Agency beyond the dyad

- *A novel paradigm for investigating triadic interaction and subgroup dynamics*

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Abstract

Every day human beings interact with each other in groups of varying size and constellations. Despite this, much research on the experience associated with collaboration in groups, has been completed on dyads. In this paper, we developed an experimental paradigm for measuring how subgrouping affects group coordination and perception of joint agency. The paradigm makes use of a simple tapping task, and rate their experience of agency after the rhythm task. The paradigm is implemented using the Bela Mini System, an embedded computing system designed for low latency recording and sound production. The current thesis validates this novel paradigm through timing tests and minimal data collection. The paradigm investigates how small group coordination is linked to group members' perceptions of agency, and their configuration into subgroups . Taken together, the present thesis develops a novel paradigm, validates the timing of this paradigm, and provides basic evidence that the experimental paradigm gives reasonable results with real participants. The paradigm may hence be used to explore the many aspects associated with the agency experience in triadic groups and subgroup dynamics. All experiment code and analysis is available at https://github.com/ACVJ/onde_bachelor.

Keywords: *Joint Action; Triads; Sub-Groups; Group Dynamics; Joint Agency; Sense of Agency*

1. Current Thesis: Overarching Aims - ACVJ

The goal of this thesis is to develop a novel experimental setup to investigate the sense of agency dynamics of triads in a collaborative rhythm task. In some experimental conditions, two members are paired together and one member is left independent throughout the trials. This paradigm will provide a tool, both for extending research on joint action in dyads onto triads, while also enabling research into collaboration and joint agency of groups containing subgroups. The thesis covers in detail the development of the experiment, such as the theoretical motivation for development, software and hardware setup and suggested hypotheses and data analysis. The paradigm is validated through both timing tests of the hardware/software set-up and a validation experiment investigating group coordination dynamics.

2. Introduction - ACVJ

To be alive is to act. By virtue of being social animals (Sakman, 2019), our actions are constantly coordinated with others in some way (Sebanz et al., 2006; Vesper et al., 2017). Examples of this vary greatly (Pacherie, 2012), and include consciously planned and explicitly coordinated joint tasks, such as two people moving an object (Loehr, 2022; Vesper et al., 2017), or in the form of abstract and unconscious behavior and arise amongst larger collectives, as when playing teamsport or in an orchestra (Keller et al., 2014; Knoblich et al., 2011). Common for all coordinated actions is an adaptation to the movements and timing of, at times, many other individuals (Sebanz & Knoblich, 2021; Vesper et al., 2017). Other examples of joint action include turn-taking in conversation (Sebanz & Knoblich, 2021), playing music, dancing (Vicary et al., 2017), helping a child get dressed (Sebanz et al., 2006), and as spontaneous, as an audience clapping at a concert (Brownell, 2011). A widely used definition (Vesper et al., 2017) of joint action, is found in the paper "Bodies and Minds moving together" by Natalie Sebanz et al. from 2006, where joint action is seen as social interaction involving two or more persons coordinating actions in the spatial and temporal dimension to cause a change in their environment (Sebanz et al., 2006, p. 70). With this definition in mind, it becomes apparent how joint action truly is everywhere, and is completely foundational for our ability to navigate through life.

Much research suggests that producing actions relies on keeping in mind a feeling of being able to cause something to happen through one's own actions, known as "sense of agency" or simply "agency" (Chambon et al., 2014; Dewey & Knoblich, 2014). Having a sense of agency allows us to distinguish between the consequences of actions ("action-effects"), such as sensorimotor information, caused by ourselves and the cues caused by something separate from ourselves (Dewey & Knoblich, 2014). In other words, having a sense of agency allows us to differentiate between action-effects caused by our own actions and action-effects caused by the environment (Dewey et al., 2014).

Newer research has proposed questions as to what happens to our sense of agency as we engage in tasks involving joint action; what happens when the lines between what "I" caused and "you" caused are blurred? Based on collaborative tasks, Loehr et al. (2022) attempt to classify the different kinds of agency that may arise in joint action, such as independent agency (such as two people solving a jigsaw puzzle), shared agency (moving a couch), and united agency (dancing together). Common for all, is the sharing of goal and intention - ie. all group members agree that the goal of grabbing the couch is moving it somewhere else (Loehr, 2022). The categorization listed here is, however, far from exhaustive.

In the present thesis, an experimental paradigm for investigating the consequences on SoA of introducing subgroups into a simple joint action task is developed and validated (see section

2.4). In the following sections, we will discuss the research on collaborative joint action, which motivated the present paradigm. Furthermore, we will discuss the research area of agency by reviewing the theoretical background of individual agency and joint agency. Lastly, in this section we present proposed research questions and related hypotheses, providing the foundation of the data analysis.

2.1. Joint Action - ACVJ

According to the paper "*Progress in Joint-Action Research"* by Natalie Sebanz and Günther Knoblich (2021), the area of joint action has been studied primarily from the following three angles:

1. The preconditions in humans which enable joint action. This includes work by, amongst others, Tomasello in cultural cognition, who found that children had a "*unique motivation to collaborate and engage in joint action*" (Sebanz & Knoblich, 2021, p. 138; Tomasello et al., 2005).

2. The role of language in coordination; both as an example of joint action, but also a device to facilitate coordination and planning of actions. Language has been theorized to be an indispensable ingredient in the origin of joint action (Tomasello et al., 2005).

3. The tendency of humans to fall into synchronous movement. This tendency is especially seen in rhythmic and musically rooted tasks ie. clapping or head bopping (Phillips-Silver & Keller, 2012; Sebanz & Knoblich, 2021), but also in more mundane tasks, such as walking side by side (Phillips-Silver & Keller, 2012; Sebanz & Knoblich, 2021). "Syncing up" in this way is also known as "*entrainment*" and is seen across the natural sciences; the croaking of frogs falling into synchrony (Klump & Gerhardt, 1992; Wilson & Cook, 2016), and in physics pendulum clocks which synchronize when mounted next to one another (known as "Huygens entrainment phenomenon", dating back to 1665 (Spoor & Swift, 2000; Clayton, 2012). We emphasize the fact that these angles are not to be viewed as an exhaustive list over the subfields in this research area.

2.1.1 Rhythmic Joint Action and Social Implications - CEGN

A broad set of joint actions are rhythmic in their nature. Keller et al. (2014) define rhythmic joint action as actions where the goal necessitates coordinating movements between individuals, characterized by the temporal dimension of the movements need be extremely precise and flexible. As previously mentioned, rhythmic joint action is a major research subfield of joint action, and includes investigating groups engaging in music, dance, marching and walking, among others (Keller et al., 2014; Knoblich et al., 2011). While joint rhythmical activity is not unique to humans (section 2.1), the behavior exhibited in groups engaging in rhythmical activity seem pervasive in human society. Studies suggest that many social structures and dynamics are affected by the ability of groups or pairs to engag/e in rhythmical activity (Keller et al., 2014). Patterns in such studies show that a higher level of social skills correlate with increased synchronization with a partner (Keller et al., 2014). The tendency to enter into rhythmic entrainment with other humans - also referred to as interpersonal synchrony - seems to be such a strong urge that it occurs even when the involved wish to keep their own rhythm and pace, or actively try to avoid falling into entrainment (Keller et al., 2014; Knoblich et al., 2011; Lucas et al., 2011). Rhythmical joint action also seems to play an important part in constituting hierarchy and group cohesion, such as by making the group members engage in marching, chanting and dancing (Howard et al., 2021; Keller et al., 2014; Pacherie, 2012; Wiltermuth, 2012), with the results including lessening social distance between group members, enhancing trust and personal connection, such as compassion, even to the point of destructive obedience (Keller et al., 2014; Pacherie, 2012; Wiltermuth, 2012). Furthermore, studies suggest that the degree of spontaneous interpersonal synchronization is higher when the persons interacting are associated with a different, positively evaluated, social group (Keller et al., 2014; Miles et al., 2011). One hypothesis is that this tendency arises to meet a “diplomatic” function, in reducing the perceived social distance between individuals, when explicit markers denote difference (Miles et al., 2011). We note that across studies investigating interpersonal synchrony, is the observation that engaging in rhythmically coordinated joint action affects the social experience of the participants in various aspects.

2.2. Agency - ACVJ

In this section we will cover what is understood by ‘Sense of Agency’ (henceforth referred to as SoA), what characterizes SoA on an individual level, and the impact SoA has on how we navigate our environment. To increase the understanding of the mechanisms and effects of joint SoA, we will first consider findings regarding individual SoA, by discussing what mechanisms and cognitive models are theorized to give rise to SoA, and the empirical findings supporting the different theories. Finally, we will discuss the link between individual SoA and joint SoA before continuing to studies on joint SoA in rhythmic joint action frameworks.

An often used definitions of SoA is that SoA refers to a feeling of having control over events through one’s actions (Bolt et al., 2016; Chambon et al., 2014; Dewey & Carr, 2013; Dewey & Knoblich, 2014; Haggard & Tsakiris, 2009; Loehr, 2022). As mentioned in section 2., having an SoA is fundamental in our daily life, as it allows for us to separate the sensory cues from our surroundings caused by our actions (action-effects) and sensory cues from our surroundings caused by external sources (Dewey & Knoblich, 2014). This in turn, makes us able to navigate through our environment and plan new intentional actions. Despite its importance, SoA is rarely something that results in a clear conscious experience, unless our actions do not produce the intended result (Chambon et al., 2014). The exact mechanisms which give rise to SoA are continuously being debated (Chambon et al., 2014; Pacherie, 2012) and have primarily been studied on an individual level (Pacherie 2012, Loehr 2022). Theories regarding the inner workings of SoA include theories of sophisticated high-level cognitive models, such as the narrative approach, low-level models, and forward models. Examples of the latter two have been quite influential within the field of SoA (Chambon et al., 2014) and are discussed below.

2.2.1 Individual Sense of Agency - ACVJ

There are many approaches to an individual's sense of agency, one of them is the comparator model. Originally developed in the 90's to model sensorimotor control within an individual, the comparator model is an internal forward model which theorizes how the central nervous system simulates the outcome of an action by combining the motor system in its current state with the motor action desired, to predict the next current motor system state (Miall & Wolpert, 1996; Synofzik et al., 2008). Since its development, comparator models have also been used as a cognitive model of SoA (Synofzik et al., 2008), as the comparator model describes a system which looks for matches between the predicted action-effect, and the experienced sensory action-effect (Chambon et al., 2014). This view implies that SoA is developed in retrospect, as it makes SoA contingent on the brain receiving and processing sensory information, the consequence of an action, before a comparison can be made between predicted action-effect and experienced action-effect (Chambon et al., 2014). This is theorized to be made possible by the brain holding a representation of the consequences of an action, and comparing this to the outcome of an action (Haggard & Tsakiris, 2009; Pacherie, 2007, 2012). The retrospective view predicts that SoA will be experienced to a high degree when there is a match between the predicted action-effect and experienced action-effect (Chambon et al., 2014). Empirical evidence of the SoA being influenced by a comparator model, is found in studies demonstrating that SoA and the ability to recognize one's own actions, is weakened, when temporal delays are introduced between action and effects (Chambon et al., 2014; Pacherie, 2012). Further empirical evidence has been interpreted from the "intentional binding effect", referring to the phenomenon of perceiving intentionally generated actions and effects as taking place temporally closer together when generated by oneself (Bolt et al., 2016; Chambon et al., 2014; Obhi & Hall, 2011; Pacherie, 2012). Despite empirical evidence, critique of the comparator model is also present in the debate surrounding the nature of the cues needed in forming SoA (Chambon et al., 2014; Synofzik et al., 2008). These include suggestions to SoA being a matter of perceptual cues, rather than sensorimotor cues, as research has found a general lack of proprioceptive feedback from actions, meaning unawareness of movement and corrections in voluntary tasks is characteristic for movement (Pacherie, 2012). Observations such as these, contribute to the increasingly accepted view that SoA is contingent on a variety of cues from different sources, all sharing the foundationally same idea, that SoA relies on the ability to compare the expected outcome to the experienced outcome (Pacherie, 2012).

