice and the process of tacit coordination. Starting points for research like this are offered by Newman et al. (2021) and T. M. C. Lee et al. (2012) in the domains of tacit coordination and meditation, respectively.

Newman et al. used EEG to show that use of working memory (WM) during tacit coordination can be measured by the P3 component of the event-related potential (ERP; see e.g. Sirevaag, Kramer, Coles, & Donchin, 1989). More specifically, they found P3 amplitude to increase by the WM load imposed by a concurrent task. A novel EEG study could study the effect of meditation inductions on P3 amplitude during tacit coordination.

T. M. C. Lee et al., on the other hand, used fMRI to show distinct BOLD responses during FAM and LKM meditation practice: FAM was linked to neural activity associated with attention-related processing, whereas LKM was linked to emotional regulation processes. A future fMRI study could examine BOLD response during tacit coordination, and compare these with BOLD response during FAM and LKM. Based on the theoretical background outlined in Section 2, it is expected that the process of tacit coordination elicits a BOLD response related to executive functions (see also Decety, Jackson, Sommerville, Chaminade, & Meltzoff, 2004), similarly to the attention-related response FAM elicits. It is also expected that brain areas linked to prosocial behavior are invoked during tacit coordination; this is supported by Kirk et al. (2016), who suggest that mindfulness training (i.e., FAM) promotes cooperation through increased activation in a brain area linked to social attachment. Additionally, tacit coordination may make use of brain regions linked to empathy and social cognition, which are invoked during LKM practice (Garrison, Scheinost, Constable, & Brewer, 2014).

Another possible research avenue concerns the way that the topic of meditation is applied to tacit coordination. For instance, a correlational study could compare tacit coordination performance between experienced meditator dyads and novice dyads. The effects of a multiple-session meditation intervention on tacit coordination could also be investigated. For both studies it is expected that meditation practice improves tacit coordination performance. Investigation of individual levels of empathy and mindfulness is recommended for these studies as well, as they are expected to differ between novice and expert meditators, and before and after a multiple-session intervention (see Medvedev et al., 2018).

4 COGNITIVE MODEL

Continuing the investigation of the social cognition behind tacit coordination, the following section describes a cognitive model that performed a task similar to the previously discussed experimental study. A cognitive architecture is used to predict human behavior by formalizing the cognitive mechanisms that are assumed to underly a specific behavior. Comparing these predictions with empirical data then provides valuable information on the assumptions that were made (Ritter, Tehranchi, & Oury, 2019).

The cognitive architecture that was used in the current study is based on the theory of instance-based learning (IBL; see Gonzalez et al., 2003). This decision was based on work by Nguyen and Gonzalez (2021) who used an IBL model to investigate behavior in a Theory of Mind (ToM) task. Since the tacit coordination task of the current experiment is also assumed to utilize ToM, an IBL model may be a suitable choice for the current task.

4.1 Methods

4.1.1 Task

The empirical study described in Section 3 concerned a task performed by two human players. If this task were to be modeled, it would involve two cognitive models playing the cooperation game against each other. It would be quite challenging to interpret the results of this complex interaction. Therefore, a slightly different task was chosen, in which a human player or cognitive model plays against a computer agent. The behavioral pattern of this computer agent is known, making it easier to interpret its interaction with the cognitive model.

The task was reproduced from Bosch (2020) and was largely similar to what is described in Section 3.1.4. As mentioned, the main difference is that the human or cognitive agent plays against a virtual agent rather than a real opponent. The behavior of the computer agent is determined by a simple algorithm. There are a few other differences: a block consisted of 70 trials instead of 90, and the meditation intervention and thought probes were not included.

