Dance Ensemble Synchronisation:
Movement Timing between two or more People

by

Juliane Jacqueline Honisch

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Abstract

Dancers' need to be coordinated in an ensemble poses multisensory challenges. The present thesis focuses on temporal aspects of visually mediated interpersonal synchronisation in dance, emphasising feedback control, using an information processing perspective.

The thesis firstly reviews previous literature on psychological factors in the coordination of dance (Chapter 1). Measurement methods and analyses to examine timing of dancers' interpersonal synchronisation are then introduced (Chapter 2). In the first two experimental chapters (Chapters 3, 4) a lead-follower paradigm is developed to quantify the temporal linkage between two or more individuals. Performer interdependence was estimated using mean, variance and serial correlation measures. Chapter 3 evaluates multimodal (auditory and visual sources) and Chapter 4 unimodal (two visual sources) on individuals' synchronisation performances. In Chapter 5, dancers' interpersonal synchronisation and the effect of visual and sensorimotor familiarity were investigated. Findings suggest that more familiar dance poses increase synchronisation accuracy. Chapter 6 examines firstly, the potential role of an internal forward model in visually mediated synchronisation and secondly, the effect of top-down modulation in interpersonal synchronisation. In summary, the paradigm and methods of this thesis provide new ways of exploring dance ensemble synchronisation.

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Chapter 1: Introduction and Overview of the Thesis

The dance is the mother of the arts. Music and poetry exist in time; painting and architecture in space. But the dance lives at once in time and space.

By Curt Sachs (p.5, 1937)

1.1 Dance as a Social Form of Communication

Dance is a part of human culture, a form of social interaction that is unique to humans. It refers to controlled rhythmic movements of the body in space and time that communicates meaning. Dance can be traced back to prehistoric times in Egyptian tomb paintings depicting dance figures from 3300 BC. Many of these early forms of dance have played an important role in ceremonies, rituals and celebrations. For example, before the invention of paper, dance was used to tell stories and myths that could be carried over from one generation to the next (Adshead-Lansdale & Layson, 1994).

Dance is universal, as it can be found across all homo sapiens. Moreover, it is closely linked to other forms of social interaction such as language and gesture. The core functions that are shared by all types of communication are to make meanings together and share experiences (Foley, 1997). The ability to create such meanings is a capacity of all human races, enabling us to socially interact. It has been claimed that nonverbal communication and language emerged together in evolution (Reynolds, 1993). Similar brain areas that control hands and gestures overlap and develop together with areas that control mouth and speech (Hanna, 2008). In addition, dance and language both contain vocabulary and grammar. Vocabularies in language are sequences of words, whereas in dance it refers to sequences of movements. Combining vocabulary requires a set of rules (grammar) that regulates transitions between either words or movements (Hanna, 2001).

All forms of social communication are influenced by culture which refers to values, beliefs, norms and rules that are shared by a group. In dance this relationship is reciprocal. Culture gives meaning to what, why, how, when, where and for whom dance is performed. At the same time dancers may reflect and influence culture by providing alternative possibilities (Hanna, 2008). Cultural influences gave rise to different dance styles that vary regionally, for example there are eight forms of classical Indian dance such as Katakh and Bhangda. Kathak is originally from Uttarpradesh and Bhangda from Punjab. Both styles contain predominantly hand gestures and facial expression, typical for Indian dance. However, they vary in the stories they traditionally tell and in the energy with which the movements are performed (Devi, 1990). In Kathak dance myths and moral tales are performed, whereas Bhangda dance includes more energetic movements that originally reflected the manner in which villagers farmed their land. Similarly, to different variations that can be found within one type of dance, different dialects are spoken in different languages. Dialects refer to regional speech patterns that are distinct in pronunciation, vocabulary and grammar (McCarthy, 1979). For example, there are major divisions in English as spoken in England to English spoken in

Scotland. Scottish English borrows words from other languages that once were spoken by conquers of this region, such as Old Norse (North Germanic language) and Gaelic (Celtic language) (Hughes, Trudgill, & Watt, 2005).

Besides similarities in the function, structure, evolutionary development and cultural-specificity of the above three forms of social communication (language, gesture, dance), there are clear differences between them. The main difference is the channel of communication that is used. Here, the channel of communication refers to the sensory channels used. In spoken language, vocal and auditory channels are used, whereas in dance and gestures somatonsensory and visual channels predominate. Therefore, spoken language exists in the temporal dimension, but gestures and dance exist in both the temporal dimension and in three dimensional space (Hanna, 2008). Within the domain of nonverbal communication there are also clear differences and similarities between dance and gesture. Both have self-oriented and communicative functions. Self-oriented functions suggest that gestures and dance movements help us to think and facilitate lexical retrieval (word finding) (Alibali, Kita, & Young, 2000; Rauscher, Krauss, & Chen, 1996; Haskell, 2001). In gesture research, Alibali et al, (2000) found that gestures help explore information, as more substantive and non-redundant gestures were used during higher conceptualisation load. Similarly, in dance therapy a kinaesthetic-basis approach for overcoming dyslexia (Kinematic teaching methodology) was found to strengthen spelling, phonemic awareness and facilitated thought processes by creating kinaesthetic and visual representations (Benzion, 2010).

Dance and gesture clearly communicate meaning; however both vary in spatial complexity and in their natural setting. Gestures commonly co-occur with speech and involve movements of the upper limbs, specifically the hand (Knapp & Hall, 2002).

Dance in comparison, is often accompanied by music and includes whole body movements, locomotion in time and space and potentially haptic contact with other dance partners (Hanna, 2008). Haptics refers to the sense of touch. Dance therefore, utilizes a multi-channelled gestural system to communicate. This multi-channelled system embodies cognition which conveys explanatory, procedural and emotional knowledge (Hanna, 2008).

As noted above, spoken language, gesture and dance exist in the temporal domain. A variety of research was conducted understanding timing patterns of events in the speech stream (Meyer, 1994). In interpersonal communications, time pauses between utterances have been found to predict turn-taking during conversations (Ferrer, Shriberg, & Stockle, 2002). Similarly, gestures such as head nods have also been suggested as an indicator of turn-taking (Cassell, Torres, & Prevost, 1999). Both temporal pause within the speech that may be longer than the average and head nods acted as a cue for initiating a turn-take between two conversant which defines interpersonal interactions that are reciprocal.

Likewise, in dance performances the timing of movements of one dancer with those of another dancer is crucial for maintaining interpersonal coordination. However, compared with literature on timing in language and gesture, no published research has so far explored the aspect of time in dancers' interpersonal coordination. The present thesis therefore aims to fill the gap in the literature by examining interpersonal timing in the case of dance.

1.2 Dance Science

Dance is a fertile source of interesting naturally occurring phenomena for researchers who are interested in linking movement control with cognition. Performing dance involves high levels of motor control, the integration of multisensory information, attention to dancers' own performances, attention to events within their environment, and memory to reproduce large sequences of dance movements (Bläsing, Calvo-Merino, Cross, Jola, Honisch & Stevens, 2012). Recently, dance has begun to be researched by a wide range of scientific disciplines, such as sport, educational, medical and psychological sciences (Bläsing, Puttke, & Schack, 2010). For instance, in sport sciences Bläsing, Tenenbaum, and Schack (2009) analysed ballet dancers' representation of dance movements in long-term memory. Expert and advanced amateur dancers but not non-dancers' hierarchical structure of performing a ballet move was found to be consistent with the functional structure of the movement, derived from the principles of biomechanics. Greater accuracy in dancers' knowledge structure of dance movements was evident and may be explained by physical and visual familiarity.

As described above, performing dance is a complex interaction of physical and cognitive factors, involving multiple aspects of cognition and motor control (Hanna, 2008; Bläsing et al., 2010). When performing a dance piece in an ensemble, dancers have to coordinate their movements in time and space to those of another dance partner, whilst keeping in time with the accompanied music. For example, two dancers in a dance ensemble may start a movement sequence at the same time, follow the dynamic path which refers to the speed and the trajectory of the movement, and finish it at the same time. Keeping time with one another requires dancers to coordinate their movements to events perceived by the movements of their dance partner. These events can be defined as target positions in space. For example in ballet, typical target positions of the arms are the first, second, third, fourth and fifth arm position (Figure 1.1). Two dancers may aim to reach such target positions at the same time and to a particular beat of the accompanied music. Coordination of these events allow for the dance performance to be seen as an integrated whole by the audience. The notion of an integrated whole is based on research in visual perception which suggests that elements moving in the same direction with a similar speed are seen as a unit (Uttal, Spillmann, Stürzel & Sekuler, 2000). Interpersonal coordination in dance is therefore achieved through uni- or multi-sensory exchange of information, which may be visual, auditory, or haptic (Lagarde & Kelso, 2006).

Figure 1.1: ***Arm and Leg Position Syllabus in Ballet***. From the left side beginning, pictures illustrate the preparation, second, third, fourth and fifth ballet positions (Ballet-Pointe.com, 2009).

1.3 Research into Timing in Dance

Research into dancer's timing performances is limited and focuses on dancers' individual performance. For example, research by Batalha and Macara (2007) compared the rhythm capacity and synchrony between professional dancers and dance students, using a set of questionnaires. They found that dancers' perception of rhythmic factors such as the organisation of time in performance was better when performing familiar compared to unfamiliar movements. However, using questionnaires to study timing in dance is subjective and, though useful as a starting point, it fails to provide data on the accuracy of dancers' movement timing.

In contrast, studies that in various ways recorded dancers' movement timing were able to provide not only more details about dancers' movement timing but also allowed testing of the underlying mechanisms that may be involved. For instance, Minvielle–Moncla, Audiffren, Macar and Vallet (2008) were interested in how interference with attention to time affects dancers timing abilities. Dancers had to learn a reference duration whilst walking a distance of 9 metres which then had to be retained and transferred to different walking distances of 2 and 16 metres. To measure dancers' timings of the learned reference durations, dancers were asked to press a button at the starting line to trigger an electronic chronometer and to press a second button at the end line to stop the chronometer. For each trial the experimenter counted the number of cyclic arm movements performed by the dancer, estimating the mean number of arm movements for each trial. Findings showed that during the transfer task, more accurate timing of the reference duration was achieved when dancers travelled 16 compared to a 2 meter distances. The authors concluded that spatial contraction is therefore more costly in attention of time than spatial extension, as potentially less attention could be directed to time. Furthermore, they asked dancers to perform another transfer condition in which dancers had to reproduce the previously learned reference duration whilst they improvised walking. For the improvised walking condition dancers were not allowed to perform cyclic arm movements and each improvisation was required to be different from the previous one, travelling a constant distance of 9 metres. The time travelled in the improvised condition was compared to the original walking condition. The results showed an increase in variability for improvised walking compared with all other transfer tasks, such as walking 2 and 16 metres. Minvielle–Moncla et al. suggested that improvisation required dancers to be creative and creativity has often been associated with demanding attention. They therefore, concluded that improvisation demands more attentional resources reducing the amount of attention given to the timing factor.

One criticism of Minvielle–Moncla et al.'s study is the recording method used. Unlike tools such as motion tracking systems, movement tracking with an electronic chronometer may only provide an estimate of dancers' cyclic arm movement timing. In comparison, movement recording devices allow movement event timing to be tracked. Therefore, motion tracking tools may be more suitable for measuring timing of complex movements in space, as performed in dance.

In traditional dance training, dancers rehearse their dance movements in time with music. To investigate how well dancers were able to internalise the timing of such rehearsed performances, Stevens, Schubert, Wang, Kroos and Halovic (2009) asked contemporary dancers to perform a piece of choreography in an ensemble with and without music. Here, dancers' kinematics were recorded using motion tracking cameras. The median of the vertical axis (z-axis) of 24 markers, attached to the dancer body, were used for further analysis. Their analysis involved identifying scaling and lapsing as indicators of time keeping. Scaling refers to slowing down or speeding up within a given section of a dance piece and lapsing refers to an omission or insertion of a movement. Dancers' movement trajectories in time and space, with and without music were overlayed and differences in scaling and lapsing were counted. Overall, dancers reproduced their choreography without music 5% faster than with music. Timing errors without music were attributed to the omission (lapsing) of movements and not to timing errors per se. The authors therefore suggested that dancers' attuned internal clock may be the felt time between dancers moving together in time without music. However there was no attempt to quantify timing relations between dancers in the ensemble.