To summarize, research suggests that individual SoA is impacted and shaped by a multitude of factors, such as the processing of various cues centered around the link between action and effect, and unconsciously detected signals centered around the link between intention and action. Common for the aforementioned studies and theories regarding SoA, is a focus on SoA as relying on the cognitive representation of an action-effect that are generated prior to the execution of an action, compared with the registered effect of an action.

In recent years, more attention has been centered around SoA in joint action (Loehr, 2022). As joint action is ever-present in our daily life, the constellations of joint action are close to endless (Loehr, 2022; Pacherie, 2008, 2012, p. 202), and these factors challenge the transferability of the findings and theories from individual SoA studies (Loehr, 2022) .

2.2.2 Joint Sense of Agency - CEGN

The presence and activity of co-actors changes the attribution of agency, both when it comes to objects and subjects of agency (Loehr, 2022). In intentional joint action, where group members engage in collaborative behaviour, the object or goals of action can include both the joint goal, and the participants own individual parts of the goal. According to Loehr (2022), the subjects of agency can hence refer both to the self and/or the partner(s) and the group. Indeed, experimental research has found that participants represent both their own parts of a joint task and the overall outcome, and that at least in some cases, they react strongly to mistakes that affect the joint outcome (Loehr, 2018; Loehr & Vesper, 2016).

Several accounts of how the subjects that perform joint action are constituted exist. It seems that for a joint SoA, some sense of joint intentionality or shared goals is necessary (such as the beloved “we are moving the couch”-example - section 2.) (Gallotti & Frith, 2013; Keller et al., 2014, Pacherie, 2012). As in individual agency, prediction plays an important role - experimental findings indicate that the SoA is shared to a greater degree when co-actors are more predictable (Bolt & Loehr, 2017). This is comparable to increased SoA for individuals, when prediction action-effect corresponds to experienced action-effect (Chambon et al., 2014). Accounts differ as to how the prediction of co-actors' actions occurs. "Individualist" accounts of how the human mind handles joint action conceptualize the predictions involved in joint agency as occurring in individuals who recursively predict each others actions and intentions (Gallotti & Frith, 2013), ie. using "forward models" of the expected consequences of own actions (see section 2.2.1) and " inverse models" of the intentions and mental states inferred to be the root of the actions of coactors (Keller et al., 2014). Another influential account is that minds enter a "we-mode", which includes irreducible collective aspects of cognition, and as such is not a recursive prediction of the co-actor' mental states, but rather a whole system operating together (Gallotti & Frith, 2013).

Related to the distinction between generalizing individual cognition to social settings, and the possibility of an emergent "we-mode", different types of joint SoA are proposed. When agency is ascribed to the group, different concepts as to how the group is constituted are used in the literature. Independent agency denotes a SoA in which each person acts independently to achieve a joint goal, and self-agency is preserved. Shared agency denotes agency that is distributed among agents, so that agency is simultaneously experienced as individual and joint, and united agency describes a SoA in which the individual "loses" its self-agency in becoming part of the collective. Researchers do encourage caution in applying the developed terms, as not to use them interchangeably (Loehr, 2022).

As mentioned in section 2.1, joint action takes many different forms, and hence can be characterized by a broad variety of aspects. Pacherie (2012) describes various dimensions of joint action, such as number of participants, hierarchical structure, division of labor, physical or virtual modality, transient or long-term nature, and involved institutions or norms. Much of experimental research focuses on a limited range of the possible configurations of these factors. The number of participants is often kept at 2, and experiments are often designed around egalitarian situations, making much of research on joint action on dyads where participants have equal prerequisites and equal tasks (Loehr, 2022; Pacherie, 2012; Palmer & Zamm, 2017). Short term effects are easiest to look at in the lab, as a result of its lack of longevity. Experiments are not alone in centering joint action research on smaller-scale, egalitarian situations; philosophical accounts of joint agency have also tended to focus on joint SoA within smaller groups where members have equal knowledge (Pacherie, 2012).

2.3 Experimental Approaches to Rhythmic Joint Action and Sense of Agency - CEGN

In the following sections we will describe the experimental approaches to researching joint action and SoA. This includes studies on rhythmic joint action, studies that inspired the present study.

When working with rhythmic joint action and SoA, many different concepts come together. Experimental studies have examined different types of interaction in different groups, the neural correlates of interpersonal coordination, and the influence of joint action on various social factors (Keller et al., 2014; Palmer & Zamm, 2017).

Keller et al. (2014) suggest working with musical ensembles as an ecologically valid, though complicated, controllable example of rhythmic joint action. Duets are the most researched ensemble, and much more research is conducted in dyads than in larger ensembles (Keller et al., 2014; Loehr, 2022; Pacherie, 2012). Research in larger ensembles, sizes ranging from quartets to orchestras, sheds light on body movement synchrony and its interaction with musical features, as well as leader/follower dynamics (Palmer & Zamm, 2017). Generally body language is more predictable in ensemble settings compared to solo playing, and successful synchronization is related to emotional expressiveness (Chang et al., 2019; Glowinski et al., 2013). Other research has attempted to quantify the influence of changing a central member (the conductor) on entrainment and external ratings of orchestra performance (Varni et al., 2022). However, most experimental work seems to fall into the large body of research regarding (mostly piano) duets, or simple dyadic interactions such as tapping along to a metronome (Bolt et al., 2016; Bolt & Loehr, 2017; Keller & Appel, 2010; Loehr et al., 2013; Loehr & Vesper, 2016; Shiraishi & Shimada, 2021; Zamm et al., 2021, 2023).

This research has yielded many interesting findings, supporting ideas mentioned in section 2.2.2: That pianists react more strongly to their own errors, and errors that affect joint outcomes (Loehr et al., 2013), the sense of shared agency of co-players is increased both when predictability of the partners increases and when interpersonal coordination increases (Bolt et al., 2016; Bolt & Loehr, 2017; Shiraishi & Shimada, 2021). Predictability seems to be so central that pianists in fact duet better with themselves (Keller et al., 2007). Other duet research has found that rhythmicities related to motor learning emerged in dyadic rhythmic tasks (Zamm et al., 2023), and that SoA is more shared when joint goals are achieved (Loehr, 2018).

An aspect that is often explored in experimental research is leader/follower dynamics. Dynamics involving leaders and followers are explicitly present in western classical music, which is often the object of study (Palmer & Zamm, 2017). Additionally, leader/follower dynamics seem to emerge in joint action, even when they are not explicitly assigned, sometimes simply based on who is the first to perform a given action (Bolt et al., 2016; Wegner & Sparrow, 2007). The way these leader/follower dynamics interact with agency seems to depend very much on the structure of the task, ie. the distance between action and response (Dewey & Carr, 2013; Obhi & Hall, 2011). Konvalinka et al. (2014) found that even quite minimal leader/follower dynamics lead to detectably different neural activity, with leaders seemingly investing more neural resources into prospective planning, indicated by frontal alpha-suppression.

2.3.1 Gaps in Research - asymmetrical interactions beyond the dyad- CEGN

One question that is not deeply explored is the question of whether interactions change qualitatively when more than two people interact. Specifically, the inclusion of three or more participants in a joint action introduces the possibility of asymmetrical interactions, in the sense that some participants are closer together in terms of entrainment, group membership, or stimulus/response dynamics. These asymmetrical dynamics likely play a large role in many aspects of human social life, for instance much interaction between people is characterized by differences in social hierarchy, such as talking with an authority.

A notable exception is the work of Kourtis et al., (2010). This experiment was designed to test how social relations modulate action prediction in the brain. One person, who was being EEG-scanned, had to do an action, sometimes in conjunction with a partner, and sometimes alone. A third person, the “loner” was present, and sometimes performed the same action, but not together with any of the others. This creates an asymmetrical relationship between the participants, and this asymmetry in the joint stimulus/response dynamics seems to have generated a sense of group-membership. This manipulation was found to modulate action preparation potentials in motor areas of the brain in such a way that when the “partner” was preparing an action, the EEG-scanned participant also showed brain activity linked to preparing a similar movement. This was not the case when the loner prepared an action, or at least the activity was significantly reduced in amplitude. **These results indicate that joint action mechanisms are not simply the same when more people than two are involved, at least not if action mechanics are asymmetrical.** Moreover, these findings motivate the central question of this thesis: **How do we coordinate with others when we have to handle several other people at the same time, in asymmetrical conditions?**

2.4 The Present Paradigm - ACVJ

The present thesis aims to develop a novel paradigm for investigating subgroup dynamics in a joint action task, and how these dynamics interact with SoA. In the following sections, we discuss in increased detail how the paradigm measures group coordination, subgroup dynamics, and agency.

2.4.1 Bolt et al. (2016): A Modifiable Framework - CEGN

One critical study investigating rhythmic joint action and agency dynamics is Bolt et al., (2016) study, upon which the present experiment is partly based. Bolt et al. tested how joint agency is affected by the degree of coordination necessary between participants. This was achieved in an experimental paradigm, in which two participants listened to four pacing tones, and then pressed a button each to play a sound in the same tempo. The two would alternate their notes in patterns either changing a-b-a-b or a-a-a-a-b-b-b-b, to test the differences based on the degree of online coordination required. SoA was measured on a linear self-report scale from individual control to shared control. The scale is described further in section 3.3.3. Control was closer to shared in cases with a high degree of interpersonal coordination, as mentioned in sections 2.2 and section 2.3. The participant who was the first to play a tone generally experienced a higher degree of individual agency, echoing some of the aforementioned leader/follower dynamics.

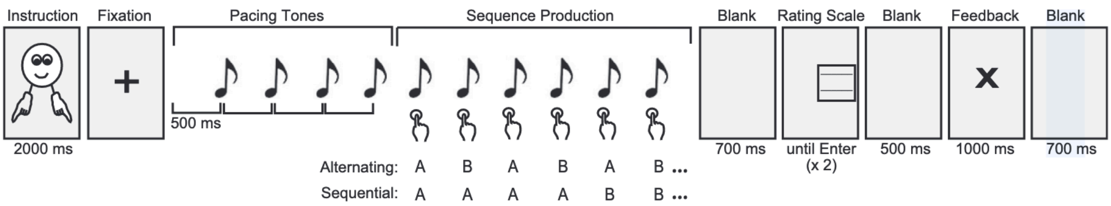

Fig 2.4.1: Illustration from Bolt et al. (2016), "Mutual coordination strengthens the sense of joint agency in cooperative joint action", p. 176, "fig. 1".

2.4.2 Investigating Groups Larger than the Dyad - CEGN

The present study paradigm crucially goes beyond dyadic interactions, by involving three participants in a joint sequence production experiment. The presence of three participants allows for testing different group configurations. The conditions in this experiment involve generating tones either by tapping individually in sequence, simultaneously, or tapping with two people in a subgroup together generating one tone, and one person generating a tone alone. This configuration makes it possible to test a range of dynamics involving subgroup membership. After producing each tone sequence, the sense of agency is measured by making the individual group members rate their experience of SoA, and hence making use of an explicit, self-reported measure of agency. SoA is rated across two dimensions, one ranging from independent to shared control, and one ranging from no to complete control, in order to investigate the idea that strength and sharedness can be independent dimensions of SoA (Pacherie, 2012).