Both the behavior of the computer agent and of the cognitive model are based on the assumption that each of the choices in a set of four images is connected to a particular strategy. In the block with shape stimuli, each of the ten different shapes represents one strategy. For color stimuli, strategies are either based on color (i.e., red, green, blue or purple) or shade (i.e., light or dark). This association between the images and strategies was formalized in an image-to-strategy mapping that was determined by a survey in a pilot study. For example, for one particular image set (see Figure 5), choice 1 corresponds to strategy “dark”, choice 2 to strategies “green” and “light”, choice 3 to strategy “red” and choice 4 to strategy “blue”. For this image set, strategy “purple” cannot be used. The aforementioned image-to-strategy mapping is used in lieu of presentation and encoding of stimuli. In each trial, the computer agent and cognitive model merely choose a strategy; their image choice then follows from the mapping.

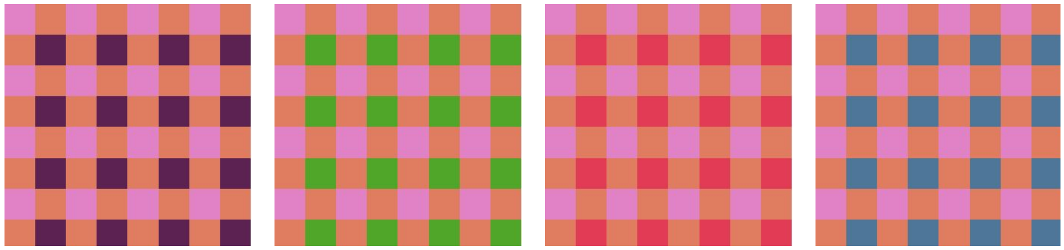


Figure 5: Example of a set of images in the color stimuli block

4.1.2 Computer agent

The behavioral pattern of the computer agent was reproduced from Bosch (2020)'s study. For each choice that the other player makes, the computer agent counts the strategy that was used. More specifically, the counter of a used strategy is increased by 2 (with a maximum of 16), whereas the counters of the unused strategies are decreased by 1. For example, if the human or cognitive model chooses the second image from the set shown in Figure 5, counters for the strategies "green" and "light" are increased by 2, counters for "dark", "red" and "blue" are decreased by 1, and the counter for strategy "purple" does not change because it is not applicable to this image set.

The choices of the computer agent are informed by these strategy counters through a simple algorithm that is shown in Figure B.2. In short, the computer agent keeps a particular strategy ("current strat") and chooses an image accordingly. If the current strategy is not applicable to the current image set, the second, third, etc. best strategy is chosen. If coordination is successful, the strategy is maintained for the next trial. On the other hand, if coordination fails, a new strategy is randomly chosen from a weighted distribution, in which the strategy counters signify the weight.

4.1.3 Cognitive model

As previously mentioned, the choice for an IBL model mostly follows from Nguyen and Gonzalez (2021)'s study on ToM. Unfortunately, there is little other work to base a model of social cooperation on. One example is Hiatt and Trafton (2010) using the cognitive architecture ACT-R (Anderson, 2007) to model behavior on ToM tasks in children. Another is Gonzalez, Ben-Asher, Martin, and Dutt (2015) using the theory of IBL to model the emergence of cooperation by repeated social interaction in the prisoner's dilemma. Additionally, Nguyen, Phan, and Gonzalez (2022) suggest using IBL to model behavior on a cooperative navigation task, though they do not compare their model's behavior to human behavior. All in all, an IBL model is deemed a suitable choice for modeling the current tacit coordination task.

The model was created using PyIBL, a Python module for modeling IBL created by the Dynamic Decision Making Laboratory of Carnegie Mellon University (see Gonzalez et al. (2003) and `http://pyibl.ddmlab.com/`). A straightforward and simple application of the theory of IBL, it is based on a Python implementation of the declarative memory portion of the cognitive architecture ACT-R. This memory is used for storing experiences as instances, which then shape behavior. More specifically, for every situation, instances are retrieved based on their activation levels, and the choice follows from the blended utility of these instances.

In discussing the model's behavior a few details are key. An instance is defined as a set of two pieces of information: the choice that was made (in this case, the strategy that was used) and the utility that is associated with the outcome (in this case, whether coordination was successful or not). A default utility is assigned to choices that have not been previously made. A high default utility causes the model to try all choices at least once since novel choices have a higher utility than options that have already been tried. A low default utility, on the other hand, causes the model to mostly choose what has already been tried.