A first step into exploring multi-person synchronisation in dance was made by Maduell and Wing (2007). They conducted their research based on the case of flamenco dance, bridging the gap between solo and group performances. An observational approach to ensemble coordination was provided by introducing a theoretical control structure that aimed to indentify directionality of information flow between ensemble members and their level of control over other members. In the case of flamenco, three levels of control were suggested. The dancer exerts primary control over the singer, guitarist and the support (palmeros), whereas on the second level, singer and guitarist interact with one another, providing information to the palmeros. At the third level, information from guitarist and singer feed back to the dancer. However, Maduell and Wing's research did not provide quantitative data to support their proposed control structure.

Recently, another research group analysed dance couples movement coordination, comparing adults with youth couples performances. Zaletel, Vučković, James, Rebula and Zagorc (2010) recorded each pairs' kinematics with video tracking tools. Six dance styles were compared (e.g. waltz and foxtrot). They researched the path and speed of the each pairs' movement trajectory combined. Results showed that adult compared with younger couples performed longer distances at a faster movement pace than younger couples which could be explained by differences in skill level and experience. However, once again, there was a failure to use motion tracking data to define the temporal relations between the two dancers' performances.

Taken together; previous research into dancers' timing performances lacks quantitative analysis of the temporal dependencies between external cues such as the perceived visual movements of a dance partner. It is therefore unclear, how accurate dancers timing to external time sources may be and what mechanism may underlie or interfere with dancers' synchronisation performances.

1.4 Empirical Model of Dance Ensemble Synchronisation

Exploring dance ensemble coordination is a complex undertaking, as numerous factors may influence individual's performance. Internal factors affecting individual performances are fluctuations that arise from psychological processes such as memory, attention and neurophysiological systems involved in producing movements. Such fluctuations introduce variability in dancers' movement production. External factors may be variable external time sources with which a dancer may have to time his or her movements.

Consider a performance of multiple dancers, in which each of them is instructed to perform a given set of dance sequences in synchrony with all other dance partners whilst maintaining time with the accompanying music. Given inevitable temporal and spatial variability within each dancer's performance, how do dancers maintain an overall cohesion with one another? What strategies might they apply to combine multisensory information and maintain time keeping? In addition to these rather low level factors, do higher level factors such as cognition interfere with lower level control mechanisms?

To answer these questions specific to dance ensemble performances, this thesis aims to explore empirically testable models for analysing dance. In dance ensembles various aspects may affect dancers' synchronisation performances. Low level factors such as the timing with an auditory pacing cue may be experimentally investigated in isolation. Once researched in isolation they may be combined with other lower or higher level factors (e.g. attitudes towards a dance partner), replicating a real-life scenario of dance ensemble synchronisation.

Inspiration for an empirically testable model of dance ensemble synchronisation comes from research into, motor control, joint action, as well as music ensemble synchronisation. Motor control refers to a process that plans, controls, monitors and executes movements. Several models of motor control have been proposed. Two models are briefly described, feedback control and the forward model. The process of feedback control states that the motor output of the motor system can be fed back into the system. Thereby, the system can correct for any errors made and deduct it from its desired motor output. Figure 1.2 illustrates such a process; the Controller includes internal models and sends information about the current system state to the Plant which is the body part that is controlled (Doyle, Francis & Tannenbaum, 1992).

However, a pure feedback control model would introduce delays in motor commands, as the motor controller (internal model) has to wait for the sensory feedback before it can be fed into the system. To avoid perceived delay, an extension to the feedback control model includes a forward model that allows for predictive corrections of the motor command (Figure 1.3). Predictive corrections in ensemble performances are useful to anticipate for example the timing of a dance partner's movements or the rhythmical beats within the music. A process of prediction may be necessary in order to maintain in time and to achieve synchrony.

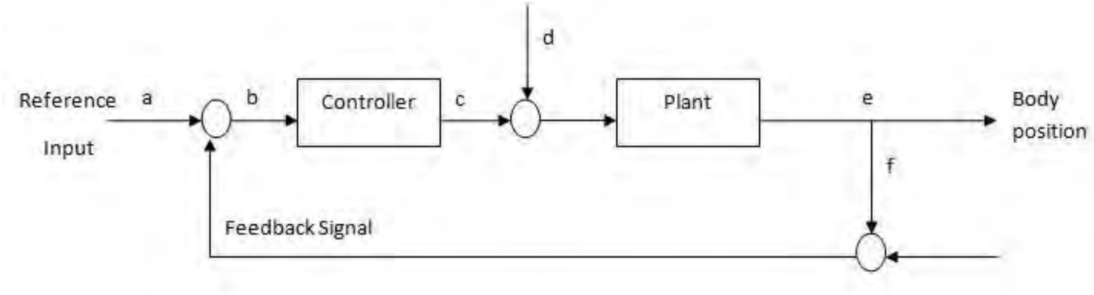


Figure1.2: ***Feedback System*** (single loop). a = reference/command input, b = tracking error, c = control signal, d = plant disturbance, e = motor output, f = sensor noise (adopted by Doyle et al., 1992).

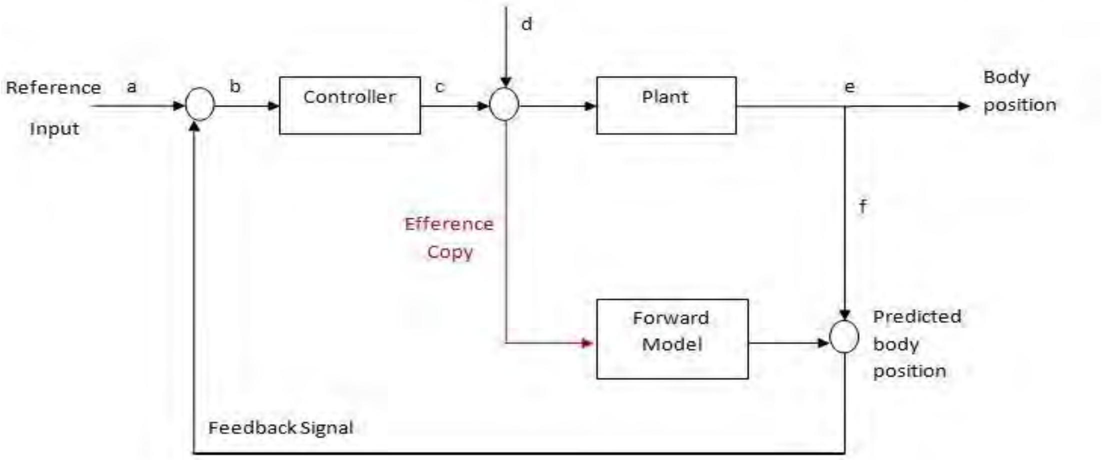


Figure1.3: ***Internal Forward Model*** (single loop). a = reference/command input, b = tracking error, c = control signal, d = plant disturbance, e = motor output, f = sensor noise. Forward model (prediction) is included in the feedback control.

The forward model contains a representation of the current state, called the efference copy (von Holst & Mittelstädt, 1950). The efference copy is a form of internally monitoring outgoing information and is the input for a forward model. The output of the forward model is the predicted position of a body part which then is compared with the actual position of the body. Due to noise, internal (sensory noise) and external (force outside the body) the performed movement in time may vary. Once a difference is detected it can be fed back as an input to the motor system and corrections for a more accurate prediction can be made (Miall, Weir, Wolpert, & Stein, 1993). Clearly, feedback control and a process that allows for prediction may be essential for dance ensemble synchronisation. Yet, there may be other aspects involved in successful dance performances.

Another inspiration for the proposed empirical model was research into joint action that suggested that interpersonal coordination between two or more individuals involve shared intentions (Clark, 2005). In specific, studies showed that joint action includes task representations of another individual (Knoblich, Butterfill, & Sebanz, 2011). Here individuals represent their own task at the same time as their partner’s task, adding the aspect of shared goals and individual task representations to ensemble performances.

A further inspiration was Keller’s model (2007) that is specific to music ensemble performances. Music ensemble performances are closely linked to dance ensemble performances as both share similar task demands. For example both ensemble groups require synchronisation to the beats of the music and to the movements of another ensemble member, integrating multisensory information. In Keller’s model all members share a common performance goal, similar to the idea of joint action. Shared goals refer to mental representation of the sounds that make up the musical piece to allow ensemble cohesion (Palmer, 1997). These act as performer's intentions and expectations about 'how his or her own sound and the overall ensemble sound should be shaped dynamically over time' (Keller, 2007).

Ensemble performances have to meet multiple-task demands. Individual members have to perform their own parts correctly, whilst maintaining the relationship between the sounds produced by other members. Keller (2001) argued that prioritised integrative attention is an optimal strategy to maintain ensemble cohesion, extending on the rather basic concept of monitoring, provided by motor control models and joint action theories. Prioritised integrative attention involves dividing attention between one's own action (high priority) and those of others (lower priority) while monitoring the overall ensemble sound. To integrate all perceptual sources the amount of attention that is available at a particular point in time is modulated, allocating specific amounts of attention to parts (low priority) that may be crucial within the piece (based on hierarchal levels, such as meters 2:1 (duple meter), 3:1 (triple)) whilst attending to one's own performance (high priority). In summary, feedback corrections, internal predictions, shared goals and task representation of others, as well as attention may all play an important role in dance ensemble performances.

This thesis proposes an empirically testable model for dance ensemble synchronisation integrating the processes stated above. Figure 1.4 illustrates the lower level and higher level factors that may be involved. Higher level factors are here represented as cognitive processes. For example shared goals may reflect the choreographers' intention of the overall piece, such as temporal and spatial synchronization of dancers' movements to those of another dancer and the accompanied music. This goal is shared by all members of the ensemble based on previous individual and collaborative rehearsals. Further higher level factors may be the task representation of another dancer. However, considering that in dance, sequences are pre-rehearsed it may play a smaller role.

In addition belief may interfere with dancers' synchronisation. Dancers may time their movements better if they belief to perform with a highly experienced solo dancer compared with a less experienced group dancer. Highly experienced solo dancers' performance may be attributed as more accurate and less variable; therefore dancers may rely on a highly experienced performer more compared to a group dancer who may be attributed to perform less accurate.

Higher Level factors may influence lower level factors and reverse. Here, lower level factors are described as perceptual events with which dancers time their movements. The sensory complexity of such multilevel coordination is considerable, as dancers may coordinate their movements to the beats of the music, to the auditory sounds produced by another dancer (foot stamps), to the haptic information of another dancer or to the visual information when observing another dancers' movements. To ensure ensemble cohesion each performer must be able to track external timing cues such as the beats of the music, predict their next onset in time and correct for any errors performed.

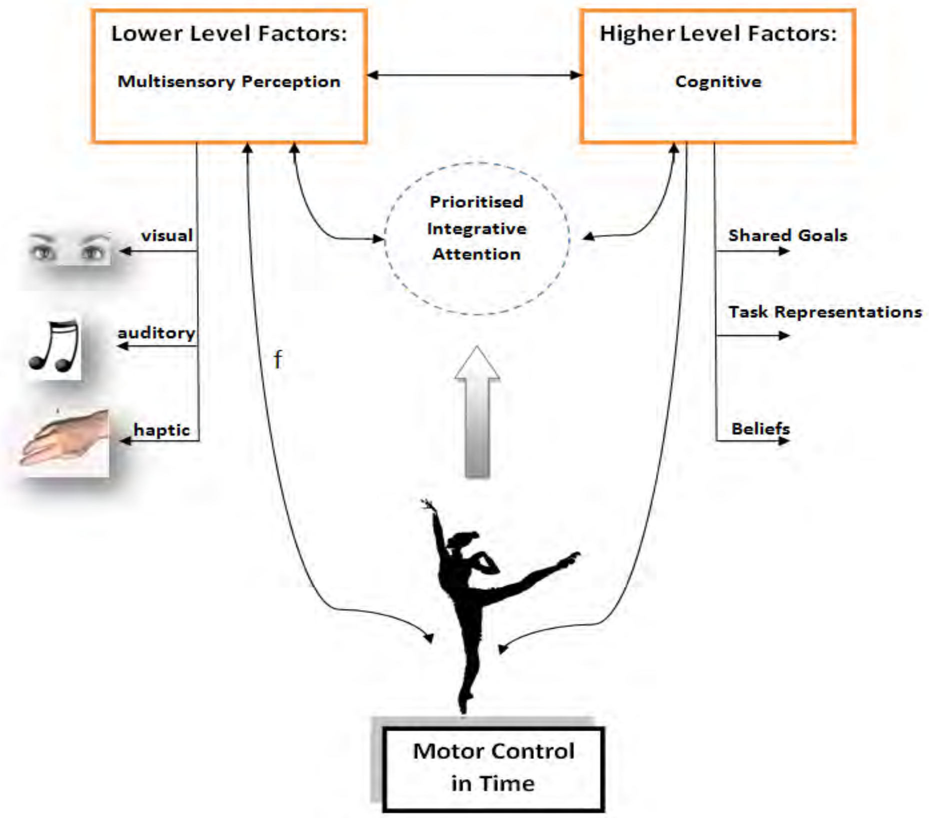


Figure 1.4: ***Empirical model of Dance Ensemble Synchronisation***. f = forward model. Lower level and higher level factors affect dancers' movement control in time. Attention may regulate dancers' integration of factors.