2.4.3 Developing an Operationalization of SoA - CEGN

When operationalizing SoA experimentally, there are a lot of considerations to make, as the concept of SoA can take on many meanings (Synofzik et al., 2008), and is proposed to be consisting of many different dimensions, especially in joint action (Loehr, 2022; Pacherie, 2012). These factors combined make agency and its different subcategories rather abstract concepts. When using self-report measures of agency, a challenge arises of unambiguously communicating the nuances of these distinctions to participants, who are not expected to be familiar with the concept of agency beforehand. However, an explicit measure of SoA was chosen for the experiment due to research indicating that implicit measures such as temporal binding and sensory attenuation measure different aspects which do not seem to be strongly correlated to the explicit measures (Dewey & Knoblich, 2014), as well as practical considerations regarding the experimental procedure. Furthermore, by implementing the same measures of agency as in previous research, it was made possible to compare the results to studies such as Bolt et al. (2016) and Loehr (2018).

A large number of studies operationalize agency in terms of control, when it comes to the questions presented to participants in the rating of their SoA (Loehr, 2022). However, different dimensions are targeted by different studies. The Bolt et al. (2016) study found that mutual coordination increased the degree of shared agency on a scale going from shared to individual, and "leaders" were found to have a more individual experience of agency. However, the joint SoA is not unidimensional, and it is unclear how the different ways of sharing agency affect the strength or intensity of the SoA. Pacherie, (2012) argues that the strength and the form or degree of sharedness should be separate dimensions. Indeed, Dewey et al., (2014) found that the strength of control reported by participants was sometimes reduced and sometimes increased by adding a co-actor. This is supporting the idea that the strength of agency and degree of shared agency are separate, and hence appeal to different aspects of the agency experience. Moreover, this indicates that sharing agency does not necessarily entail relinquishing agency. Based on these considerations, a scale for rating agency was developed: A question regarding the dimension of sharedness was adapted from Bolt et al. (2016), while a question regarding strength of agency was adapted from Dewey et al., (2014). The two were combined orthogonally to create a rating plane, further described in section 3.3.3 As this is a novel approach to agency, it will require further study and validation before being used extensively.

2.4.4 The Bela System for measuring group coordination - ACVJ

In order to investigate the impact of introducing subgroups into a rhythmic task, we make use of the Bela Mini Audio - Microcontroller system. The Bela system is a tiny computer, including its own environment, “the Bela IDE”, which is made accessible through connecting the Bela to a laptop browser (*Bela & Bela Mini*, 2024). The Bela was developed to allow for low-latency digital instrument development, and therefore allows for us to create an experiment with very low latency, while also generating tones, keeping track of keypresses and producing an audio output. Where latency below 10ms in ie. music production is considered acceptable (Jawed, 2024), and previous studies have considered 3ms low latency (Bolt et al., 2016) the Bela system allows for a round-trip audio latency below 1ms (*Bela & Bela Mini*, 2024). This makes it ideal both for producing and recording audio data. The system is constructed using a RTOS (Real Time Operating System) which can give hard timing guarantees. This is made possible, as the Bela makes use of the linux extension Xenomai, which guarantees that the Bela code has top priority on the hardware (Bela Platform, 2020).

2.4.5 Research Questions and Hypotheses tested in validation study - ACVJ

As mentioned in section 1., the present thesis validates a novel paradigm for measuring group interaction by running a validation study (see section 3.3 below) that tests the following hypotheses::

Research Question 1: *Is overall coordination stability lower in conditions with subgroups compared to conditions with no subgroups?*

$RQ1\ H_0$: *There is no difference in coordination stability between conditions with subgroups and conditions without subgroups.*

$RQ1\ H_1$: *The degree of coordination stability is higher for conditions with subgroups present compared to conditions without subgroups present.*

$RQ1\ H_2$: *The degree of coordination stability is lower for conditions with subgroups present compared to conditions without subgroups present.*

Research Question 2: *Is agency generally experienced as more shared for members of subgroups compared to individuals in the same condition?*

$RQ2\ H_0$: *There is no difference between the sharedness ratings for members of subgroups compared to individuals in the same condition.*

$RQ2\ H_1$: *Agency is experienced as more shared for members of subgroups compared to individuals in the same condition.*

Research Question 3: *Does the coordination stability of participants predict the degree of experienced shared agency?*

$RQ3\ H_1$: *The coordination stability positively predicts the degree of experienced shared agency.*

$RQ3\ H_2$: *The coordination stability negatively predicts the degree of experienced shared agency.*

3. Methods - ACVJ

The following sections address four major points of our proof-of-concept experiment; 1) the setup, 2) a sanity check of the Bela systems recorded timing 3) The experimental paradigm.
All code used for the experiment and data analysis is accessible through the following git-repository: https://github.com/ACVJ/onde_bachelor.

3.1 Hardware and software setup - ACVJ

This section covers the hardware and software used, the setup and information flow (fig. 3.1). The details concerning each element can be found under the corresponding headlines.

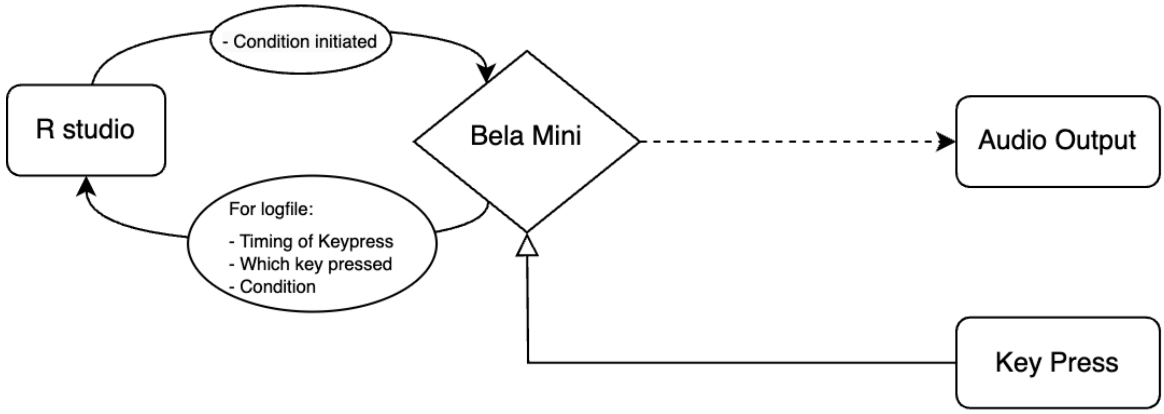

Fig 3.1: Information flow. The experiment is initiated and controlled through rstudio, conditions are programmed in Bela, eliciting and recording audio output and registering keypresses. This information is sent back to be logged in files in rstudio.

3.1.1 Overview of hardware and software setup - ACVJ

The experiment was made using a variety of hard- and software. When the experiment is run, an *R* script is started and presents instructions to participants on the computer screen. The messages used to start the experiment are sent via terminal to Bela, while simultaneously starting the script and providing information about the trial number and condition to the Bela. Each trial, participants press designated keys on a MIDI-keyboard to elicit sound. Executing audio processing is done through the Bela Mini System. Managing the conditions sent to the Bela and instructions given to participants, is done in r on the experiment computer. Once a series of trials are over, the r session sends a message to the Bela to terminate the terminal, and extracting a log file from the Bela. Then, Rstudio presentes the participants with rating instructions, and a rating scale. Once the participants have provided ratings on the computer, the r-script moves on to the next trial. The study was setup using a Lenovo Thinkpad (Processor AMD Ryzen 5 PRO 3500U, 16.0 GB RAM), running on Windows 11 Pro (V. 23H2).

3.1.2 Audio & Bela: Generating sound and recording taps - ACVJ

The script for executing sound and recording the participants' key-presses was coded in C++ using the Bela IDE (Bela image, v0.3.8g, 28 June 2022), accessed through the Chrome browser (Version 131.0.6778.86 (Officiel version) (64-bit)). The Bela IDE is the software made accessible through the use of the Bela Mini System, consisting of a Bela Mini cape and a PocketBeagle.

The Bela mini was connected to the Lenovo Thinkpad computer via. a micro USB cable, to a MIDI-keyboard (Akai Professional MPK mini MK2) via. a USB 2.0 A/B cable. On the MIDI-keyboard, three of the keys were each marked with a dot - either blue, black or pink (noted in logfile as key no. #1 = blue, key no. #12 = black, key no. #24 = pink). Picture of MIDI keyboard with color indication can be found under appendix 3.1.2. The audio-output was channeled through a single pair of Beierdynamic DT 990 pro headphones. The headphones were placed on the table about an arms width from the participants, to make up for a speaker.

To increase the engagement of participants, and the social aspect of the task, the pitch sequence created by participants would follow the tones of the pentatonic A major scale. A scale makes up a simple "melody", which in turn makes the tones dependent on one another, in comparison to repeating a single tone. The tones were created using a simple sine wave oscillator, with no envelope.

When the conditions for playing a tone are met, i.e. participant B and C press a tone simultaneously in a subgroup condition, a pitch would be elicited, starting at the 440 Hz A. The next elicited tone would be corresponding to the following tone on the scale, continuing up to the A at 880 Hz. The scale is visualized in fig. 3.1.2.

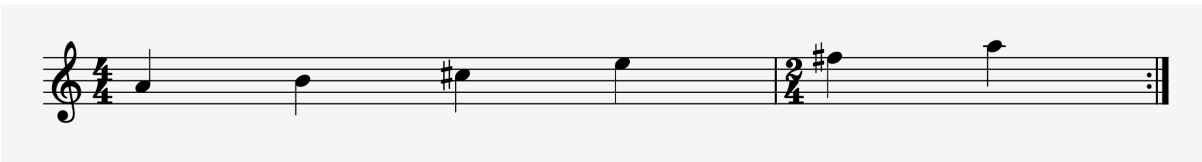

Fig 3.1.2: The pentatonic A-scale used in the experiment.

The scripts for testing timing (section 3.2), and setting up the experiment were coded in R (version 4.4.1), and run in rstudio (2024.09.1+394). For the timing test, the packages tuneR (verison 1.4.7), seewave (version 2.2.3) and tidyverse (version 2.0.0) were used. For presenting instructions and rating scales, the packages tcltk (version 4.4.1), tidyverse (version 2.0.0), magick (version 2.8.5) and the rstudioapi (version 0.16.0) were used.

3.2 Validation tests of paradigm implementation - CEGN

In order to ensure that the experimental setup logs the timing correctly, a timing test was conducted. The timing test consists of two parts: 1) testing the timing of the metronome beats that start each condition, and 2) testing that the timings of the taps recorded by the Bela match with the actual intervals between tones.

In order to test the metronome, the experiment Bela script was modified so that the metronome would keep running for a hundred tones instead of 4. The output of the Bela was then recorded using a "scarlett solo usb 2nd gen.", and Ableton Live 11. The other timing test was conducted to test the timing of the keypress registering. The original Bela script was run for a few trials, while recording into the computer in the same way as for the metronome.

The sound files were imported and cropped to remove the very beginning and end of the sound files. Then onset detection was carried out using a threshold of 55% of the max volume and a cooldown period of 0.5sec. This algorithm was implemented to most efficiently and precisely capture each event, and avoid registering several onsets for the same tone. The cooldown period was implemented to solve an issue of onset detection: The onset detection algorithms varied quite randomly between detecting the end or beginning of each tone because the audio has no envelope, and there is quite a lot of clipping. However, this was resolved by implementing a cooldown in the onset detection algorithm. Plots visualizing the onset detection without cooldowns can be found in appendix 3.2a and appendix 3.2b.

Once the IOIs were extracted from the sound files, the procedure deviated slightly for the two timing tests. For the metronome test, the mean IOI and the standard deviation of the IOIs were recorded, and those are the relevant results, found in section 5.1.1.

For the tap-timing test, IOIs were extracted from the sound files in a similar way as to the metronome timing test. The IOIs that were actually related to participant-generated tones(all the ones that were not metronome tones) were then compared to the ITIs recorded by the Bela for the same trial. Subtracting the IOIs measured in the sound file from the ITIs recorded by Bela, gives us a value describing the difference. The mean difference and standard deviation of the differences was measured, and is found in section 5.1.1.