4.1.4 Data analysis

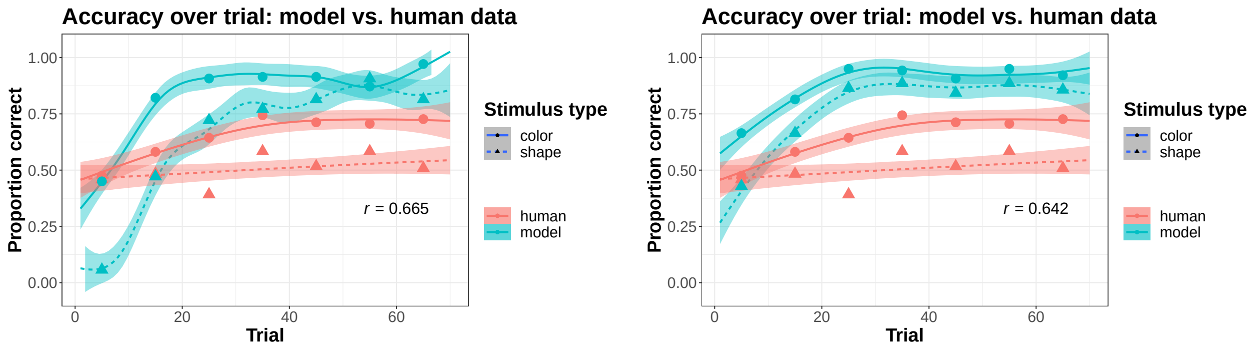
The model's performance over the course of a block of trials was examined through comparison to human data from Bosch (2020). Qualitative comparisons between model and human behavior informed modifications of the model. Additionally, Pearson correlations between human and model data were calculated for every model. More specifically, the average accuracy for every 10 trials was compared between human data and model data.

4.2 Results

The decision-making process of the simplest version of the model (Model I; see Figure B.3) is as follows. Upon the presentation of an image set, the model selects the strategies that are applicable to these images. It then chooses one of these strategies based on previous instances. After the model and the computer opponent have responded, the trial is saved as an instance. At first (i.e., for Model Ia), the following settings were used. Noise and decay parameters were set to their default values. The utility of a successful trial was set to 1.0, and of a failed trial to 0.0. The default utility was set to 10.0. The resulting behavior of Model Ia, compared to the human data, can be seen in Figure 6a.

The trends produced by Model Ia generally do not match human behavior, although correlation is moderate ($r = 0.665$). Accuracy increases too quickly and then remains too high compared to human data. To illustrate: overall accuracy for humans is 65.5% for color stimuli and 50.4% for shape stimuli, whereas it is 83.6% and 65.1% for the model, respectively. Interestingly, the difference in performance for color and shape stimuli that can be seen for humans is present in the model, but in an opposite manner. For humans, performance for both stimuli types starts similarly and then diverges (with performance for color stimuli being superior). In contrast, the model performs worse for shape stimuli at the start, after which the two curves converge. Additionally, performance for shape stimuli is quite unstable, markedly showing a dip in performance at the start of the block.

The latter issue is resolved by changing the model parameters, which also makes the trajectory of the model performance appear more stable. Instead of using a utility value of 0.0 for unsuccessful trials, a value of -1.0 was used. Furthermore, the default utility was decreased from 10.0 to -1.0.



(a) Parameter settings: default utility = 10.0, success utility = 1.0, failure utility = 0.0

(b) Parameter settings: default utility = -1.0, success utility = 1.0, failure utility = -1.0

Figure 6: Performance during coordination task with computer opponent. Human data from Bosch (2020) ($N = 14$) are compared to 14 runs of Model I. Plots were smoothed using GAM; the ribbons represent a 95% confidence interval around the mean. Points represent the mean proportion correct per bin (bin size = 10 trials). The Pearson correlation (r) between the binned accuracies for human and model data is shown.