Clearly, multisensory coordination requires integration of one's own movements and those of others which may be achieved with prioritised integrated attention. In traditional ballet performances, priority may be given to one's own movements, and then secondary to specific beat levels of the music (metrics) and then attention may be allocated to the visual and haptic information of other dancers' movements. The integration of perceptual information may be easier if they can be integrated into a single Gestalt (re-occurring simple rhythm) (Keller & Repp, 2008). For instance, the more complex the rhythm may be, e.g. Jazz music, the more difficult it is to integrate the perceptual information into a whole. This consequently requires more attentional resources that may be taken away from other events to which a dancer allocates his or her attention, increasing the chances of drifts or discrepancies in temporal and spatial coordination to other external sources such as the perceived movements performed by the dance partner.

In summary, all lower and higher level processes involved in ensemble synchronisation may be modulated by attention. Research investigating aspects of the present empirical model may help us understand how successful coordination between multiple dancers can be achieved and facilitated.

1.5 Chapter Overview

Exploring the nature of dance ensemble synchronisation is a complex undertaking, as expert dancers coordination is influenced by numerous factors (multisensory information, cognitive). The present thesis focuses on the temporal aspects of visually mediated interpersonal synchronisation in dance. To explore the underlying mechanism of visually mediated synchronisation, an empirical model of dance is presented using feedback control in various contexts.

The present work consists of seven chapters, two reviewing the literature, four experimental chapters and one discussion chapter. This first chapter has discussed the importance of researching dance ensemble performances as a form of social communication. A brief literature review of dance research focused on dancers' timing skills. Lastly, a model of motor control and ensemble performances was discussed, followed by a proposal for an empirically testable model of dance ensemble synchronisation. Chapter 2 is a second literature review chapter, focusing on different techniques on how to capture dance movements and different measures on how to quantify sensorimotor synchronisation (SMS) between two or more individuals.

To investigate visually mediated synchronisation between two individuals, Chapter 3 introduces a paradigm that emphasises feedback control. The paradigm consists of a lead and follow person performing oscillatory arm movements together in time. The lead synchronises his or her movements with an auditory metronome and the follower synchronises his or her movements with those of the lead. Both individuals use feedback corrections in order to get into phase and to reduce their synchronisation errors with either the auditory or visual cue. Three research aims were set, with the first one aiming to quantify visually mediated temporal linkage between the lead and follower, using measures of the mean and variability of asynchrony and inter-movement intervals. Strong temporal dependence between the lead and follower was expected. The second aim was to to investigate whether the interval produced by the metronome is internalised by the lead, a continuation phase was introduced. The lead maintained the interval without the availability of feedback information, indicating that the internal timekeeper was adjusted to the correct interval. Therefore, sensorimotor synchronisation may not only be based on feedback control but also involve internalised temporal information to reduce synchronisation errors. Lastly, in real-life dance scenarios, dancers synchronise their timing to the beat of the music and observe the movements of their dance partners. Chapter 3 researches whether visual feedback of the follower may be used by the lead to be closer in time with one another. Here, the access of the lead's visual feedback from the follower is manipulated. The lead was found to use visual information from the follower even when explicitly asked not to do so, suggesting that all available timing cues are combined in the mechanism of sensorimotor synchronisation.

Chapter 4 applies the previously presented lead-follower paradigm focusing on visually mediated multi-person synchronisation of six individuals. The first goal was to investigate how timing information is carried forward across a chain of individuals using feedback control. One individual is assigned the role of the lead, four the role of the follower and one the role of the integrator. The four followers are split into two chains, each consisting two followers. One chain is placed on the left hand side of the lead, and the second chain is placed on the right hand side of the lead, each forming a half circle. In each chain of followers, the follower (follower 1) next to the lead synchronises his/her movements with those of the lead. The second follower (follower 2) who sat next to follower 1 synchronises his/her movements with those of follower 1. Closing the circle, at the end of each chain sits the integrator. Compared to the followers who time their movements to one visual feedback cue, the integrator times his/her movements to two visual feedback cues, one from follower 2 of the left chain and one from follower 2 of the right chain. Similarly to chapter 3, strong dependencies between all individuals are suggested and an accumulation of timing variability across each chain was found. Secondly, chapter 4 researches the integration of two visual feedback cues in sensorimotor synchronisation. The integrator timed his/her movements to those of two feedback cues. Integration of two visual feedback cues led to better synchronisation compared to one feedback cue as no accumulation in variability was found.

Chapter 5 introduces an experimental design in which the variability of the lead was controlled. A virtual three dimensional performer is introduced with whom individuals coordinate their timing. Expert ballet dancer’s synchronisation performance is examined. Three research aims are set. The first aim was to provide quantitative data of expert dancers timing skills focusing on visual feedback corrections. The second aim was to explore how dancers time their movements to various alternate events within the visually perceived movements of the virtual performer. And lastly, the third goal was to research whether motor and visual familiarity interacts with dancers' synchronisation skills. Findings showed that expert ballet dancers timed their movement less variably to the dynamics compared to the target position in space of a movement. Furthermore, performing highly practised compared to less practised movements resulted in less variable synchronisation with the virtual performer.

The previous paradigms focused on relatively low level factors affecting sensorimotor synchronisation. Chapter 6 presents a paradigm that aims to investigate both whether internal predictions play a role in interpersonal synchronisation and whether high level cognitive factors affect visually mediated synchronisation between two individuals. The paradigm manipulates participants' belief about the visual cue with which they time their movements. Individuals synchronise with movements they either believed to be their own or another person's movements. This was either true or false. The cognitive factor belief interacted with individuals timing performances. Participants' synchronisation performance was more accurate when they believed they synchronised with their own recording compared to another person's recording, regardless with whom they actually synchronised. Therefore, sensorimotor synchronisation may be modulated by top-down information.

The final chapter 7 briefly describes the methods and analyses proposed to research dance ensemble synchronisation. It then summarises empirical findings of each experimental chapter and critically discusses the role of a feedback model, and the potential roles of an internal forward model and the ‘Mirror Neuron’ system, based on the findings of Chapter 5 and 6. This is followed by a brief summary of the strengths and limitations of each experiment. Lastly, suggestions for future studies are provided.

Chapter 2: Analysing Timing in Dance

The previous chapter introduced dance and the nature of scientific interest in dance. Attention was drawn to multifaceted aspects of dance ensemble coordination in time. This thesis is concerned with interpersonal synchronisation between two or more people engaged in dance and the role of visual feedback control. In order to research this, dance movements have to be characterised. Traditional methods of doing this use dance notations, whereas latest methods involve motion tracking. The latter allow dance movements' temporal and spatial aspects to be analysed. The present chapter examines these two approaches to characterise dance. This is then followed by introducing an information processing approach on how to analyse synchronisation between two dancers.

2.1 Dance Notation

Early methods of characterising dance movements involved dance notations. There are three main systems of describing the form of dance used in Western culture; Benesh, Eshkol-Wachman notation and Labanotation. All three systems record how movements are performed capturing kinematic movement features on paper. Movement notations of choreographic work were invented to provide literary heritage for dance that captures the original intentions of the choreographer. For instance, the famous ballet piece *The Nutcracker,* was intended to be replicated by several generations to come. One way of accomplishing this was the use of dance notation.

One of the three most widely used notations was the Benesh notation; invented by Joan and Rudolph Benesh in 1956. It is based on abstract stick figure drawings on a music stave (McGuinness-Scott, 1983). Benesh is specific to ballet and therefore typically used by ballet companies such as the Birmingham Royal Ballet (Bonner, 2008). In comparison to the Benesh notation, the Eshkol-Wachman notation and Labanotation are based on analytical descriptions of the body movements. In 1958 Noa Eshkol and Abraham Wachmann developed their notational system to express movements in terms of degrees of planar, rotary and conical movements, aiming to notate any manner of movements irrespective of them having been generated in dance (Teitelbaum, Benton, Shah, Prince, Kelly & Teitelbaum, 2004). Labanotation unlike the Eshkol-Wachman and Benesh notation is a system not only capable of describing changes in angles of the limbs, but also in capturing dynamic changes and spatial qualities of the movement. Thus, Labanotation allows for the richest description of movements, out of the three notation systems.

Labanotation was invented by the Hungarian dancer Rudolf Laban in 1954. His formal universal language system is constructed by meaningful symbols (Bartenieff & Davies, 1980). These meaningful symbols outline aspects of four main categories; body, space, effort and shape. Kinematic movement features are represented by the categories body and space, describing how spatio-temporal body and limb relationships change in relation to one another or to the environment. Laban used the idea of a vertical axis to represent the body, with the axis dividing the body in two symmetrical parts (left and right, see Figure 2.1.a). Any further added line on either side of the axis represents different body parts. The directionality of movements is also described for each limb (Figure 2.1.b).

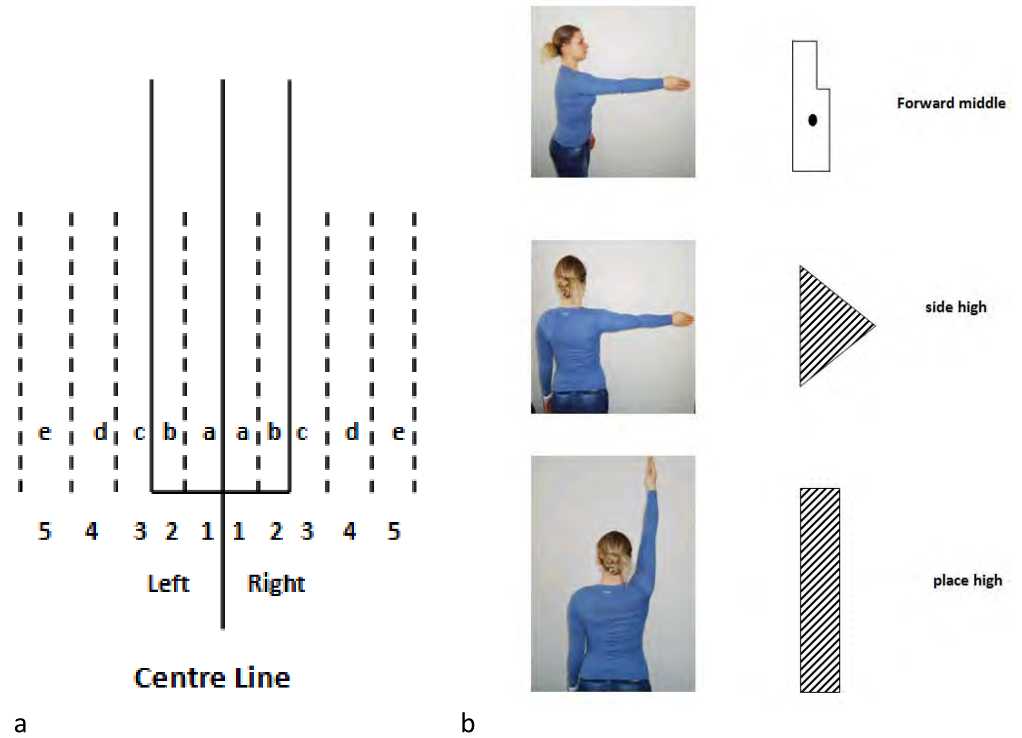


Figure 2.1: ***Labanotations***. Division of the staff into columns into left and right side of the body 1, a= Support, 2, b=Leg column, 3, c= Body column, 4, d = Arm column, 5, e = head column (a). Directionality of body parts are represented by symbols as shown in (b).

Non-kinematic features of movements are represented by the categories effort and shape, providing information about the intensity, shape, flow and rhythm of a movement (Bradley, 2009). This non-kinematic feature of the Labanotation is qualitatively different from the kinematic measures provided by optical tracking systems that are used in experimental sciences. The latter kinematic measure can quantify what the spatio-temporal changes are in numbers; however such biomechanical analysis lack descriptions and classifications of these changes into linguistically meaningful categories. One example of a 'how' description in Labanotation is defining the shape and form that the body may take. In dance, shape forms can be used to contrast for example an arm movement that produces a zigzag-like shape to a circle-like shape. Linguistic classifications of shapes, forms and movement transitions through the use of symbols are part of this dance notation.