3.3 The Experimental Paradigm and Validation Study - CEGN

Here we cover the foundations of the experimental paradigm, the demographics of our proof-of-concept participants, conditions and rating system.

3.3.1 Participants for Validation Study - ACVJ

Data was collected from 6 participants (4 females, 2 males, mean age = 35.83 years, range = 23 - 62 years), with three participants needed for the experiment, making up two sets of data, where only one consisted of the full set of conditions. All participants were right handed, with normal or corrected to normal vision, normal hearing and no recorded history of amusia. No participant had experienced formal musical education. Participants provided informed consent prior to the experiment. As the focus of this experiment is to develop a novel experimental paradigm and propose relevant analysis steps, the development of exclusion criteria has not been prioritized. We do recommend, however, that exclusion criteria be developed and implemented, such as no to little formal musical training, to contribute to creating a sample with equal prerequisites.

3.3.2 Conditions - ACVJ

This study design consists of 6 conditions, where each condition is made up of 1 practice trial and 3 experimental trials. One trial consists of 4 metronome tones, 24 tones made by the participants, and is ended by each participant rating their experience of SoA on our custom rating scale (see section 3.3.3 for details on rating scale). An experiment trial is exemplified in fig. 3.3.2. 24 tones were selected to give the joint dynamics more time to stabilize, as seen in (Konvalinka et al., 2014).

The conditions can be represented as follows:

(1) $$A - B - C - A - B - C$$

(2) $$B - C - A - B - C - A$$

(3) $$C - A - B - C - A - B$$

(4) $$ABC - ABC - ABC - ABC - ABC - ABC$$

(5) $$A - BC - A - BC - A - BC$$

(6) $$BC - A - BC - A - BC - A$$

The letter(s) between the dashes above represent the members needed for eliciting a tone, and each tone is separated by the dash.

Each condition is defined by the order of tapping. In all conditions, the participants have to continue the pace of the metronome tones, until 24 tones have been produced by the participants. In the individual conditions (as in lines 1 to 3, seen above), the participants tap one at a time, from the first participant (A) to the last (C). The order of who taps first in a condition is varied, to make sure each participant gets to begin. This is done as some studies suggest that initiating a task is seen to influence the feeling of ownership over the task completed (Bolt et al., 2016). In the simultaneous condition (represented in line 4) all participants are instructed to tap at the same time, and sound is only generated once all 3 have pressed their assigned key. In the subgroup conditions (seen in lines 5 and 6), participant A ("loner") can generate sound by pressing their button, while the 2 other participants, participant B and C ("subgroup") have to press together in order to elicit a tone. In condition 5, the loner is the first to tap after the metronome tones. This is altered in condition 6, where the subgroup is the first to tap after the metronome tones. Conditions 1 through 4 act as control conditions, as they do not entail subgroups.

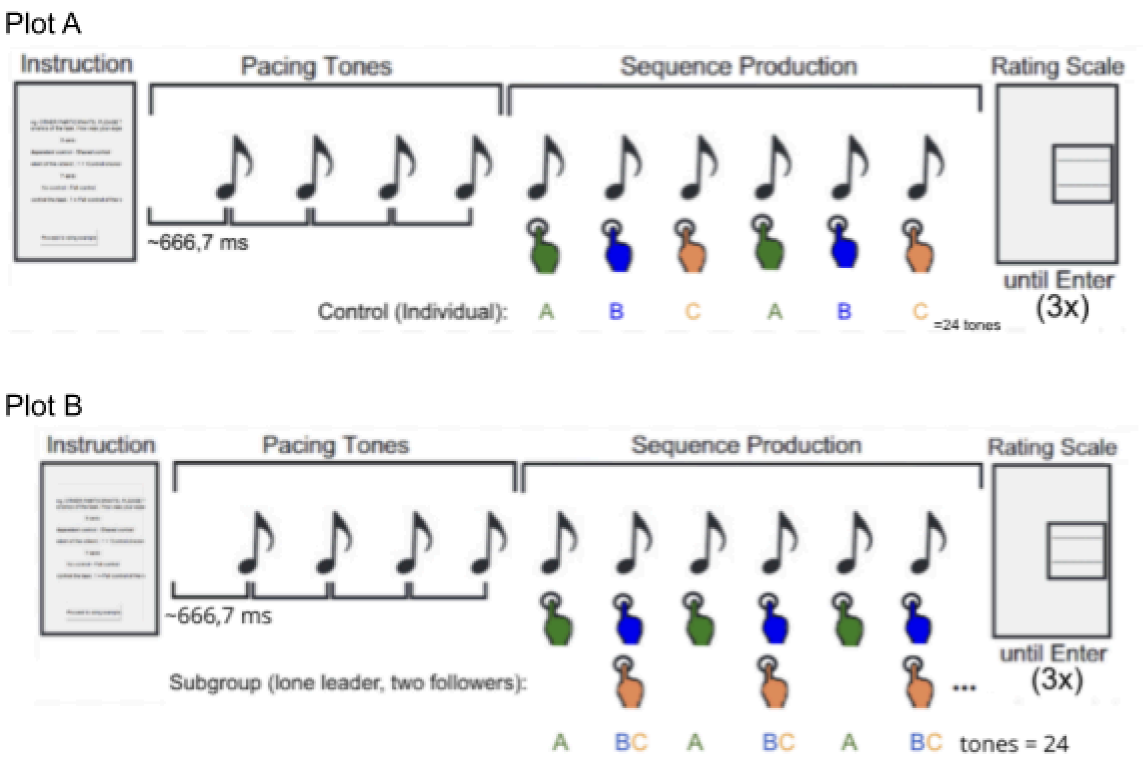

Fig 3.3.2: The flow of a trial of the experiment. A is in an individual condition and B is in a subgroup condition. Illustrations adapted from Bolt et al., (2016).

3.3.3 Sense of Agency Rating Scale - CEGN

As described in section 2.4.3, a novel rating scale was developed based on the scales used in Bolt et al. (2016) and Dewey et al. (2014). The scale is presented three times after each trial in the experiment, including practice trials, but only the experiment trials are actually recorded. As in other agency experiments, the questions are phrased in terms of control (Bolt et al., 2016; Dewey et al., 2014; Dewey & Knoblich, 2014; Loehr, 2022). The scale includes two dimensions - a dimension of strength of control and a dimension of sharing control with the other participants. The dimensions of strength and sharedness are crossed to make a plane that allows participants to rate their experience on both of the dimensions. The scale as it appears to participants is shown below in figure 3.3.3. Prior to being presented with the scale, instructions are shown on screen explaining how the scale works and following the instructions, an example of what different markings upon the scale would reflect, are shown. Instructions and examples can be found in appendix 3.3.3a and 3.3.3b.

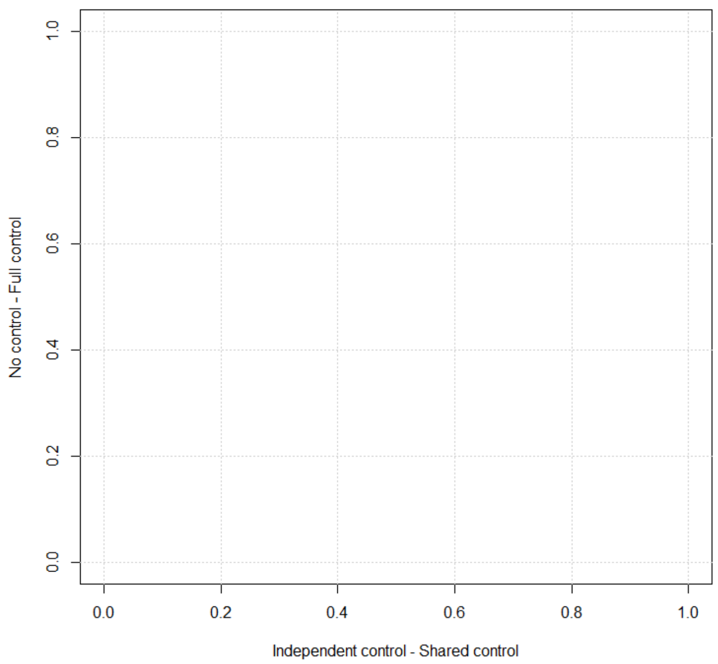

Fig. 3.3.3: Rating scale presented to participants.

3.3.4 Experiment - CEGN

The present study design was inspired by Bolt et al. (2016), as described in section 2.4.1. As in Bolt et al. (2016), the task that participants are presented with is to jointly continue a tone sequence at the speed defined by four initial metronome tones. In the present study, 3 participants are required. First, participants are asked to complete a consent form, and are instructed about the contents of the study from the experimenter. The participants were allowed to talk to each other during the task.

Each participant is assigned a key on the MIDI-keyboard. A colored dot has been taped onto each key, for orientation. Participants are asked to listen to a metronome beat, and continue tapping in such a way that the tone sequence that they create has a tempo that matches the metronome tempo.

When the participants tap, an A major pentatonic scale is played. The tapping is distributed among the participants in patterns dependent on the condition. the participants tap until they have played 24 tones, and then sound generation is stopped. Once sound generation is stopped, an experimenter steps in, and moves on to the SoA rating scales. After each trial, the participants have to rate their experience of agency or control over the production of sounds, using a scale (for details see section 3.3.3). The scale is shown three times, each time emphasizing that the other participants should turn away from the screen while the rating is going on. After all three participants have completed their ratings, using the computer mouse, the rscript moves on to the next trial, and if all trials in a condition are complete, new instructions are presented before a new condition is started.

4. Analysis of the Proof-of-Concept Data - CEGN

The analysis of the proof-of-concept data consists of a preprocessing of the data, followed by building model syntax, and finally running the models.

4.1 Preprocessing - ACVJ

Prior to building the models used for analysis, the data underwent the following pre-processing (done post validation of timing tests - see section 3.2).

1. Combining the files containing rating data and tapping data
2. Removal of NA's and practice trials
3. Adding subgroup columns - dummy variable indicating presence of subgroup in trial
4. Calculating inter-tapping intervals (ITIs)
5. Calculating inter-onset intervals (IOIs)
6. Calculating coefficient of variation (CV)

The data processing and analysis was carried out in R (version 4.4.1) and Rstudio (version 2024.09.1+394) using the packages Tidyverse (version 2.0.0) and lmerTest (version 3.1.3).

The inter-tapping intervals (ITIs) were computed by grouping the data by trial, condition and group ID, and arranging the data in the order of the tap timestamps. This allowed for the dataframe to alternate between participants, reflecting the order of occurring keypresses. Based on the order of keypresses, the function 'lag()' (from dplyr (version 1.1.4)) is used, first by extracting the previous tapping time, then subtracting this from the current tapping time. This is repeated throughout the dataframe and saved in a new column.

Once the ITIs have been computed, these values are used in computing the IOIs (inter-onset intervals). As the experiment design only allows for a tone to be elicited once specific requirements have been met, such as all participants need to press their key in the simultaneous conditions (see section 3.3.2 for details), the IOIs need to be extracted strategically.

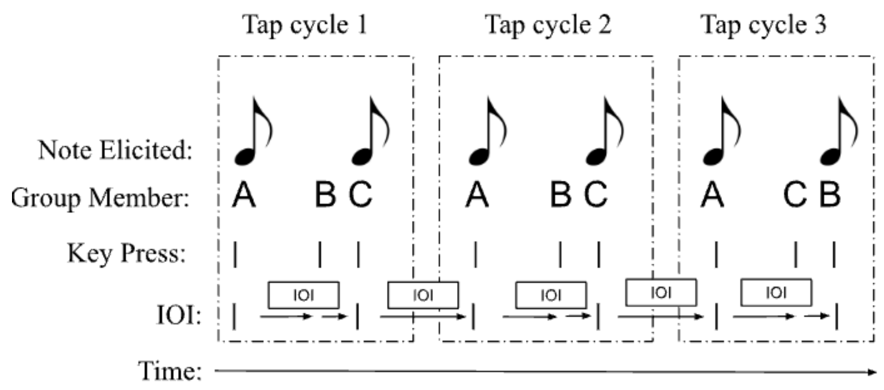

Fig. 4.1: Visualization of the relationship between tone onsets and IOIs produced. Temporal dimension indicated by bottom arrow.