The resulting behavior of the new model, Model Ib, is shown in Figure 6b. Correlation with human performance ($r = 0.642$) is similar to Model Ia.

Based on the performance of Model I, a new element was added to the model's decision-making process. Whereas the simple model chooses a strategy from the ones that are applicable to the current image set, Model II includes the strategy "random". If this strategy is chosen a random image is selected, and the instance in memory reflects the strategy "random". The performance of Model II is shown in Figure 7.

Accuracy has generally decreased to be similar to human performance. This is also visible in an increase in correlation as compared to Model I ($r = 0.882$). A notable difference between human performance and model performance, though, is that the model's accuracy decreases near the end of the block, which is not observed for humans.

4.3 Discussion

A cognitive model was used in an attempt to shed light on the cognitive mechanisms associated with tacit coordination. Following Nguyen and Gonzalez (2021) an instance-based learning (IBL) architecture was used to model behavior in an image selection task involving cooperation with a computer agent. Results show that IBL can partially explain tacit coordination performance and the emergence of focal points, on the condition that extra randomness is added to the model. The randomness decreases model performance, making it much more similar to human performance. However, the randomness also causes the learning curve to decline at the end of the block, which is not observed for humans. All in all, the current IBL model, with the inclusion of randomness, does not suffice in simulating human behavior in the tacit coordination task. The following sections are aimed at explaining the behavior that the models exhibit, comparing this behavior to human

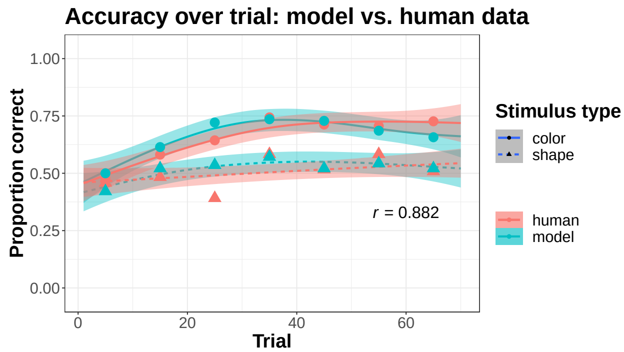


Figure 7: Performance during coordination task with computer opponent. Human data from Bosch (2020) ($N = 14$) are compared to 14 runs of Model II. Plots were smoothed using GAM; the ribbons represent a 95% confidence interval around the mean. Points represent the mean proportion correct per bin (bin size = 10 trials). The Pearson correlation (r) between the binned accuracies for human and model data is shown.

behavior, and offering suggestions to improve the model.

4.3.1 Explanations of model behavior

For both the model and humans, performance for color stimuli is higher than for shape stimuli. This can be explained by the number of possible strategies for the different types of stimuli. For color stimuli, there are six possible strategies (the four colors, and “light” and “dark”), whereas there are ten possible strategies for shape stimuli (the ten different shapes). The more strategies there are, the more difficult it is to converge on them.

The differences in the learning curves of Model Ia and Model Ib (see Figure 6) can be explained by the changed utility values. First, Model Ia shows a relatively unstable trajectory, with some incidental decreases in performance over time. These are less pronounced in Model Ib. This can be attributed to the larger difference in utilities between successful and unsuccessful coordination in Model Ib, which more strongly reinforces existing strategies. A smaller difference in utilities makes the model behave more uncertainly. Moreover, performance at the start of the task is worse for Model Ia than for Model Ib, which can be explained by the difference in default utility. Model Ia behaves in an exploratory manner, first trying all possible strategies before settling on one. This especially decreases performance for shape stimuli due to the large number of possible strategies. Model Ib on the other hand acts more “confidently” from the start (i.e., quickly settling on a strategy), causing performance to start high and increase steadily.