Labanotation has started being used in sciences. For example, it has been recognized to be a useful addition to the traditional biomechanical description of movements, in classifying and diagnosing motor disorders (Foroud & Wishaw, 2006) and in simulating human movements (Lourens, Berkel & Barakova, 2010). Furthermore, its rich description led to the design of a computerized machine language that can interpret and produce animated display of human movements (Badler & Smoliar, 1979; Loke, Larssen & Robertson, 2005; Lourens, et al, 2010). Nonetheless, it should be noted that the method of notation is time consuming as each aspect of a single movement and their transition in time and space are coded one by one.

2.2 Optical Tracking Systems

In contrast to the rather slow process of dance notation, methods of film and video recordings are less time consuming and require no notational or technical expertise. Video camera software can track human contours in real time, which means the incoming information of human' contour and its related time frame are recorded at the same rate as it receives this information. In short, it records and tracks movements simultaneously. Real-time usage of video cameras is not common except for video games such as Kinetic. Video is widely used and the method of choice of coaches and trainers in sports, due to its low cost (Bartlett, 2007). Teachers pre-dominantly use this method to uncover mistakes in individual and team sports after failed performances. Further advantages of recording dance movements with video recording software are an increased ecological validity, as this procedure is more field based. Moreover, video recordings may also simplify the understanding of movement patterns as they are visualised directly instead of being represented symbolically as in the case of dance notation. Nonetheless, limitations of video arise in judgments made at the stage of reviewing the recording. Thus, this procedure's weaknesses include lack of reliability and objectivity and absence of numerical data. For example, movement patterns recorded by video cameras may be interpreted based on the observer's previous knowledge and his or her own view on how an ideal performance may be performed. Such interpretation may vary from one to another observer and therefore lack of objectivity.

Optical motion tracking systems can increase objectivity and provide rich numerical data of a dancer's movement in time and space. In comparison to dance movement notations and in line with video recordings, the method does not capture the original intentions of how a movement should be performed; instead it records the actual kinematics of movements performed by dancers at the time of capture. However, unlike digital video recordings, optical tracking systems allow real time viewing of two and three dimensional data with detailed spatio-temporal information of the moving limbs, sampling 50 up to 2000 frames per second (Scheirman & Cheetham, 1990). Simple as well as more complex dance movements can be tracked instantly, in a time-efficient manner. Yet, in contrast to low cost video cameras, optical motion tracking systems are expensive and require technical skills. A further limitation is that this process is mostly applied in a laboratory setting and thereby less convenient for the use of coaches or dancers' themselves. At the same time controlled laboratory settings are ideal for early scientific research that aims to unfold biomechanical aspects of human movement control such as involved in dance.

Dance movements of human bodies can be represented as stick figures (Figure 2.2.a); 2D contour (Figure 2.3.a), volumetric models (Figure 2.3.b) or point light displays (Figure 2.2.b). The most widely used representation of human bodies is point light display. The presentation of human motion as arrays of point lights was firstly introduced by Johansson (1973). In his films no familiar cues such as the clothing and faces were shown. The reduction of such cues made it an ideal technique used in experimental settings, especially in the area of perception.

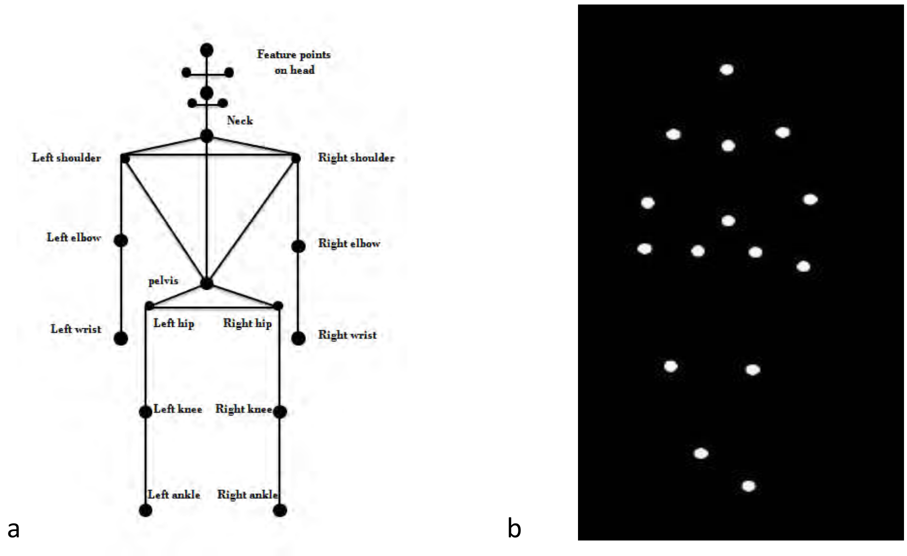


Figure 2.2: ***Human Body Representations.*** A stick-figure human model based on Lee and Chen's work (1985) is presented on the left (a) and a point-light representation is presented on the right (b).

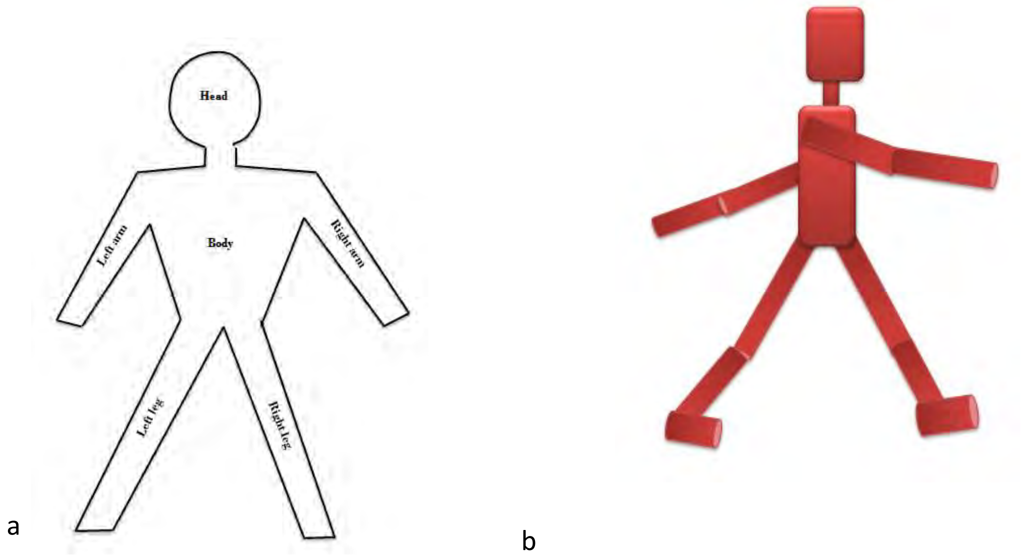


Figure 2.3: ***Human Body Representations***. A 2D contour human model (based on Leung and Yang' model (1995) (a) and a volumetric human model similar to Hogg's work (Hogg, 1993).

Nowadays, optical tracking systems range from passive (e.g. Qualisys) to active (e.g. Codamotion) optical markers system up to markerless techniques (e.g. Kinetic Systems). Both passive and active optical marker systems use cameras to track reflective bright points on the camera's xy plane. The calibration of the motion tracking system provides knowledge about cameras relative positions to one another which allows triangulation of the sources of the bright light and with that three dimensional data. Passive optical systems use reflective markers that can be tracked by cameras which emit infra red light, whereas active optical systems use markers which are powered to emit their own light. The advantage of active optical systems is that marker tracking is not affected by marker occlusions (e.g. limbs hiding a marker to be seen by the camera) or by blind spots in the camera system. However, active marker systems require wires or electronic equipments to be worn. Thus, passive systems may be more suitable for tracking dancers' complex movements in space. In contrast to passive and active tracking systems, recently developed markerless techniques do not require any equipment or even markers to be placed on the body (e.g. Kinetic). Markerless techniques may be better than passive systems, but in fact such techniques use contour rather than volumetric models which are less accurate than marker based techniques.

Motion capture systems provide quantification of body segments in relation to one another and enable research into their trajectory profiles over time in space. Such systems help quantify forces created by movements. Motion is a change of position of the body or a body segment which can be described as velocity, acceleration or as a displacement in time. In order to change direction in motion, forces have to be applied. Such forces may be internal or external. Internal forces act upon joints moment such as muscles, ligaments and structural constraints. External forces may include the weight of the dancer related to the gravitational pull of the earth. A further force is reaction force that refers to forces that may be exerted by dancer A through touch on dancer B and dancer B therefore reacts to the force produced by dancer A.

Human motion can be analysed under various experimental settings. For example conditions that may interfere with human's natural performances such as secondary tasks (dual task) or tasks that introduce constraints (e.g. additional weight, or prohibition of sensory feedback cues such as vision). Research into human motion in experimental settings gives insights into the biomechanics and the psychology of movement execution and production. Accurate measurement of functional movements is also essential for studying movement dysfunction, to develop treatments, validate interventions in rehabilitation and improve diagnostic accuracy (Riener & Straube, 1997; Phillips, Forrester, Purdue & Stokes, 2010). Similarly, in dance medicine and therapy motion tracking tools have been widely used to enhance diagnostics of injuries and investigate dancers' biomechanics to improve their performances (Charbonnier, Kolo, Duthon, Magnenat-Thalmann, Becker, Hoffmeyer, & Menetrey, 2011). For instance ballet companies, such as the Birmingham Royal Ballet (UK), use such diagnostic measures in their physiotherapy.

Taken together, dance notation and motion tracking systems can characterise dance performances. However, dance notation compared to motion tracking tools, cannot provide objective data about the exact timing down to milliseconds, the exact force used to move a limb and the exact positions and angles of a limb in space. Thus, the application of motion tracking systems is a powerful and time efficient tool to investigate dancers' performances in sciences. Such systems are able to track movements performed by multiple dancers. The application of motion tracking analysis is therefore suitable for the present thesis that aims to investigate dance performances.

Clearly, this recording method will help to explore how dancers synchronise and maintain their movement coordination with the movements of other external timing cues such as ensemble members. After discussing methods of recording human movements the next step into quantifying dancers' motion data is to analysis data provided by optical motion tracking systems. Approaches on how to analyse synchronous dance data will be discussed next

.

2.3 Sensorimotor Synchronisation in Dance

Dance movement coordination is a form of sensorimotor synchronisation (SMS) in which an action is temporally coordinated with an external event (Repp, 2005). Coordination of perception and action is of profound importance in dance ensemble performances. Dancers have to synchronise their movements with the visible movements performed by other ensemble members and with the audible rhythm produced by the orchestra. Traditional research into sensorimotor synchronisation focuses on simple finger tapping tasks to an auditory sequence produced by a metronome or to a visual pacing signal, such as flashing lights (Repp, 2003; Repp & Penel, 2004; Fouriezos, Capstick, Monette, Bellemare, Parkinson & Dumoulin, 2007). Findings revealed that different forms of movements (tapping on a hard surface vs. no surface), different types of feedback sources and different types of external referents (auditory or visual stimuli) have different effects on the accuracy of SMS. The accuracy of SMS here refers to the synchronisation error performed by an individual's response relative to an external timing cue. With respect of the last point, synchronisation to auditory stimuli was found to be better than with visual stimuli. The modality difference could be explained by closer neural connections between the auditory cortex and the spinal motor neurons, enabling faster perception and entrainment of motor behaviour (Thaut, Kenyon, Schauer & McIntosh, 1999).

Another factor that affects SMS performances are feedback cues. For an example, research by Aschersleben, Gehrke and Prinz (2001) found that finger tapping with an auditory pacing signal on a hard surface produced less synchronisation error compared with tapping with an anesthetized finger tip that eliminated tactile feedback. Accordingly, the authors concluded that tactile feedback plays an important role in the time control of finger tapping. Further support for the importance of tactile feedback in finger tapping comes from research by Goebel and Palmer (2008) who showed that the finger key contact enhanced the timing accuracy of the upcoming keystroke during piano performances.

With respect to the effects of performing different forms of movements in SMS, the use of different effectors (limbs) has also been found to affect the accuracy of SMS. For instance, research by Aschersleben and Prinz (1995) revealed that foot tapping compared with finger tapping resulted in an increased absolute synchronisation error. Their findings were explained by differences in the peripheral conduction time. Evidence for such differences comes from a physiological study by Shibasaki, Barrett, Halliday and Halliday (1981) using EEG. They showed that kinaesthetic feedback from the foot takes longer to be received by the brain than kinaesthetic feedback from the hand. Thus, the further away a signal has to travel the more time it takes to submit a sensory signal.