To do this, a “tap cycle” was initiated, incrementing every three steps. “Tap cycle” keeps track of every “round” throughout the dataset (ie. in a subgroup condition, a-bc-a-bc would be tap_cycle 1 and tap_cycle 2 etc.) In the subgroup leader-follow condition (illustrated in fig 4.1) the IOI were computed as follows: The IOI between the last tone elicited in the previous cycle and the first tone elicited in the following cycle corresponds to the ITI between the last tap in the previous cycle and the first tap in the following cycle. This is because group member A would only need their own tap to elicit sound. To get the IOI between the tone generated by the loner (Participant A in this case) and the tone generated by the subgroup members together, the ITIs between the subgroup members were added together, as this would correspond to the time a tone was elicited. In fig. 4.1, this is exemplified with one of the subgroup conditions, where group members B and C aim to press simultaneously. This results in one subgroup participant tapping slightly before or after the other (see fig. 4.1, group member tap-order in tap cycle 2 compared to tap cycle 3). For the simultaneous condition, all ITIs within a cycle and are added together, to reflect a similar pattern.

The term CV (coefficient of variation) reflects the stability of a condition, by being calculated on the foundation of the mean of a measure, divided by its standard deviation. In our analysis we calculated the CV by taking the standard deviation of the inter onset interval (IOIs). The CV was calculated grouped by condition and trial, resulting in a single CV value for each trial.

4.2 Model Syntax - CEGN

The following analysis is a proposal as to how to answer the research questions stated in section 2.4.5. As the data gathered does not represent a proper sample, but is rather a proof of concept (see section 1.), this is a proposal for an analysis.

To answer research question 1, whether overall coordination stability is lower in conditions with subgroups compared to conditions without, we build a linear mixed model (LMM), with the following syntax:

<u>Model 1:</u>

CV ~ subgroup present or not + (1 | group) + ε

Here, we use the coefficient of variation (CV) as an expression of coordination stability, and use the term as the dependent variable. This model predicts CV by making the presence of subgroups the independent variable and coded as a fixed effect (encoded with a dummy variable 0, 1) and the model provides a random intercept for each group.

To answer question 2 and 3, another LLM was created, with the following syntax:

<u>Model 2:</u>

Shared Agency Rating ~ Is participant a subgroup member + CV + (1 | group) + ε

Here, we predict the rating for shared agency as a function of subgroup member status (binarily encoded as well, with 0 and 1). We use subgroup-member status and CV as fixed effects, and provide the model with a random intercept for each group.

5. Results of Experiment and Timing Validation - CEGN

In this section we report the results of the timing test, covering the test of metronome timing and tap timing, and the results of the proposed data analysis for analysing future experiment data.

5.1 Results of Timing Validation Tests - CEGN

Here, we report the results of the two validation tests of the timing accuracy of the Bela system by doing a metronome timing test, and a tap timing test.

5.1.1 Metronome Timing Test - CEGN

When testing the metronome, the goal was to get a timing of 2/3rds of a second, since this would correspond to 90 BPM. The procedure for the test is described in section 3.2.

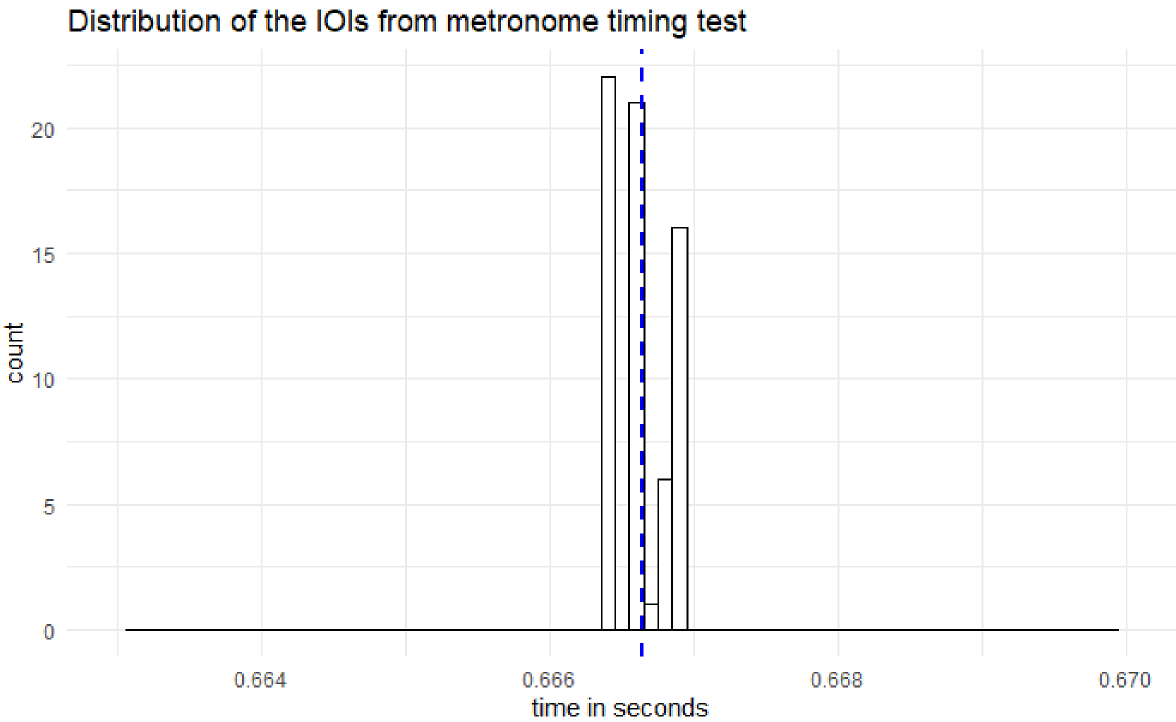

Fig 5.1.1: Distribution of the IOIs of the metronome tones - the mean represented by the blue dotted line.

For the timing test of the metronome, the distribution of inter-onset intervals had the mean of 0.6666399, which means it was correct down to the 4th decimal (10th of a millisecond). The standard deviation of the timings was 0.00018854 (approximately a fifth of a millisecond). This is considered a very stable and precise timing.

5.1.2 Timing Test for Taps - CEGN

For the tap timing test, the goal was to get as small a difference between the taps recorded by the Bela, and the tone onsets recorded from the output as possible. The procedure for the test is outlined in section 3.2

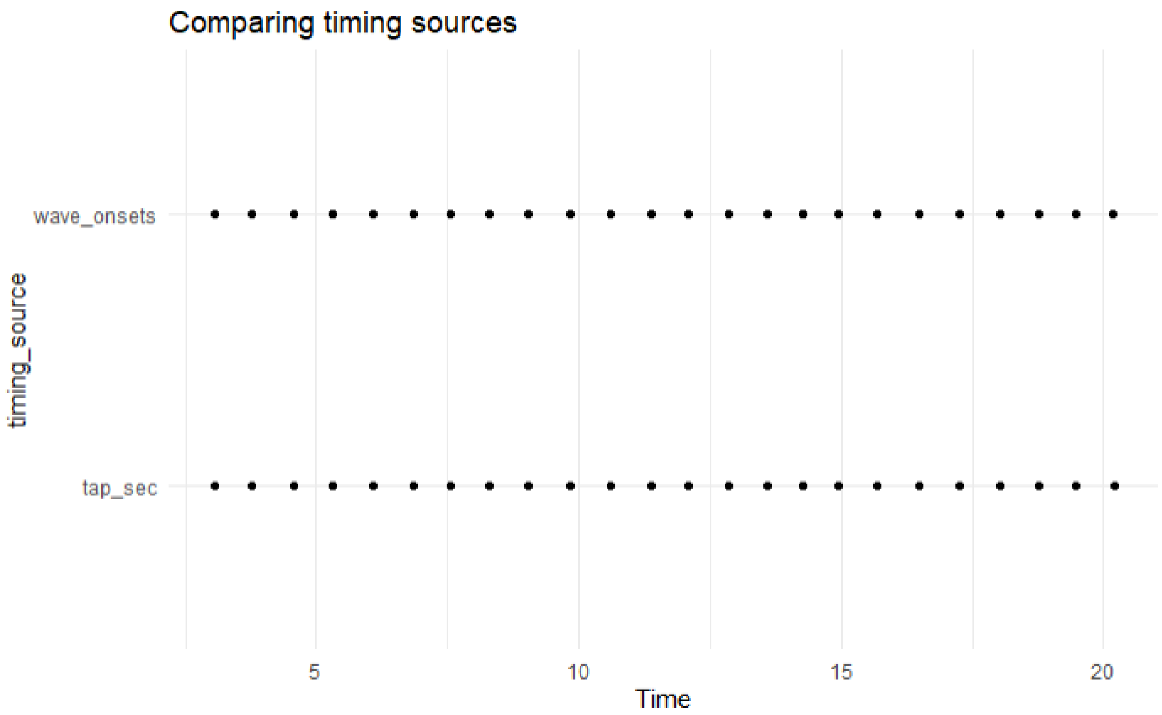

Fig 5.1.2a: The timing of events are visualized. Wave_onsets represent the onsets extracted from the sound file. Tap_sec represents the recorded key presses from the Bela. We see a great degree of correspondence between elicited tone and recorded tap.

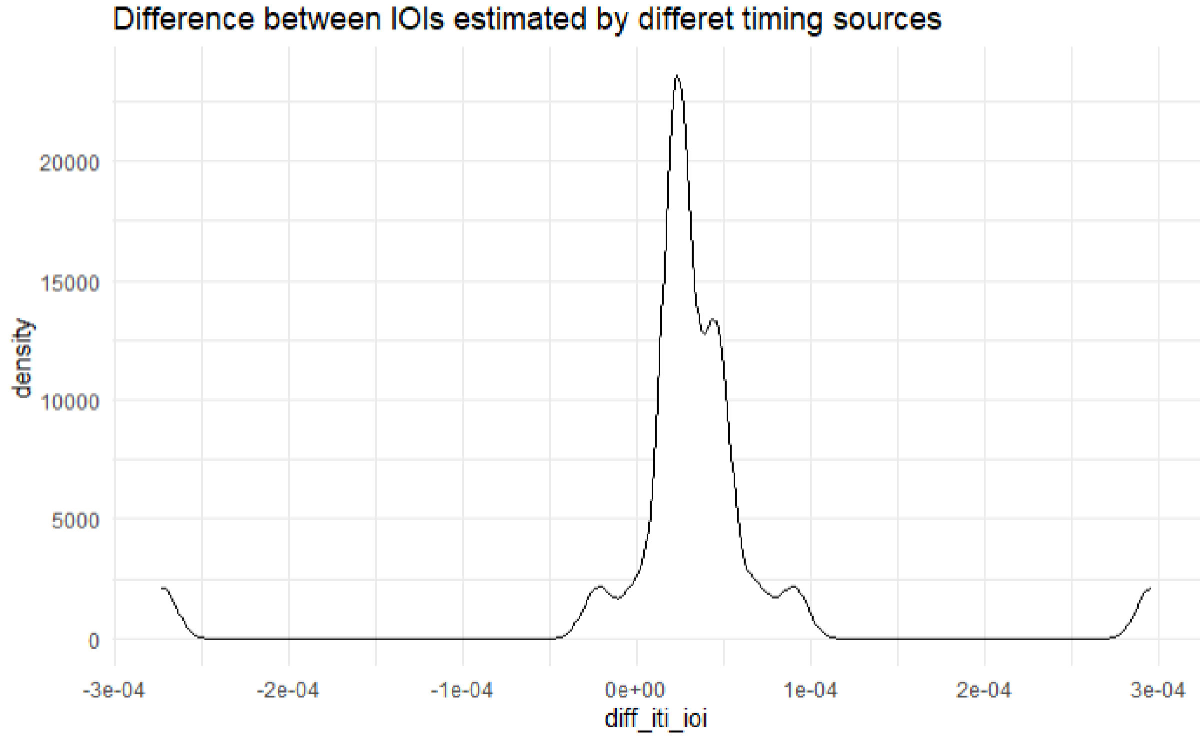

Fig. 5.1.2b: Illustration of the distribution of differences between IOIs extracted from the sound file and ITIs recorded by the Bela. We see a narrow distribution centered around 0, indicating a very small difference between elicited tone and recorded key press.