It is not hard to explain why adding the option of strategy “random” to the model decreases its performance: choosing an image at random amounts to employing no strategy at all, which does nothing to contribute to the emergence of a focal point. Interpreting the decrease in performance near the end of the block is a little more complex. It is first useful to look back to Figure 6: Model I also exhibits a dip in performance after the thirtieth trial, more or less. Looking at individual trials, it seems that a few focal points are emerging at this point in the block, which may be incongruent with each other. This conflict is generally resolved successfully in Model I, leading to a high coordination performance in the end. In Model II, however, there is the possibility of the random strategy. It is more likely to be chosen during this “conflict phase”, and if it happens to be successful, the likelihood of it being chosen again increases. Moderately established focal points then weaken, decreasing coordination performance.

4.3.2 Comparison to human behavior

As indicated previously, the IBL models that were created are deemed insufficient for explaining human behavior in the tacit coordination task. First, it is important to look back to Nguyen and Gonzalez (2021)’s work and recognize the distinction between their Theory of Mind (ToM) task and the image selection task. While Nguyen and Gonzalez modeled a passive observation task in which humans or the IBL model predicted a computer agent’s behavior, the image selection task of the current study involves social interaction and cooperation. As mentioned in Section 2.1.2, these two situations may not be comparable in terms of the cognitive processes involved (see Schilbach et al., 2013). The current results offer support for this hypothesis.

When it comes to explaining the social process of cooperation, a microphenomenology study by Röder (2022) offers a valuable basis. Interviews after the image selection task indicated that most participants based their behavior on their interpretation of the other participant’s strategies. In other words, individuals employ perspective-taking. This phenomenon cannot be reproduced by the IBL model, as it does not include observation of the other player’s choices and only uses the coordination result (success/failure) as feedback. One caveat here is that Röder (2022) had dyads play the tacit coordination game together instead of with a computer agent. Therefore, the findings from the interviews may not be extendable to a situation in which a human or cognitive model plays against a computer agent.

4.3.3 Suggestions

Future research should focus on incorporating perspective-taking into the model. A theoretical model on team cognition by Kanno, Furuta, and Kitahara (2013) could offer support here. The PyIBL architecture is too simple to implement this higher-level aspect of social cognition. ACT-R (Anderson, 2007) may therefore be a suitable tool (see also Hiatt & Trafton, 2010). The other player’s choices could then be stored in declarative memory, as well as the player’s own choices. Every trial then involves retrieval of past choices that are applicable to the current image set, and extracting a new choice from this information. Past choices can be incongruent, in which case conflict resolution should occur. In other words, contrasting perspectives need to be coordinated in order to reach a decision. Research has suggested that working memory (WM) is employed during tacit coordination (Mizrahi et al., 2020; Newman et al., 2021), and it may specifically be invoked in this resolution of conflict (see Maehara & Saito, 2011). Implementing this in an ACT-R model could provide support for the hypothesis that tacit coordination requires WM specifically for coordination of perspectives. In order to strengthen evidence, a concurrent WM task such as in Newman et al. (2021) should also be incorporated: if the model can simulate the negative impact of WM load on coordination performance, this would solidify the theory that WM is involved in coordinating perspectives during tacit coordination.

5 GENERAL DISCUSSION

This Master's Thesis was aimed at investigating the process of tacit coordination in two main ways. An experimental study focused on the possible effects of focused-attention meditation (FAM) and loving-kindness meditation (LKM) inductions on thoughts and performance during a tacit coordination game. It was hypothesized that focused-attention meditation would improve coordination performance through increasing on-task thought, and that loving-kindness meditation would improve it through an increase in other-focused thought. No effects were found across the board, and possible reasons for this were discussed.

A cognitive modeling study tried to explain the emergence of focal points over time in the same image selection game. A model of instance-based learning was found to moderately approximate human performance, but was ultimately deemed insufficient for explaining human behavior. Suggestions for improving the model were provided.

The current work has made new connections between research areas. It is the first to investigate meditation practice in the context of a tacit coordination game. The conclusions drawn from this investigation were limited, leading to many suggestions for future work. Moreover, a valuable perspective was offered on the novel approach of cognitive modeling of tacit coordination. As such, this work can be considered a starting point for more extensive research on tacit coordination, meditation, and the modeling of social cognition. The remainder of this section describes possibilities for future directions outside *pure cooperation* tacit coordination games.