There have been two different theoretical approaches in studying SMS; the information processing approach and the dynamical systems approach. The information processing approach (IP) assumes that responses are represented as discrete events (time series), whereas the dynamical systems (DS) approach deals with continuous movements (oscillation). With regard to the latter (DS) approach, timing is not explicitly controlled. Instead it is assumed to be an emergent property of movement parameters that influence movement frequency and amplitude. DS investigates the topological properties of trajectories in space, using continuous measures of coordination between two units, such as two limbs. This model assumes a deterministic basis for human motor timing within the motor system. However, the measure used in the DS approach has been criticised to be sensitive to noise, resulting in difficulties to acquire coherent results from measures of biological systems (Pressing, 1998).

In contrast to the DS approach, the IP approach aims to gain insights into the internal processes that underlie timing behaviour. The IP approach assumes the existence of a central abstract representation that may control discrete timing (e.g. finger tapping). Measures used to analyse discrete events in human behaviour are for example auto regression analyses. Such analysis aims to predict an output of a system based on the previous outputs and in the instance of IP, they are based on linear combinations of noise sources. For example, Wing and Kristofferson (1973) proposed two sources of noise in the human motor system; one central (clock) and one peripheral (motor). Both are suggested to contribute independently to human response times. Thus, in comparison to the DS approach, the IP approach provides a causal model for motor timing. The present thesis did not adopt a DS approach as little interest was given to structurally describe dancers' synergies with another dancer. Instead, the present thesis adopted an IP approach in order to investigate the underlying process involved in dance ensemble synchronisation.

Previous research on SMS that adopted an IP approach used pre-dominantly finger tapping paradigms. Such studies have provided consistent findings that the finger tap precedes the metronome tone, called negative asynchrony. This negative asynchrony varies amongst individuals from as close as zero (mainly in musical trained individuals) up to 100 ms (Repp, 2005). One of the first accounts of this phenomenon was proposed by Paillard (1949) and further developed by Fraisse (1980). It suggests that synchrony is obtained at the level of a central representation of the perceived tone and tap. However, because the nerve transmission time for the sensory information of the finger tap to the brain takes longer than the auditory information from the ear to the brain, for perceived synchrony, taps have to precede the tone (Figure 2.4). As previously mentioned; evidence for this account came from findings that the negative asynchrony for foot tapping is larger than for finger tapping (Aschersleben & Prinz, 1995). However, while there are other alternative accounts, the discrepancy between sound and the visual afferent latencies raises problems for dancers attempting to time their movements with a musical beat or movements of another dancer.

Sensory information is crucial to maintaining synchrony. Synchronisation of dance movements to an auditory sequence of tones requires synchrony between the perceived auditory beat and the proprioceptively perceived movement (based on somatosensory feedback). Similarly, synchronising dance movements to visible movements performed by other dance members follows a similar strategy. Dancers may synchronise their movements to visually perceived cues of their dance partners' movement trajectories. Visually perceived events may be the start of the reached target position, produced by their dance partner (See Chapter 2, 2.5). In dance ensembles dancers time their movements with multisensory cues. Therefore dancers synchronisation requires more information to be processed (Figure 2.5) compared with simple finger tapping to an auditory pacing signal as illustrated by the Paillard – Fraisse hypothesis.

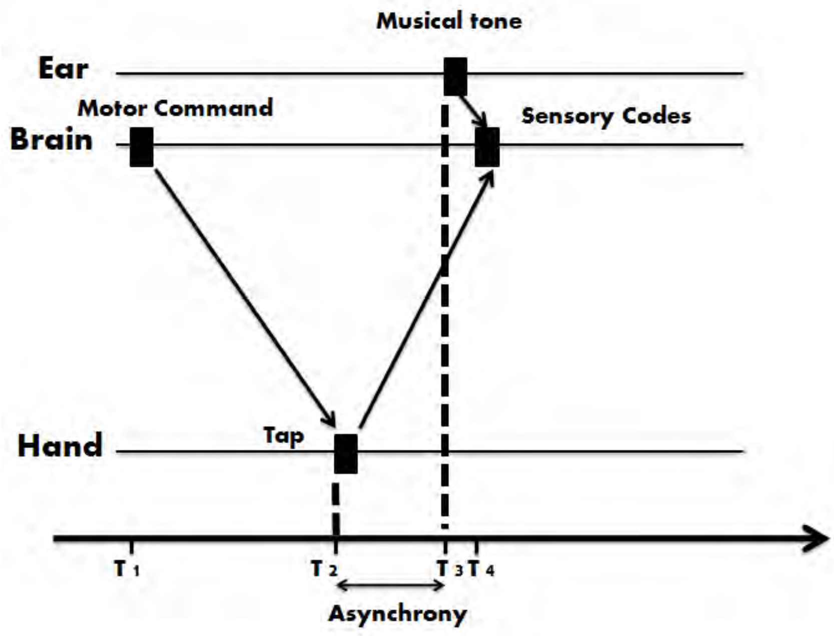


Figure 2.4: ***Illustration of the Paillard – Fraisse hypothesis.*** Different distances between the ear and the brain & the hand and the brain represent functional distances (modified after Prinz, 1992).

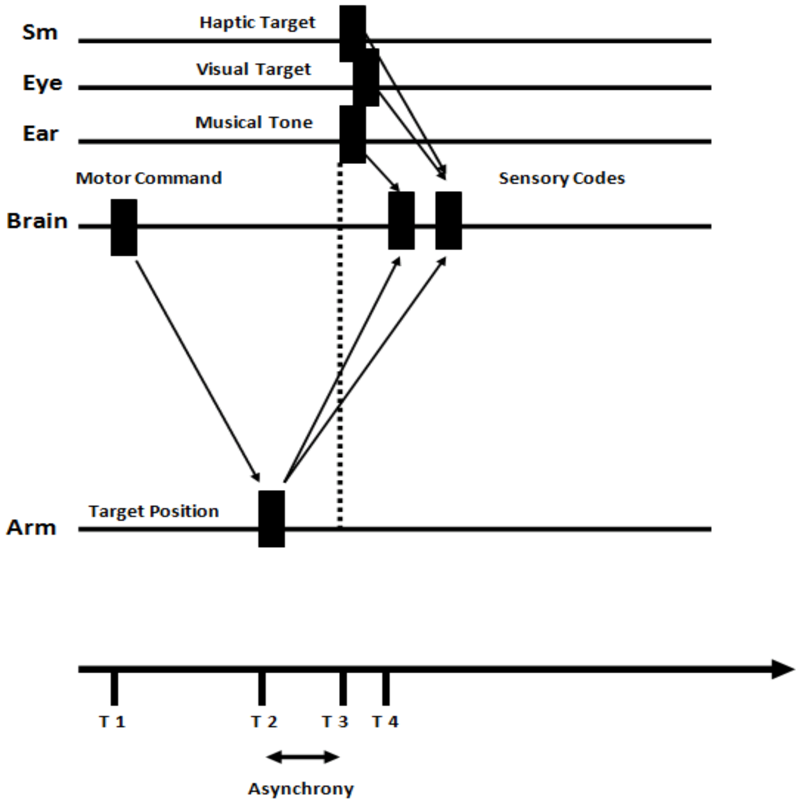


Figure 2.5: ***Illustration of an Adaptation of Paillard – Fraisse Hypothesis in Dance.*** A dancer may perceive multiple time cues, such as visual movements from another dancer or haptic information when having contact with a dance partner. Each cue is perceived by a delay that may vary compared to other types of sensory feedback. The dancer then has to integrate all sources into one response time.

2.4 Linear Model of Error Correction

According to Wing and Kristofferson (1973), timing of movements involves two sources of variability; the clock in the central nervous system and the motor system in the peripheral nervous system. The central timer produces intervals set by an external stimulus. Intervals within the central timer are suggested to be generated by an accumulator – pacemaker process. The timer sends at the end of each interval a pulse to the motor system. Both, the central timer and the motor system, add their own temporal fluctuations to the overall variability that can be observed in the actual timing of movements. The produced inter – response interval (Ij) is the sum of the timer interval (Cn) plus the difference in motor delays (Mj-1, Mj) (Figure 2.6).

$$Ij = C1 + Mj - Mj1$$

The timer interval (C) is independent from the motor delays (M), with that the variance of the inter-response interval (I) is given by

$$\mathrm{Var}\ (I) = \mathrm{var}\ (C) + 2\mathrm{var}\ (M).$$

In the Wing and Kristofferson model (WK) the response time variability has been associated with the variability in the clock. This finding however, is specific to finger tapping and the question arises, whether similar findings may be true for dance movements.

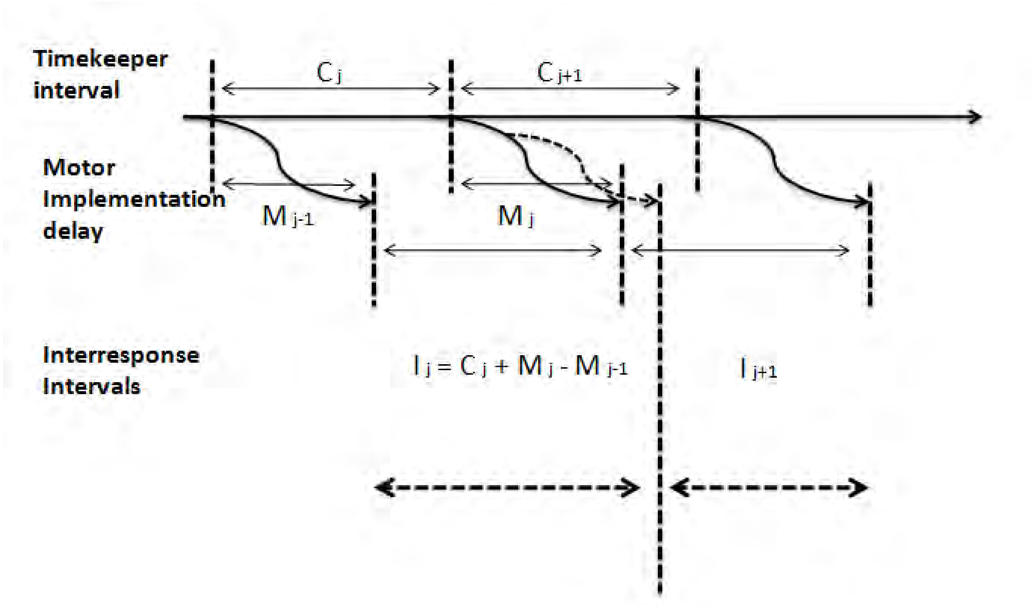


Figure 2.6: ***The WK two level timing model***. The timekeeper intervals (C) are dependent on motor implementation delays (M), generating the interresponse interval (I). The mean of I matches the mean of C. Discrepancies between I and C are caused by variations in C and M. Variation in M results in negatively *correlated I (short I is followed by a long I).*

Dancers' timing in an ensemble requires synchronisation with external time sources. Yet, dancers' movement synchronisation to an orchestrated music or to another ensemble member seems effortless. Nonetheless, there will be moments in which a dancer losses the beat. In this situation, a dancer needs to employ strategies to correct this error fast. One fundamental aspect of SMS is that it requires constant error corrections in order to maintain synchrony. This is caused by the accumulating variability from one tap to another that is attributed to any periodic motor activity. However, the WK model shown above, cannot account for synchronisation to a paced stimulus. Therefore, extensions of this model include linear error correction components which will be described below.