The mean difference between the ITIs recorded by the Bela, and the IOIs recorded from the sound file was 2.958e-05s - which is three 100ths of a millisecond. The standard deviation was 8.868e-05s, which is nine 100ths of a millisecond. The timing tests support the notion that the Bela timing is exceptionally precise, both in generating sounds and recording the ITIs. In the rest of this paper, the Bela timestamps are used as the main measure of timing.

5.2 Results of Experiment Data Analysis - ACVJ

In this section, the results of the analysis of 1.5 groups of participants are reported, as a guideline for further research. None of the results are to be taken as generalizable findings, due to the low sample size.

5.2.1 Research Question 1 - CEGN

Research question 1 is as follows: *Is overall coordination stability lower in conditions with subgroups compared to conditions with no subgroups?* To address this question, the following model was used: CV ~ subgroup present or not + (1 | group) + ε. Coefficient of variation was significantly predicted by the presence of subgroups. However, the marginal explained variance is quite low: Conditional R^2 = 0.581, Marginal R^2 = 0.140.

Summary of the lmerTest model.

	β	*SE*	*t*	*p*
(Intercept)	0.10	0.02	4.27	.145
subgroup_present	-0.04	0.00	-12.35	<.001

Table: 5.2.1: Estimated model output of the model CV ~ subgroup present or not + (1 | group) + ε.

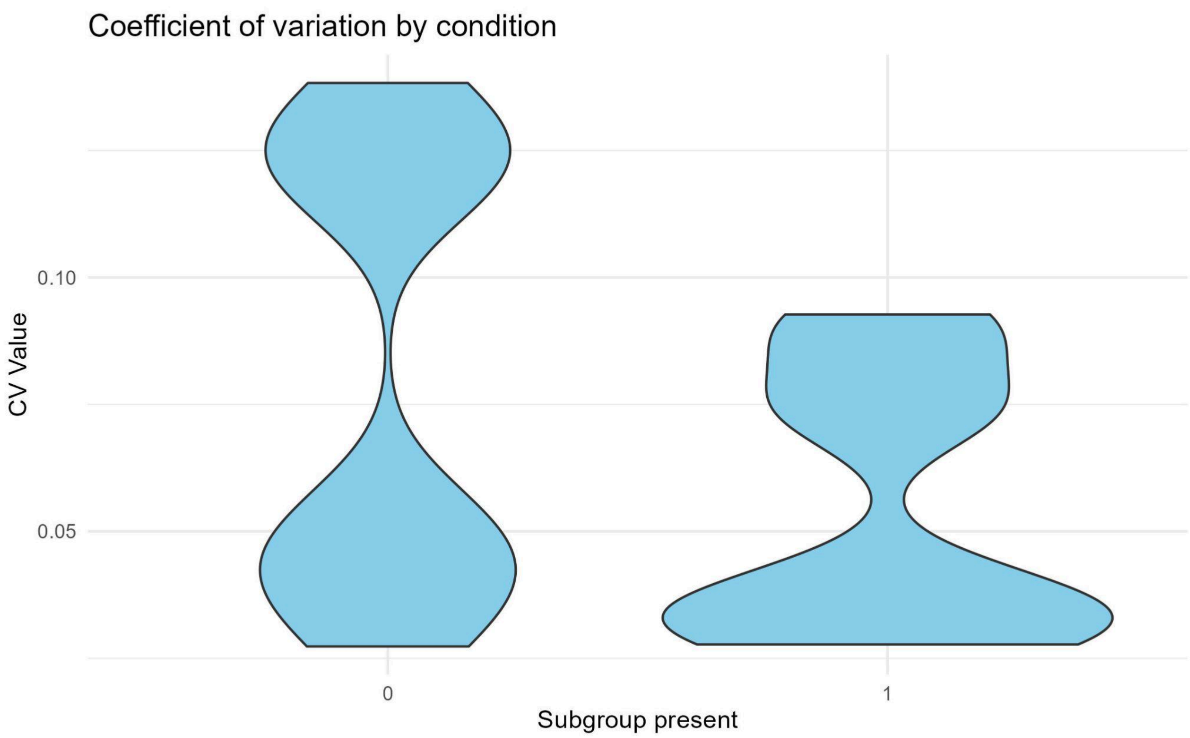

Fig. 5.2.1: Illustration of the difference in CV value and how it is predicted by the presence of subgroups. 1 means subgroups are present in the condition.

In fig. 5.2.1, we see the distribution of CV values grouped by the presence of subgroups. Based on the plot, we see there is a difference in CV values depending on the presence of subgroups.

5.2.2 Research Questions 2 and 3 - CEGN

Research Question 2 is as follows: *Is agency generally experienced as more shared for members of subgroups compared to individuals in the same condition?*

Research question 3 is as follows: *Does coordination stability predict the degree of experienced shared agency?*

Both research question 2 and 3 are investigated using the following model syntax: S*hared agency rating ~ is participant a subgroup member + CV + (1 | group)* + ε.

The coefficients are given in table 5.2.2. In the preliminary data, the effect of being a member of a subgroup is not significant (p = .663). The effect of CV is significant and positive (p = <.001, β = 0.43), meaning that when CV increases, so does the shared agency ratings. This means that the less coordination stability, the more shared the SoA is rated. The variance explained by the fixed effects is modest: Conditional R^2 = 0.610, Marginal R^2 = 0.122.

Summary of the lmerTest model.

	β	*SE*	*t*	*p*
(Intercept)	0.43	0.17	2.54	.194
subSubgroup	0.01	0.03	0.44	.663
cv	4.39	0.96	4.56	<.001

Table 5.2.2: Estimated model output of the model Shared agency rating ~ is participant a subgroup member + CV + (1 | group) + ε*. 'Subsubgroup' is the effect of being a member of a subgroup.*

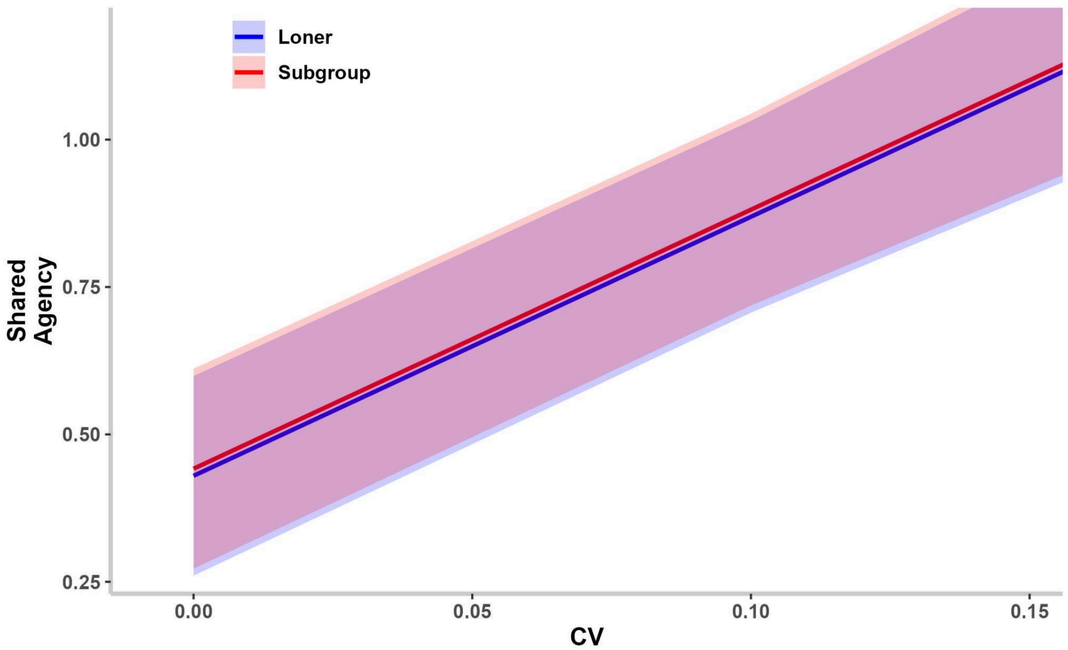

Fig 5.2.2: Illustration of the model output of model 2. The shared SoA ratings seems to be predicted by the CV, quite similarly for all participants, both the loners and the subgroup members. Shaded areas represent variance of random intercepts by group, where the purple shade is reflecting an overlap between the loner and the subgroup.

In fig. 5.2.2 we see that the sharedness ratings of the SoA are higher when the CV is higher, and this effect seems similar across subgroup members and loners.

6. Discussion - ACVJ

The aim of this thesis is to develop a new paradigm in which to investigate subgroup dynamics rather than conducting an extensive data gathering process (see section 1. Current Thesis: Overarching Goals), we have gathered data from 2 groups of participants, of which only 1 completed the whole array of conditions. These findings are not expected to be generalizable. Because of this, considerable attention is paid to developing the experiment and hypotheses on the foundation of current knowledge of joint SoA.

First, we briefly discuss the results of the validation of the timing. After that, we outline the hypotheses based on existing evidence. Then, we compare the proof-of-concept data we have collected to the hypotheses, more as an example than as actual results, in order to discuss the possible implications that can be derived from this experimental paradigm. After this, we briefly list some limitations of the experimental paradigm, while pointing to possible remedies where possible. Finally, we suggest further related avenues of research, made possible by utilising the present paradigm.

6. 1 Validation Tests of the Paradigm - CEGN

The experiment software/hardware setup was validated with the timing tests outlined in section 3.2. As the results given in section 5.1 indicate, the timing is very precise. This means that the paradigm results regarding coordination stability are reliable. A higher level of precision of the timing means that less noise pertains to the results, allowing higher degree of precision in determining coordination stability and timing of keypresses in general. The MIDI keyboard does not make the same promises to extreme low latency, as the Bela does, but is nonetheless created for music production, in which low latency is a must. Additionally, the results of the validation experiment, outlined in action 5.2 and discussed in the next section, we deem acceptable, another indication that the setup is working as intended. Possible limitations are discussed in section 6.3.

6.2 Hypotheses, and Implications of Possible Results - ACVJ

As mentioned, the amount of data that is gathered in this experiment works as proof-of-concept, and not to warrant a full analysis that can generate any evidence of generalizable findings. Therefore, in the following sections we will discuss hypotheses for the results. The possible interpretations of results are contingent on more data being collected and showing patterns similar to those in our validation data set. These should help to highlight some of the questions our paradigm could help to elucidate.

6.2.1 RQ 1: Overall Coordination Stability in Subgroup Conditions - CEGN

Our first research question asks whether overall coordination stability is lower in conditions with subgroups compared to conditions with no subgroups, to which we proposed two hypotheses. The first hypothesis, $RQ1\ H_0$, states that no statistically significant difference will be found between conditions containing subgroups and conditions not containing subgroups. As very little research has looked at the agency dynamics associated with subgroups in collaborative rhythmical tasks, and hence we do not know the impact of adding subgroups on coordination, this hypothesis seems possible. Another hypothesis, $RQ1\ H_1$,states that the CV is higher for conditions with subgroups present.