Divergent interest tacit coordination games would be an interesting direction to pursue in the context of meditation. As discussed in Section 2.1.1, these games do not only involve a goal that is shared between players, but also individual goals that may be incongruent with the common goal (Mizrahi, Laufer, & Zuckerman, 2021a). For example, payoffs for particular solutions may be dissimilar between players (see Crawford et al., 2008; Mizrahi et al., 2021b). Meditation practice could then change individuals' social value orientation, i.e., their motivations and strategy (Balliet, Parks, & Joireman, 2009), to be more directed toward the common goal than individual goals (see Sun, Yao, Wei, & Yu, 2015). In particular, this change may be induced by FAM through increasing prosocial behavior (Donald et al., 2018) and by LKM through eliciting feelings of social connectedness (Seppala et al., 2014; see also Reb, Junjie, & Narayanan, 2010). Manipulation of the payoff asymmetry could be employed to expose the boundaries of individuals' willingness to cooperate (as opposed to pursuing their own interest), and could demonstrate the effects of meditation on these boundaries.

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B FIGURES

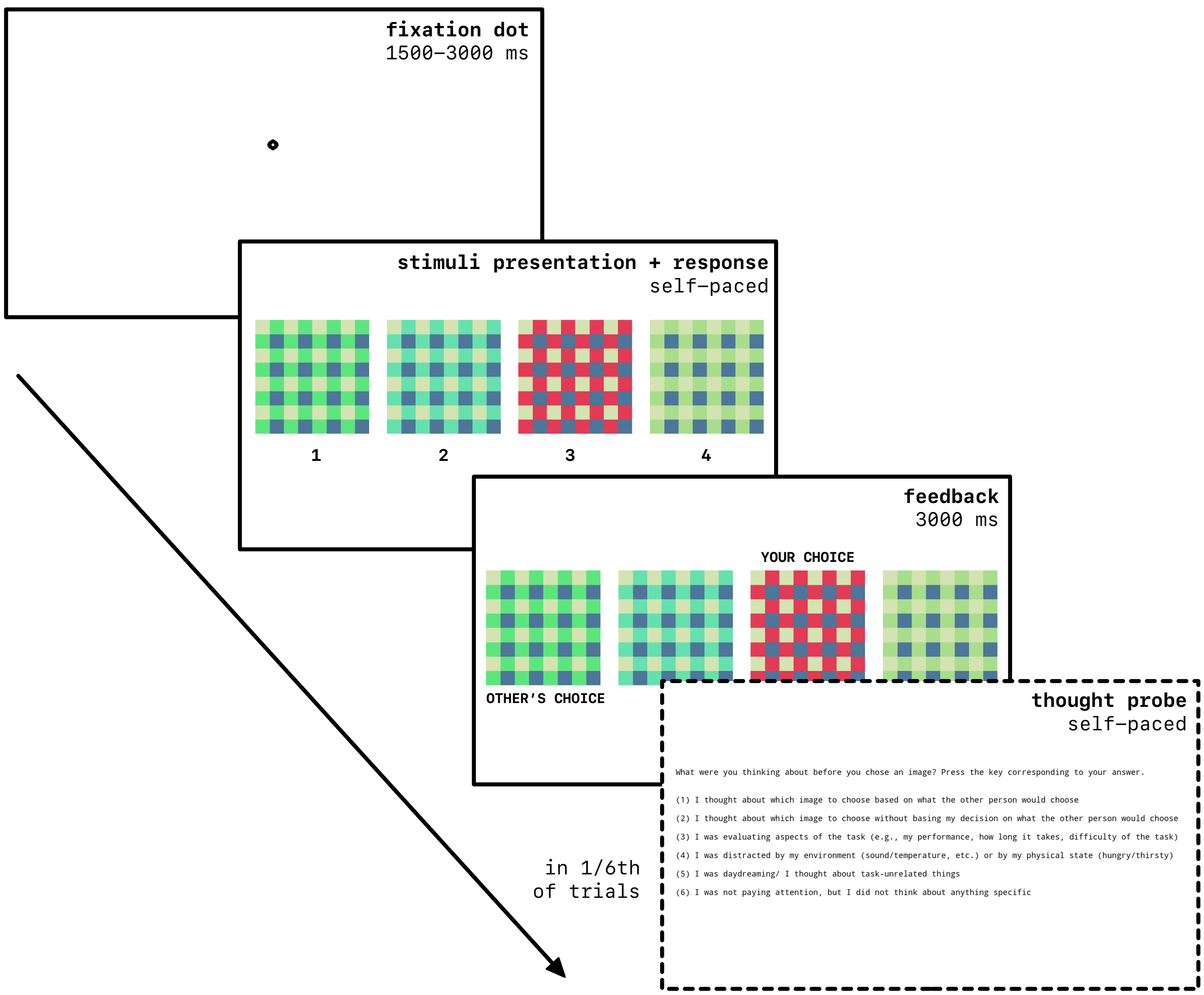

Figure B.1: One trial sequence of the image selection task.