Insights about how well one can synchronise to an external pacing stimulus can be derived by two measurable variables; the synchronisation error (SE) and the differences between the inter-response interval (IRI) and the inter-stimulus interval (ISI) (Vorberg & Wing, 1996). In the scenario of a dancer synchronising to musical tones, the dancer aims to produce a movement interval (IMI, time length between a reached dance position to the next dance position) that exactly matches the perceived interval of the musical tones (ISI, time length between the onset of one tone to the next one), with ideally zero phase deviation between the reached target position and the onset of the musical tone. Since the timing of the motor activities fluctuates, dancers have to correct their movement intervals in relation to the perceived error in phase or period. Errors in phase refer to the deviation between the reached target position and the corresponding onset of the musical note, which are errors at a more local level. Instead, errors in period refer to the deviation between the IMI and the ISI. Assuming that error correction is based on the SE or asynchrony, the error may be adjusted immediately in the next movement, which has been referred as a first order linear correction. A first order linear phase correction can be estimated by

$$C^*n = Cn - \alpha\ An..$$

C is the central timer, comprising an interval generated by the timekeeper and a correction term. By this equation the dancer corrects an error by subtracting (or adding

$An < 0$) a fixed proportion α of the last synchronisation error from the current timekeeper interval Cn. The second-order linear phase correction (Pressing, 1998) adjusts to synchronisation errors two instead of one dance movements back in the dance movement sequence (Figure 2.7).

$$C^{*}n = Cn - \alpha\ An. - \beta\ An.\text{-}1.$$

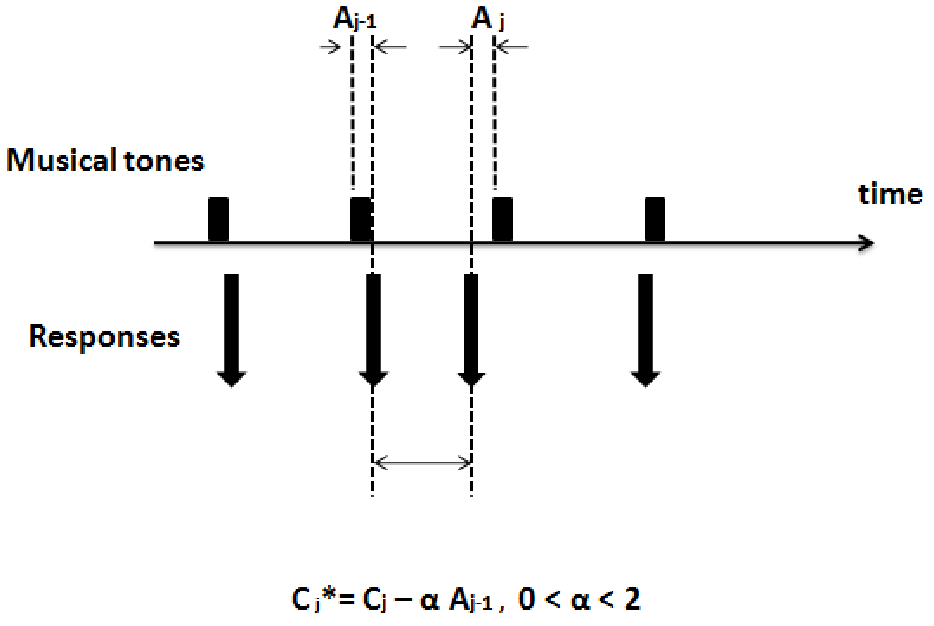


Figure 2.7: ***First-order linear error phase correction of the interval timekeeper (C).*** Error correction occurs at the preceding asynchrony (A) of the movement response and the musical tone onset.

Linear error correction models assume that no correction of the interval (period) has to take place. Yet, in dance the tempo of the music may also change, referred as a period change. This consequently would require a correction of the period; dancers' IMI. Figure 2.8 illustrates corrections to a period change and to a phase shift, based on finger tapping literature.

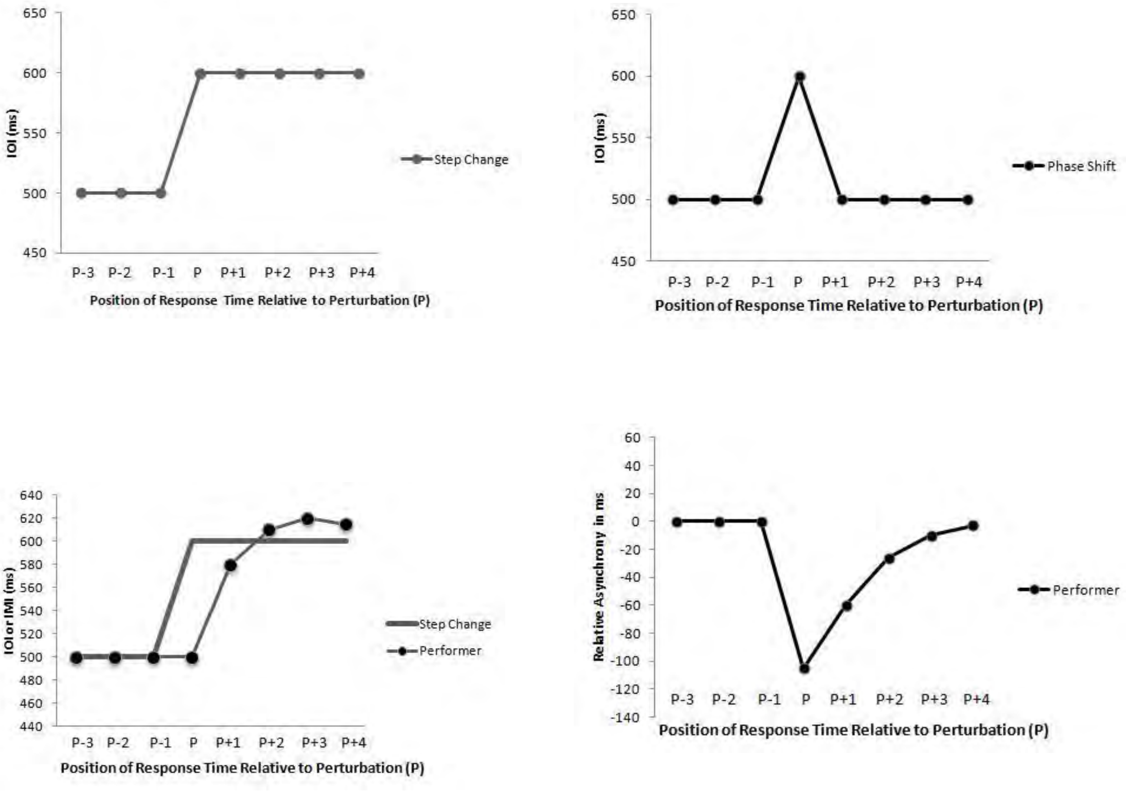


Figure 2.8: ***Period and Phase Shifts***. Top left corner shows a period change in the stimuli, top right corner shows a phase shift in the stimuli. Bottom left graph illustrates a correction after a period change and the bottom right represents the correction after a phase shift.

2.5 Proposed Method of Analysing Dance

The current thesis aims to explore dancers' interpersonal synchronisation, emphasising feedback control. To our current knowledge no research has yet investigated dancers timing accuracy with an external referent whilst performing dance movements. The presently proposed method of analysing dance movements adopts measures that have been widely established using tapping paradigms, applying an information processing approach. Measures of the mean and variability of the inter-movement-interval and asynchrony were used. Two movement events were chosen as the event to which a dancer may synchronise his or her movements with an external referent. One is the start of a reached target position in space and the other is the peak velocity of a movement. The former is defined as the first point of reaching the maximum displacement in space, when the velocity is closest to zero. The latter measure of velocity defines the speed of a moving limb in a given direction. The speed of the limb movement is the magnitude of its velocity and the peak of the velocity refers to the greatest magnitude of its rate change; thus it reflects the highest speed.

Synchronisation errors were estimated as followed; for synchronisation to an auditory tone, the time difference between the target position or the peak velocity and the corresponding tone onset was calculated (Figure 2.9.a, d). For interpersonal synchronisation between two dancers, the synchronisation error between target position of dancer A relative to the target position of dancer B, or the peak velocity between A and B were estimated (Figure 2.9.b,c). Inter-movement interval (similar to IRI) discrepancies between performer and target interval were calculated by comparing the IMI of dancer A relative to the ISI of a metronome or the IMI of dancer B.

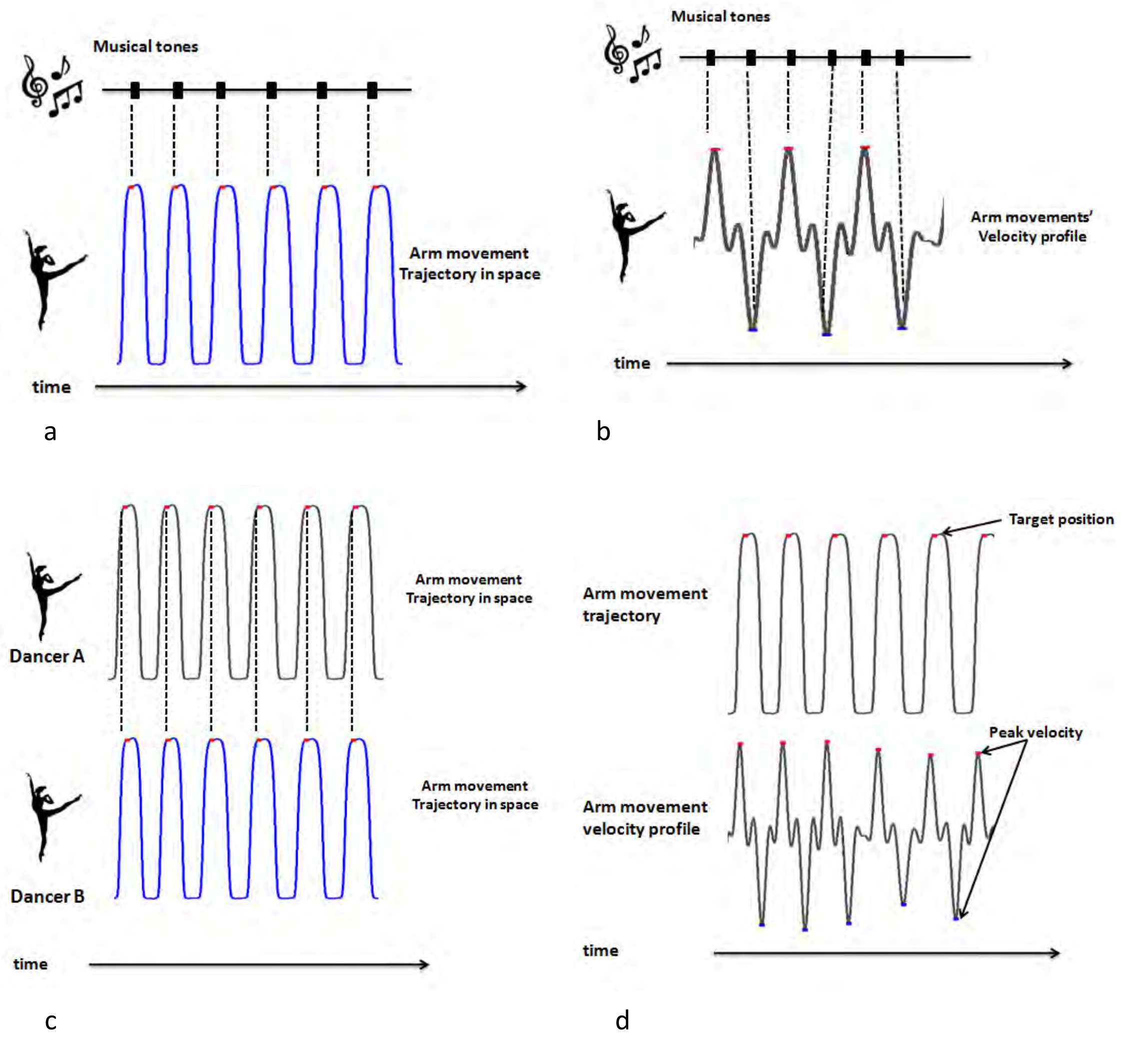


Figure 2.9: ***Timing Analysis of Dancers' Movements***. Synchronisation with an auditory tone is shown target position (a) and peak velocity (b) and with another dancer's movements for target position (c) and peak velocity (d).

The proposed method of analysing dance movements in synchrony with an external referent may be a robust way of analysing SMS of dancers' complex movements. Measuring SE and IMI errors will help to describe how accurate dancers may time their movements with those of another dancer. Moreover it could provide insights into the movement events dancers may time his or her movements with more accurately. Such events, as earlier noted, may be the target position in space or dynamic events such as the peak velocity.

In summary, approaches how to describe dance movements have been discussed. The method of motion tracking analysis has been suggested to be a powerful and time efficient tool, due to its ability of obtaining objective detailed data of human forces and positions in time. Therefore, in this chapter the application of motion tracking tools was chosen. This was followed by a brief description of two approaches that quantify timing in human movements. The present chapter considered an information processing approach that has been widely used in researching SMS. Measures such as asynchrony and inter-movement-intervals were described and detailed methods of analysing dance movements in time with auditory and visual time cue were introduced. As earlier noted, there has been a limited amount of research that investigated dancers' timing with external sources. It therefore may be crucial to look into finger tapping studies that investigated timing with external sources, to develop a paradigm for analysing dance.