As CV is used as measure for the coordination stability, a higher CV would reflect a higher variety of IOIs, meaning the tones would have been elicited at many different intervals. We would interpret this as the condition being characterized by higher levels of instability, and more asynchrony between the individual participants.The H_1 hypothesis could be supported by an EEG-study by Kourtis et al. 2010, which found that the social relationship between participants impacted motor activation. The authors created a task, in which two members were actively interacting, while one member was acting independent of the others. Authors found that the participant, who was acting with a partner and EEG-scanned during the task, exhibited a smaller action preparation potential in motor areas linked to prediction when the "loner" was acting. The same participant exhibited more action preparation when the partner was acting. We could hypothesize that this would mean that subgroup members are not as effective at predicting the actions of those who are not part of their subgroup, thus impairing coordination in the experiment. However, unlike in the Kourtis et. al. (2010) paper, all our participants are dependent on each other's actions, so this effect is not necessarily transferable.

The results of linear model 1 indicate that CV is lower in conditions with subgroups, meaning that coordination stability is higher in those conditions. This results counters hypothesis $RQ1\ H_1$ and $RQ1\ H_0$. If this result was consistently found in larger samples, one theory could be that this is due to tapping every second time is simply a more stable configuration for western participants, as western popular music is dominated by the time signature 4/4. This time signature might mean that 4 beats constitute a complete phase, and the first tone is interpreted as the beginning of a phase. When engaging in rhythmical or musically founded tasks, chances are that participants are more used to engaging in phases divisible by 4 beats - ie. we clap at every 2. beat in popular music. Hence it might be more intuitive to tap every second time.

6.2.2 RQ 2: Experience of Shared Agency - CEGN

The second research question asks whether agency is experienced as more shared for members of subgroups, compared to individuals in the same conditions.For this question, we can formulate several hypotheses: $RQ2\ H_0$states that there is no difference in the experienced sharedness of agency. It could be that there are no differences between the sense of sharedness of agency for members of subgroups and individuals in the same condition, as all participants have to coordinate closely to determine the overall outcome (Bolt et al., 2016). Another hypothesis, $RQ1\ H_1$, states that agency is experienced as more shared for members of subgroups compared to "loners". It might be that agency is experienced as more shared for members of subgroups, as the generating of tones is actually shared between subgroup members in a different way than for loners. The subgroup members need to coordinate more closely to maintain intuitive action/stimulus mappings, and their actions jointly generate one tone. Closer coordination should result in more shared coordination (Bolt et al., 2016).

The results of model 2 indicate that the sharedness ratings of the SoA was not significantly different between subgroup members and individuals in the same conditions. This is consistent with $RQ2\ H_0$. If the result was supported by more data, this would be slightly surprising, considering previous findings suggesting that the degree of coordination increases sharedness of agency (Bolt et al., 2016).

If a significant effect of subgroup membership is found in a proper sample, comparing the sharedness of SoA of the subgroup members with that of those performing in the simultaneous condition, could help elucidate whether this is due to more coordination, or whether it could partially be an effect of the subgroup dynamic itself. This would require controlling for coordination stability, which seems higher in the simultaneous condition. Including a loner that is not part of the group might enhance SoA, and feelings of group cohesion, compared to the simultaneous condition, where everyone is part of the group, so that there is no outgroup.

6.2.3 RQ3: Coordination Stability and Sharedness of Agency - ACVJ

Research question 3 asks whether the coordination stability of participants predicts the degree of shared agency. For this question, a number of hypotheses can be proposed. In this thesis, we proposed the following two: $RQ3\ H_1$, proposes that the coordination stability positively predicts the degree of sharedness of agency. It could be that an experience of greater successful cooperation could mean more sharedness. Much research has indicated that greater degree of shared agency is correlated with successful collaboration (van der Wel et al., 2012; Wen et al., 2015). Loehr (2018), worked experimentally with this question in a somewhat similar setup, and found that more successful coordination did indeed correspond to more shared SoA. Another hypothesis, *RQ3 H_2,* Proposes that the coordination stability negatively predicts degree of sharedness of agency. Coordination stability might negatively predict sharedness of agency to due a self-serving bias, or simply a cultural conception that high agency means high individual agency (Hernandez & Iyengar, 2001; Shepperd et al., 2008).

The results of Model 2 indicate that the sharedness of SoA is positively correlated with CV. This is in conflict with $RQ3\ H_1$, and seemingly in conflict with previous research, which indicates that more successful coordination leads to higher degree of sharedness in the SoA (Loehr, 2018). If larger samples yield similar results, it would therefore be surprising. However, several things are different in our setup than in previous experimental designs: Firstly, the present experiment includes 3 participants, and the addition of a third participant might interact with the complex dynamics of ascribing agency in joint action (see section 2.2.2). The participant providing the rating now plays a smaller role in the collective constructing the beat, compared to dyadic studies. This might alter the relationship in such a way that it is easier to ascribe negative performance to the others, in line with research on self-serving biases (Mezulis et al., 2004; Shepperd et al., 2008). Therefore we would not necessarily expect effects to replicate. Additionally, the question and rating scale presented to participants were different in the present study compared to previous research, in that there were two dimensions present simultaneously. This might prompt participants to think of agency in a different way. In addition, Loehr (2018), the only experiment directly addressing this that we could find, measures coordination success in mean deviation from the goal ITI, while we measure it in CV of IOIs. This means that a completely stably coordinated sequence, at a slower tempo, would be considered a success at our measure but not in the measure used in Loehr (2018). Combining these measures in the same analysis might elucidate the relationship between them.

6.3 Limitations - ACVJ

In the following sections, we will discuss the limitations we see as inextricably united with research of SoA, and the limitations we see remedies for.

Inherent to SoA research, and hence a recurring limitation in SoA research, is the self reported sense of agency. This measure forces participants, who likely are not familiar with SoA research, to respond and rate their experience regarding quite complicated and abstract concepts. Alternatives to this introspective approach to agency evaluation do exist in the form of implicit measures, however, do not seem to track the same as SoA (see section 2.4.3). Another recurring limitation in SoA tasks, especially those using rhythm and the like, is that participants can approach the task in different ways, using a variety of different conscious and unconscious strategies to match the right tempo. Such strategies may include attempting to stay true to the metronome without adapting much to the other participants, or adapting to others without heeding the metronome. These strategies are also affected by verbal and nonverbal communication between participants. A third inherent limitation to this type of experiment is that the deconfounding of conditions is complicated - i.e. it is not possible to create two conditions with and without subgroups, where the total number of participants and the order of tapping is the same.

In our experiment, we reimagine the measure of SoA rating, by combining the previous agency evaluation question from the SoA studies, Bolt et al. (2016) and Dewey et al. (2014) (see section 3.3.3). However, by using a novel rating scale, the scale has not been previously validated. This also means that any issues with the scale, before being evaluated, will go undetected - such as participants finding it impossible to navigate or misunderstand the questions. These factors coupled with the low number of participants, means that even little confusion amongst participants can greatly affect results.

In addition to the more inherent limitations mentioned above, we see a number of other limitations that can be addressed by minor adjustment to the setup. These adjustments include changing the agency scale to allow for confirming responses after marking a point on the grid evaluating SoA (see fig. 3.3.3), before having the response registered. Currently, the rating scale also allows for ratings slightly above 1, which should be adjusted to only allow for ratings ranging between 0 and 1 - not above 1. Furthermore, one might consider changing the generation of the tone so the tones are of equal duration length. In addition, an envelope can be added to avoid clipping. We also propose fine tuning the experiment's internal communication, to make the experiment continue after each trial without the need for experimenter interference. Additionally, the experiment could be improved by allowing for the use of separate monitors, to ensure that the rating scale is presented on a different screen, to avoid ratings being affected by participants feeling their SoA responses are being observed by other participants. Although the Bela timing is very precise, MIDI does not promise the same precision. This could perhaps be alleviated by switching the midi keyboard for Bela sensors or an interlink force sensitive resistor (FSR), as has been the case in previous agency studies (Bolt et al., 2016; Bolt & Loehr, 2017; Loehr, 2018). Switching out the MIDI keyboard could also allow for seating participants differently, to avoid priming by position (sitting in the middle of two other participants) and to allow for easier anonymization of ratings. One additional thing that might ease data processing is to change the Bela script to record the tap cycle, so that it does not have to be inferred after the fact (see section 4.1). Based on feedback from the participants, we suggest slowing the pace of the metronome, as some participants reported that the sequence pace was rather fast. Testing similar experiments with slower BPM may be interesting.

6.4 Further research - CEGN

We have, in the present paper, developed a paradigm for investigating joint action and the related experience of agency. By virtue of being a proof-of-concept experiment, it can hopefully become a tool to be used by researchers, and as such may contribute to research within SoA in joint action. Here, we outline what seems to us to be some of the most promising avenues for further research. Firstly, running the experiment as is, perhaps with the above minor tweaks (described in section 6.3), would help answer the questions described and discussed above.

One fundamental step for further research would be verifying the scale used for measuring agency, and the validity of the dimensions we used, as well as the 2 dimensional representation. One could compare it with other dimensions, ask the questions one at a time instead of as a continuum, or use other agency rating questions in a similar or identical setup. Using the data from the same experimental setup as described in this paper, research questions such as “ is strength of agency higher for individual leaders compared to individual followers?” or “ is strength of agency lower for individual followers when subgroups are present, compared to conditions without subgroups? ”can be investigated. Such research questions would have implications in researches investigating whether the existence of subgroups makes the “loner” feel more alone or powerless, and could be investigated using either dimension of our agency rating scale. Furthermore, such research questions could be interesting in investigating whether our agency dimensions are correlated with each other.

The setup in its current format allows for easily implementing further conditions to answer new research questions. One could imagine adding a condition with alternating tapping between two people, which when compared with the subgroup conditions in the present setup, might help illuminate the question of whether the time signature dominant in culture means that alternating taps are easier (section 6.2.1). Adding feedback could allow for investigation of how the effect of successful coordination on SoA is in triadic joint action. Additionally, adding dyadic or even individual conditions to the same experimental setup to allow for more direct comparison of results found in dyadic setups with those found in the present study. Common across these potential uses for the experimental paradigm is the possibility to accompany future research with EEG. In this case, experimenters would need to encode triggers into the scripts.

Another point could be looking at how previous findings in rhythmic tasks between dyads translate in tasks with a triadic group formation. Zamm et al (2023) found that participants jointly created a rhythm superimposed rhythmicities related to turn-taking structures onto the rhythms they were supposed to play (Zamm et al., 2023). Such a finding could be investigated in triadic group formations, to see whether similar results are replicated or novel dynamics are uncovered.

Another unexplored aspect lies in cross-cultural effects, such as whether a high degree of control is viewed as being an individual in full control, or whether a high degree of control is viewed as sharing control with others (Hernandez & Iyengar, 2001). If success in a culture is stereotypically being in control as an individual, such as in western societies (Heine & Lehman, 1997; Higgins & Bhatt, 2001), shared ratings might be lower in well-coordinated trials, however in more collectivist culture, things might change. This is in part a question about self serving biases, but also a question of the idea of control or success, and how that is conceptualized (Heine & Lehman, 1997; Hernandez & Iyengar, 2001; Higgins & Bhatt, 2001; Morris et al., 2001; ojalehto et al., 2017). Running the study using participants from different cultural backgrounds could give interesting insights into this topic.

One could further investigate social and cognitive processes in triadic structures, and the consequences of joint agency for social and cognitive processes, an area scarcely researched (Loehr, 2022, p. 202). This could be achieved i.e. by modifying who is present in the subgroup during the execution of the experiment. Changing who is in the subgroup during the experiment, might modify the social dynamics between the subgroup members. Another social cognition aspect of this experiment could be that of subconscious perception of others. The IAT (Implicit Association Test), which measures just this and is often used in exploring unconscious biases, could be added to this experiment, to study pre-existing biases or relations among participants.

In short, the opportunities within social cognition in the context of joint action and agency, are plentiful, as this area is still just beginning to be explored experimentally (Loehr, 2022).