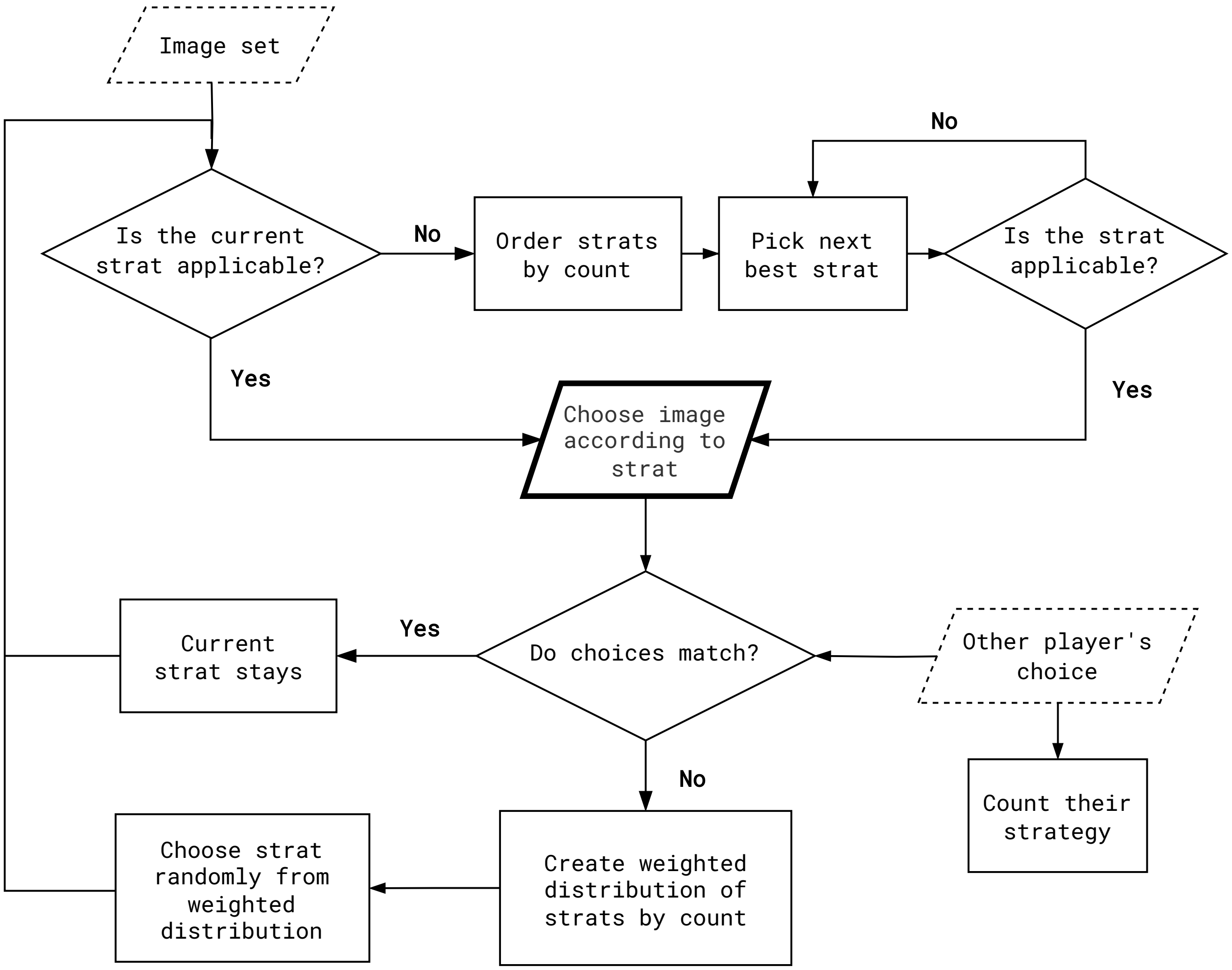

Figure B.2: Flowchart of the algorithm underlying the computer agent's behavior. External input is indicated by dashed borders, and the agent's output is indicated by a bold border.