Chapter 3: Visual Mediated Synchronisation between Performers: A possible Paradigm for Dance?

3. 1. Introduction

In dance ensembles dancers may time their movements with multiple external cues such as the perceived rhythmical movements of another dance partner, or the perceived auditory beats of music. However, it is not known how dancers achieve synchronisation with one or several external timing cues. To help understand issues facing dancers' keeping time with external cues, the previous chapter introduced an information processing approach for analysing sensorimotor synchronisation (SMS), based on finger-tapping paradigms. Research into SMS emphasised the importance of feedback control based on perceived sensory information, whilst assuming a prediction mechanism for the sensory effects of movements, as provided by a forward model (Stenneken, Cole, Paillard, Prinz & Aschersleben, 2003). In line with the first order linear error correction model, as described in the previous chapter, in dance, corrections may be based on the perceived preceding synchronisation error between a dancers target position in space compared with those performed by another dancer. Thus, perceived timing via the visual sensory path may be important for dancers to keep in time with one another during ensemble performances. The present chapter introduces a paradigm to investigate visually mediated synchronisation between two individuals, emphasising feedback control. First, a series of paradigms and measures that were previously used to quantify interpersonal cooperative timing are reviewed.

Exploring visually mediated synchronisation between two people has recently been of interest to cognitive psychologists who researched the phenomena of spontaneous interpersonal synchronisation, or SIS (Richardson, Marsh & Schmidt, 2005). SIS is the mutual synchronization in terms of a network of oscillators whose individual behaviour is altered by interactions with close neighbours (Bottani, 1996). Research on this topic pre-dominantly adopted a dynamical systems approach. Under the dynamical systems approach it is assumed that timing is not explicitly controlled, but is instead an emergent property of movement parameters, such as stiffness which influences movement frequency and amplitude. In this approach, timing is typically evaluated using continuous measures of coordination between two units, such as the phase difference between two moving limbs calculated over all time samples (continuous relative phase).

A good example of a study that applied a dynamical systems approach to study visually mediated SIS is that of Oullier, deGuzman, Jantzen, Lagarde and Kelso (2008). They proposed the following paradigm to quantify the nature and strength of social interaction in a collaborative timing task. Pairs of participants were seated opposite each other and were instructed to actively produce continuous up and down movements of their dominant index finger at their own preferred pace. Pairs were matched based on their preferred frequency; individuals who preferred a faster pace were paired with those who preferred a slower pace. To explore the nature of the social interaction, the rhythmical task was performed under two conditions; visual versus no visual information exchange. Participants were both either asked to close or open their eyes throughout a trial. The key measures were relative phase and frequency overlap between the finger movements of the individuals forming the pair. Results revealed that spontaneous phase synchrony occurred during periods of visual information exchange compared to periods of no visual exchange. This was evident even when participants were not instructed to synchronise their movements with their task partner.

Oullier et al.'s study not only highlighted the importance of the accessibility of visual information in order to mutually synchronise with rhythmical movements performed by another partner, but also underlined the strength of visual cues in social interactions. The study presented in this chapter explores a paradigm in which pairs of individuals perform a cyclic movement task similar to Oullier et al. However, in the present study, arm movements are preferred to finger movements (to be more relevant to the scale of dance) and visual feedback is controlled differently (to clarify the source of the effect). In addition, the analysis in the present study focuses on time series of response events in contrast to the continuous relative phase measure of Oullier et al. It was felt that this analysis approach would be more consistent with the information processing framework adopted in this thesis, and would offer a method that would be more applicable to studying how dancers time their movements with one another and how error corrections take place, based on feedback information.

As noted in the previous chapter, the dynamical systems approach (DS) focuses on the stability between two units in terms of qualitative changes or phase transitions over a long time scales. In contrast, the information processing approach (IP) is concerned with the variability of human motor timing on a much smaller time scale. IP assumes the existence of central abstract representations that may control discrete events, such as the finger tap onset during a repetitive finger tapping task in time. In line with the IP approach, experimental measures investigate fluctuations in response timing relative to an external timing cue. Response times may be researched by estimating the intervals between successive responses (IRI) in comparison with those produced by an external timer (ISI). Thus, measures commonly used in analyses from an IP perspective, may be ideal for analysing smaller time scales of visually mediated timing, based on feedback control.

Quantifying interpersonal synchronisation based on the IP approach has been performed by Maduell and Wing (2007). In one experiment they aimed to quantify one person's rhythmical timing in relation to another person. In order to examine this, one participant was designated the role of the lead and one the role of the follower. The lead introduced intentional variations in tempo, using a simple finger tapping task. The follower was asked to tap in synchrony with the tapping of the lead. The mean inter-response-interval (IRI) of the lead and follower were analysed and compared. Moreover a cross-correlation analysis, a measure of similarity between two time functions, was performed on the IRIs, investigating the linkage within the pair. Maduell and Wing found strong dependencies between both, the lead and follower's finger tapping. This linkage provides evidence of temporal corrections performed by the follower in relation to the lead. In addition to the measure of IRI, estimation of the synchronisation error (asynchrony) is a complementary measure to investigate timing between two people. For instance, in traditional tapping-paradigms the measure of timing discrepancy between the tap onset and the onset of an auditory tone quantifies the synchronisation error (asynchrony) of an individual's response time with that of a perceived auditory cue (Repp, 2005).

Relatively few studies have used measures of asynchrony to analyse visually mediated synchronisation between two individuals. However, in a study of interpersonal attraction, Hove and Risen (2009) analysed synchronisation error in a joint tapping task. In their study participants were asked to perform a simple finger tapping task in time with a visual pacing signal on a computer screen. The timing of the visual pacing signal for the two participants was either the same (synchrony) or different (asynchrony). Participants were unable to see the pacing signal with which their partner had to time his or her tapping. Yet, both participants were able to see their partners' finger tapping in their periphery and taps of each individual produced an audible feedback cue. The asynchrony between each other's finger tap onset was calculated and correlated with affiliation ratings. Smaller asynchronies were associated with higher likability. For Hove and Riesen, the key finding was that the asynchrony task led to overall lower affiliation ratings, presumably because the 180 degree phase shift would have meant partners were less able to judge their relative performance. However, from our perspective, the study raises interesting questions about how their participants might have integrated the visual pacing signal provided by the experimenter and the auditory and visual cues from the other participant.

The experimental paradigm used by Hove and Risen (2009) could be used as a paradigm model for dance. Despite its potential, providing pacing cues to both dancers may be overly complex. It therefore, may be more suitable to explore a paradigm that specifies the lead and follower between two individuals as proposed by Maduell and Wing (2007). Furthermore, with respect to the finger tapping tasks applied in previous work, movements of a larger scale that produce no additional tactile and auditory feedback are favourable to explore the causality of asynchrony. In contrast to Oullier et al.'s (2008) phase drift analysis, the present study employs time series analysis, specifically cross-correlations to quantify linkage between two people. In addition, a period shift is introduced as a means of exploring between participants' dependencies. Period shifts refer to the speeding up or slowing down of interval durations, thus individuals have to adjust to new interval durations.

3.1.1 Present Study

Three research aims were set; firstly to quantify visually mediated temporal linkage between two individuals, using measures of the mean and variability of asynchrony and inter-movement intervals (IMI) and the nature of the variability (dependence). Maduell and Wing's (2007) lead-follower paradigm is adopted and further developed to ensure more control over the lead's performance. To control the rhythmical movements performed by the lead, a metronome is introduced that provides an auditory pacing cue for the lead. In order to obtain better control over temporal perturbations than in Maduell and Wing's study, here the metronome pulse presented to the lead is used to introduce controlled perturbations in the form of changes in interval. Throughout the experiment, the lead times his or her movements with the perceived beats of the metronome, whilst the follower times his or her movements with those performed by the lead. Several predictions were made; firstly, with respect to the asynchrony between metronome and lead and metronome and follower, follower's relative mean and variability of asynchrony was expected to be larger and more variable compared with those of the lead. This was hypothesised because when synchronising to the lead the follower would perceive slight fluctuations within the lead's performances. The follower then may introduce additional variability through his or her own timing variability on the top of the perceived interval. Secondly, in line with the first-order linear correction, the follower was predicted to correct for fluctuations in lead's timing one response after the error was apparent. Tow analyses were used to examine this. The first, method was a time series analysis (correlation) for which follower's IMIs were expected to correlate maximally at lag 1 with those performed by the lead. Here, lag 1 implies that the follower may be one IMI behind the lead, due to the directionality of information flow within this paradigm. The second method was an analysis of means (asynchrony) based on the introduction of the period shift. For the latter analysis, a lag effect between lead and follower was also expected.

In real-life dance scenarios, dancers synchronise their timing to the beat of the music and simultaneously observe the movements of their dance partners. Therefore, the second research aim was to investigate whether the visual feedback of the follower's movements would affect the lead's timing with the auditory metronome. In the present study, the lead times his or her movements with the beat of the metronome with either closed or open eyes. In comparison, the follower always performed his or her timing with eyes open affording visual cues to synchronise with the movements of the lead.

Previous research into synchronisation with different modalities suggests that audition is more accurate in terms of temporal resolution than vision (Repp & Penel, 2002). However, one study conducted by Kato and Konishi(2006) found that when participants tapped in time with an auditory pacing signal whilst perceiving a visual distracter signal that introduced large temporal perturbations, participants variability of asynchrony relative to the metronome increased. Besides the dominance of audition over vision in the temporal domain, visual timing signals negatively affected the timing accuracy with an auditory pacing signal. Therefore, it was expected that the lead's asynchrony and variability of asynchrony would increase with vision compared with no vision.

Lastly, the effect of the lead's internalisation of the interval produced by the metronome is examine by introducing a continuation phase in which the auditory pacing signal is terminated. Introducing a continuation phase has been widely used to investigate the existence of a central timekeeper (Wing & Kristofferson, 1973). In the present paradigm the goal is to investigate whether the lead's synchronisation performance may be solely based on feedback control or whether some internalisation of the temporal information could also contribute. It was predicted that the lead would internalise the interval produced by the metronome. Therefore it was expected that the lead would produce IMIs equal to IOIs (inter-onset –interval of metronome) in no visual feedback conditions. If this turned out to be true, the present study would provide further evidence, that error corrections may not solely be based on feedback information of the perceived pacing signal. Instead, predictions based on internal representations of the interval may also contribute to visually mediated interpersonal synchronisation.

3.2 Method

3.2.1 Participants

Seven pairs of participants were recruited (N=14, all right handed) from staff and students at the University of Birmingham. The mixed or same gender pairs comprised six men (mean age 28.5) and eight females (mean age 22.5) with an age range of 18-37 years. All participants provided informed consent, were naive to the purpose of the study and reported no neurological or auditory deficits.

3.2.2 Apparatus

Participants sat at separate tables opposite each other (Figure 3.1). The gap between the two tables was 5 cm and each table had a dimension of (50 x 50 cm). Both participants placed their right elbow on a cushion in order to move their forearms freely and comfortably. One 20 mm diameter spherical reflective marker was attached with double sided sticky tape at the tip of the index finger of each participant within each pair (Figure 3.1). Two computers were used to run the present study; one to run the metronome and one to record the movement data. Metronome presentation was generated using the MatTAP toolbox (Elliott, Wing & Welchman, 2009) in Matlab (version 2009a; The Mathworks Inc., MA, USA) operating through a data acquisition device (USB-6229, National Instruments Inc., USA). The follower within each pair listened to white noise presented by an iPod headphone set. The volume of the white noise was set to a level where the participants reported not being able to hear the experimenter talking. The movement kinematics were recorded at 200Hz using a twelve camera motion tracking system (Oqus, Gothenburg, Sweden).

Figure 3.1: ***Experimental Set Up.*** This picture illustrates a pair of participants facing each others. Both participants wore headphones and rested their elbows on a cushion. One reflective was placed on their index finger. The black lines indicate that two tables were used.

3.2.3 Metronome Stimulus

The metronome stimuli were based on a 2 x 2 x 2 experimental design with factors: *Synchronisation Type* (synchronisation, continuation phase), *Trial Type* (F-S, S-F) and *Interval Duration* (400, 800ms).