7. Conclusion

Research in joint agency has been dominated by studies concerning these dynamics within dyadic group structures. In this thesis, we have developed a novel paradigm for investigating SoA in rhythmic joint action, based on existing paradigms. The new paradigm includes three participants. This experimental setup allows for investigations in how individuals manage to coordinate their actions while engaging in a triadic rhythm task, both in subgroups, simultaneously and individually. Furthermore, the experiment collects ratings of the SoA of the participants on two dimensions: 1) Experience of shared agency - did they feel that their control was dependent on the others in the condition, and 2) Experienced strength of agency - did they feel that they were in full control over the generated tone sequence? The experimental setup is tested as a proof-of-concept and a subsequent analysis has been run on proposed research questions. Running this experiment with a proper sample could elucidate questions regarding previous findings in dyads, regarding the effects of adding subgroups in joint action, so as to have asymmetric collaboration, and how strength and sharedness of agency interact with coordination stability in different configurations. By implementing various adjustments, an array of unanswered questions regarding agency in joint action, social cognition, successful coordination, experienced strength of agency and cross-cultural effects could be investigated. In conclusion, we believe that much could be learned from a rigorous approach to moving beyond the dyad in joint action research.

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9. Appendices - ACVJ

Appendix 3.1.2

Appendix 3.1.2: Picture of the MIDI keyboard used, with colored dots on the keys participants were assigned.

Appendix 3.2a

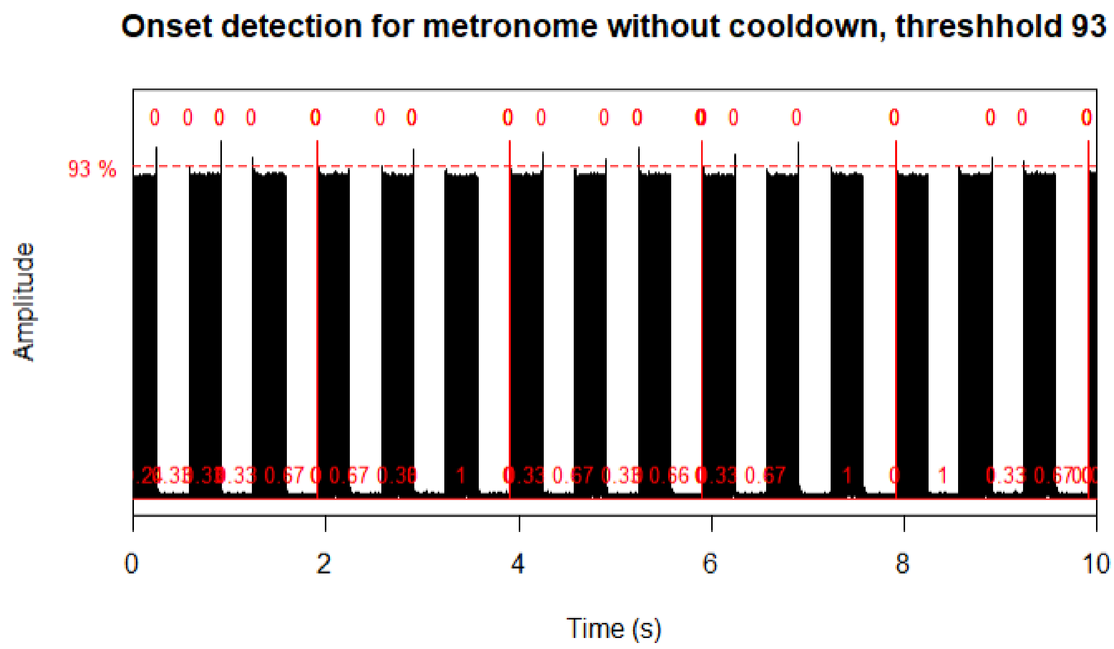


Fig.3.2: Visualization of the onset detection without adding "cool-down" - threshold 93.

Appendix 3.2

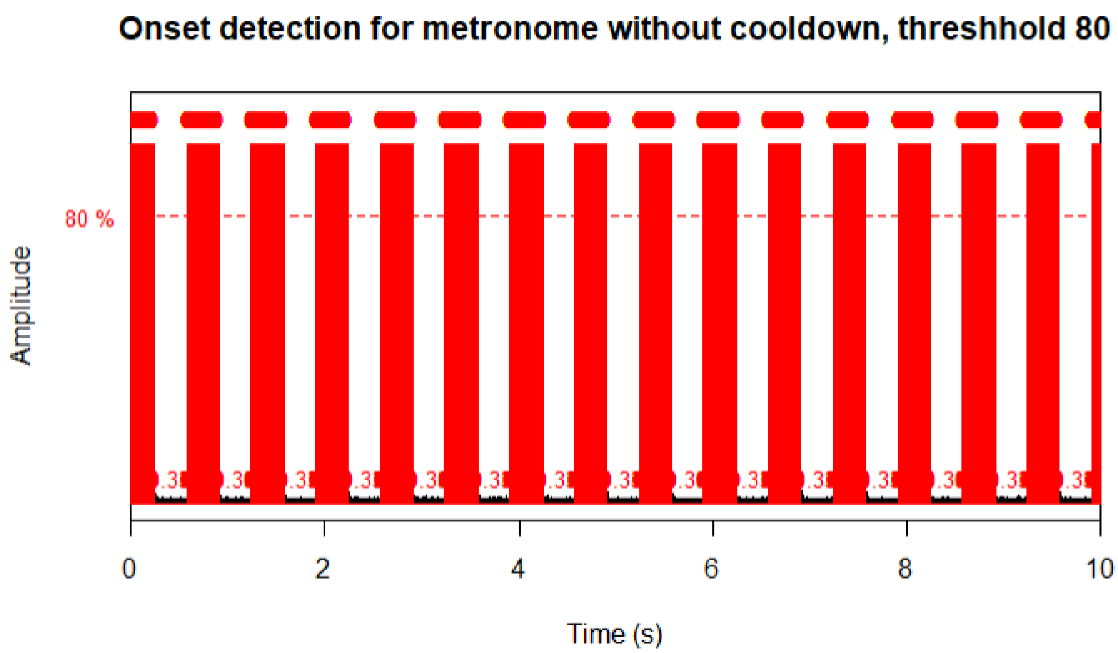
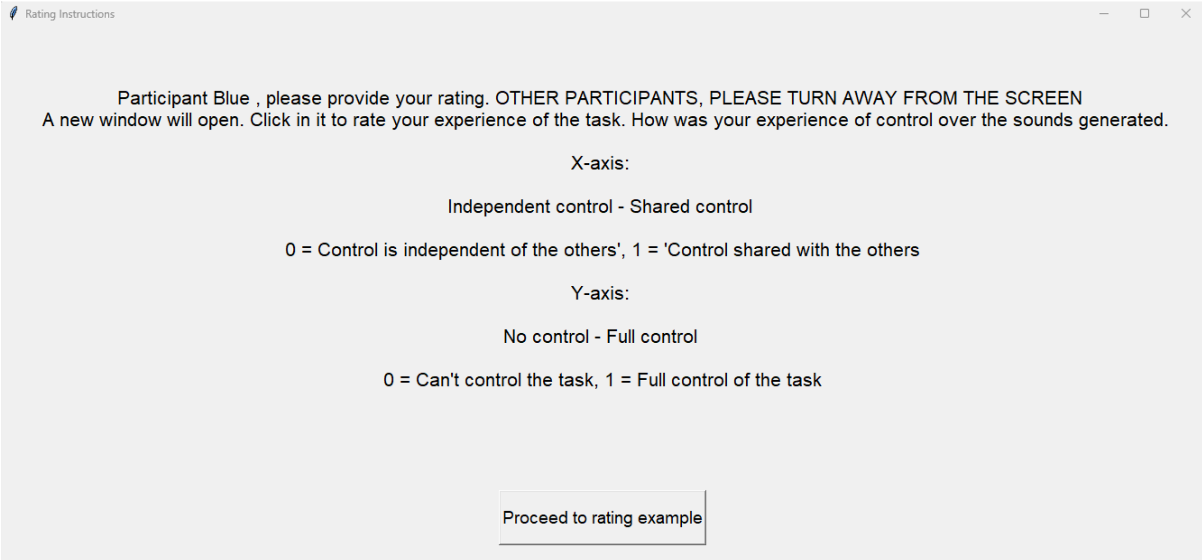


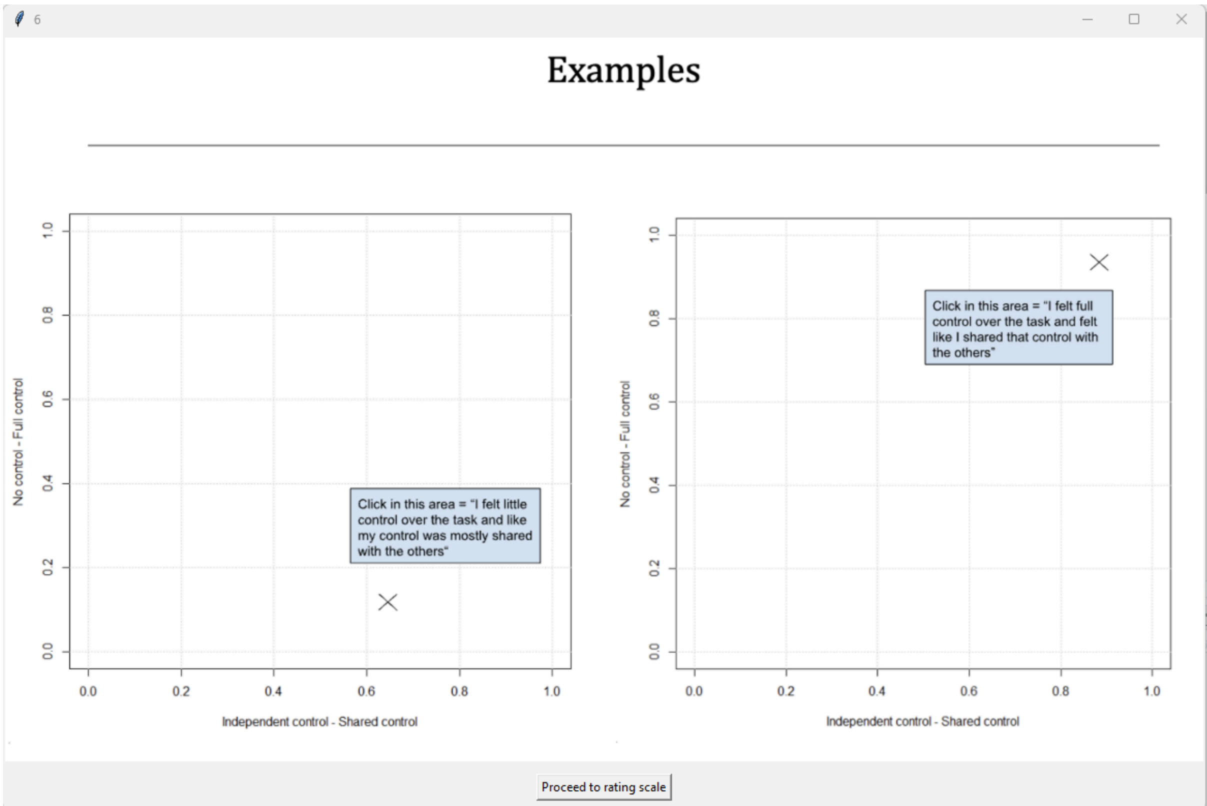
Fig.3.2: Visualization of the onset detection without adding "cool-down" - threshold 80.

Appendix 3.3.3a



Appendix 3.3.3a: Instructions shown to each participant prior to seeing evaluation of agency examples.

Appendix 3.3.3b



Appendix 3.3.3b: Examples shown to each participant prior to evaluating agency.