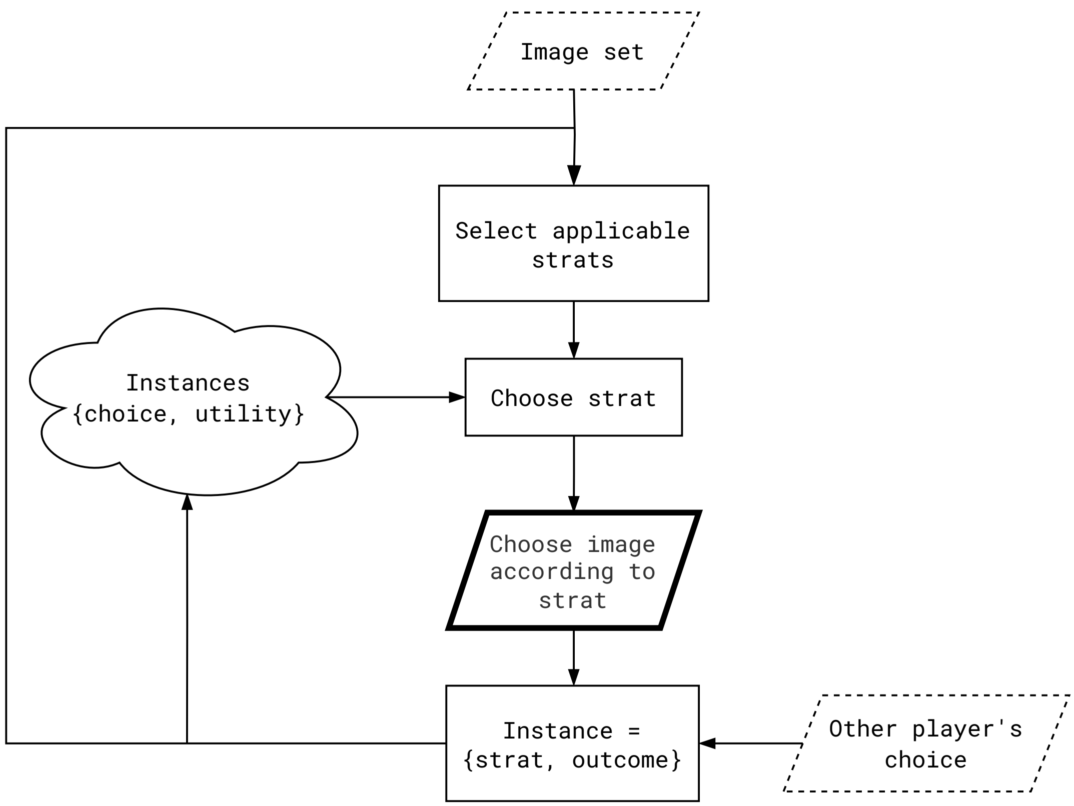

Figure B.3: Flowchart of Model I. External input is indicated by dashed borders, and the model's output is indicated by a bold border.