Synchronisation phase (SP) referred to conditions in which the metronome generated beats with which the lead was instructed to time his or her movements. In contrast, continuation phase (CP) referred to conditions that occurred immediately after the SP in which the metronome was discontinued (silence) for 10 seconds (Wing & Kristofferson, 1973). After 10 seconds of the CP phase a metronome beep indicated that this phase has ended. Each synchronisation phase consisted of one of the two Trial Types. Trial Type F-S (fast to slow interval), began with twenty metronome inter-onset-intervals (IOI) of 400 ms and continued with another twenty IOIs of 800 ms. For Trial

Type S-F (slow to fast interval) trials started with twenty metronome IOIs of 800 ms and then continued with twenty IOIs of 400 ms. Lastly, the factor Interval Duration referred to the IOIs generated by the metronome. IOIs were on average either 400 ms or 800 ms with a spread of 5% around the mean IOI, for example an F2S trial may have started with twenty IOIs of the interval duration of 420 ms followed by twenty IOIs of the interval duration of 780 ms (Figure 3.2). IOI variations were randomly generated by Matlab and then hard coded into the MatTap toolbox to ensure that all pairs synchronised to exactly the same metronome IOIs. The variation of the IOI was intended to avoid anticipation of the interval by lead and follower. Thus the lead would be required to pay active attention to the metronome period and the follower to the period of the lead's responses.

Overall ten F-S and ten S-F trial types were generated, with a total of 20 trials. Each metronome trial, including synchronisation and continuation phase, lasted around 40 seconds.

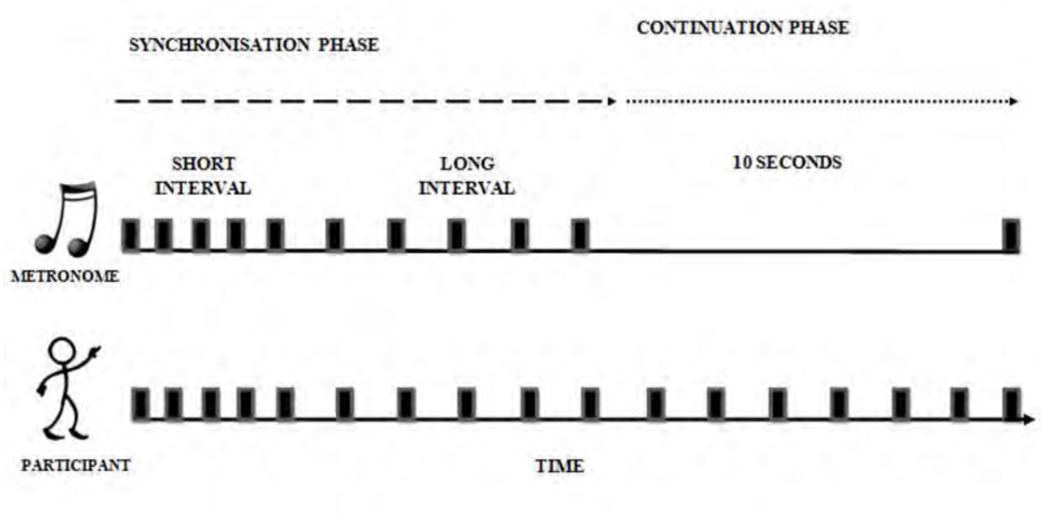


Figure 3.2: ***Illustration of the Synchronisation (SP) and Continuation (CP) phase.*** This is an example of Trial Type F-S. 20 IOIs of short, followed by 20 IOIs of long interval durations are generated by the metronome. The participant, here the lead, was asked to time their arm movements with those of the metronome. After the 20th IOI of the long interval duration was presented, the metronome was discontinued for 10 seconds. Participants were asked to reproduce the last interval until the metronome indicated the end of the continuation phase with an auditory tone.

3.2.4 Procedure

Testing involved two sessions conducted on separate days, one day apart. The first session lasted around 60 minutes and the second session lasted around 40 minutes. The difference in experimental duration times occurred due to extra time that was needed to explain the experimental task and fill in all forms required for this study. Session 1 and 2 only varied in one aspect, either visual feedback of the follower to the lead was provided or prohibited. For three pairs, all experimental trials in session 1 were performed by the lead without receiving visual feedback from the follower's performance, and receiving visual feedback in session 2. For the other four pairs the reverse was the case, the lead receiving visual feedback on session 1 and no visual feedback on session 2.

At the beginning of session 1, participants were asked to read an instruction sheet and fill out a consent form. Then, within each pair, one was randomly designated the role of the lead and one the role of the follower. Once the roles were assigned, a reflective marker was placed on the right index finger of each participant. The experimenter instructed participants to move their right forearm vertically up and down with only the elbow touching the surface of the table. They were asked to not move any other body parts such as the head or trunk when performing the oscillatory arm movement. Their wrist and finger were required to stay aligned with the forearm, so that the forearm and hand moved together as one unit. (Figure 3.1). After the oscillatory arm movement was rehearsed, the pair was then asked to wear headphones and the volume was tested for each participant. After demonstrating that they could correctly perform the movement, the experimental task was explained. The lead person was instructed to synchronise his/her downwards movements (peak extension of the elbow) in time with the beats of metronome under two visual conditions; access to and no access to the visual movement cues of the follower. As a CP was introduced immediately after each SP, the lead was instructed to continue with his or her performance, maintaining the interval timing of the preceding metronome pace until an auditory beep signal was presented. Once the lead heard the beep signal he/she was asked to discontinue their oscillatory arm movement and rest.

For conditions in which visual cues of the follower were prohibited, the lead was asked to close his or her eyes and time his or her movements with those of the metronome. In contrast, for conditions in which access to visual cues of the follower was provided, the lead was asked to visually focus on the index finger of the follower but to time his or her movements to the metronome beats. The participant assigned as the follower was instructed to synchronise his or her movements in time with those of the lead; specifically, to time his or her downwards movement with the downwards movement of the lead. The follower performed this task whilst listening to white noise presented via headphones throughout all experimental trials. Overall, each session contained 20 trials (ten F-S and ten S-F trial types) resulting in a total of 40 experimental trials per pair.

3.2.5 Analysis

3.2.5.1 Kinematics

Participants' kinematic data were aligned to the metronome data. The vertical axis of each participant's index finger was selected for further analysis as the performed arm movement was an up and downwards movement along the vertical axis. All following analyses were conducted in MATLAB. Each participant's movement data was digitally low-pass filtered at 1Hz (dual pass 8^{th} – order Butterworth filter). Two peak detection algorithms were used, one to determine each beat onset of the metronome and another one to identify the lowest vertical value of the participants' index finger trajectory. In each trial a total of 40 metronome peaks and a minimum of 52 and a maximum of 60 movement peaks (depending on whether the continuation phase was included) were detected.

Two dependent measures were determined; participants' asynchronies (A), for the lead and follower relative to the metronome and participants' inter-movement-onsets (IMI) were calculated (following the definitions given in Chapter 2). Those then were computed for the two phases in the S-F and F-S trials. The resulting mean asynchronies (A), mean standard deviation of the asynchronies (sdA), mean inter-movement-interval (IMI) and standard deviation of the inter-movement-interval (sdIMI) were statistically analysed by two separate analyses of variance; one for the SP and one for CP. Participants' first timing response at the beginning of each trial and at the beginning of the second interval duration were excluded to avoid potential outlier values.

For the synchronisation phase a 2 x 2 x 2 x 2 ANOVA mixed analysis of variance was conducted, with *Participants' Role* (lead, follower) as between subject-factor and *Feedback Cue* (LNV (lead no vision), LV (lead vision)), *Trial Type* (F-S, S-F) and *Interval Duration* (400, 800 ms) as within-subject factors.

Analysis of the continuation phase (CP) was performed to test whether participants internalised the inter-movement-interval produced during the synchronisation phase. Two separate 2 x 2 ANOVAs mixed analysis of variance, one for 400 ms and one for 800 ms target interval were conducted with the factor of *Participants' Role* (lead, follower) as between subject-factor and *Feedback Cue* (LNV, LV) as within-subject factors. Greenhouse-Geisser corrections were made for sphericity violations where necessary. Non-significant results ($p>.05$) are not discussed. Post-hoc comparisons were performed using the Bonferroni t-test (Howell, 2002).

Cross correlations were calculated to examine the relationship between lead and follower's IMIs. Cross correlation coefficient is a measure of statistical similarity between the two interval time series. It also provides an index of strength and time relationship between two time series. As the two series of IMI (lead and follower) may differ by a slight shift along the x-axis (time), the formula shown below slides the IMI series of the lead (Y) along the x-axis by a lag k = 1, 2, 3, 4… and so on. In the present study lags -5 to +5 were estimated. Therefore,

$$\text{Cross-corr}(X, Y) = \text{sum}\ \{(X_i - \text{mean}(X)) * (Y_{i+k} - \text{mean}(Y))\} / (N-k-1),$$

with X and Yi referring to lead and follower IMIs (Wing & Woodburn, 1995). This was calculated and averaged separately for the first and second phase of F-S and S-F. For instance, strong lag +1 correlations would suggest that the follower corrected his/her IMI relative to the preceding IMI of the lead. In contrast strong lag -1 correlations would suggest the opposite; the follower corrected his/her movement one movement ahead of the lead's IMI. Lastly, strong correlations at lag 0 would indicate that the follower's adjustments were in phase with the lead's IMIs. For each participant the lag position of the strongest dependence between his/her movement IMI and the stimulus IMI was estimated. Once the lag was identified, correlations were examined by a three-way repeated measure ANOVA with factor condition (LNV, LV), (F-S, S-F) and (400, 800 ms).

Lastly, to investigate how long it took for the follower to adjust his/her timing to those of the lead after a period change, a simple post-perturbation recovery analysis was conducted. Here lead's IMIs from the start of the period change were compared with those of the follower. Follower's recovery was estimated by determining the first IMI value that was within 1,5 standard deviation of the followers new target interval performance. The first eight trials of each session were taken, to avoid potential anticipation of the point of period change by the follower (total 48 trials). Once recovery positions were identified, a two-way repeated measure ANOVA with factor condition (LNV, LV) and (400, 800 ms) was conducted to examine whether *Feedback Cue* and *Interval Duration* affected followers' performances.

3.3 Results

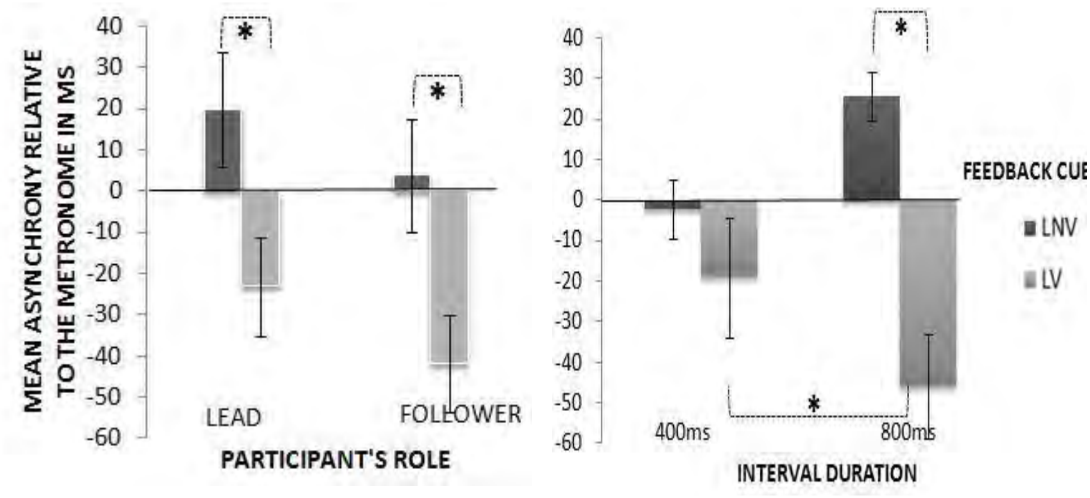
In the following section, the first analyses were conducted on the mean and variability of the asynchrony (A) and inter-movement-intervals (IMI). These analyses were conducted separately for the synchronisation phase (SP) and continuation phase (CP).They were performed to investigate the relationship between the lead and follower and the effect of visual feedback cues on the timing accuracy of the lead and follower together. The second analysis presented is a cross correlation analysis to identify dependencies between lead and follower's IMI. Lastly, post-perturbation results of the follower are shown.

3.3.1. ANOVAs of Synchronisation Phase

For the measures of asynchrony a main effect of *Feedback Cue* was expected, with larger and more variable A predicted for LV compared with LNV conditions. This was based on previous literature that suggested that observing a variable visual distracter whilst synchronising with an auditory beat resulted in larger A and sdA (Kato & Konishi, 2006).

3.3.1.1. Mean Asynchrony (A)

The mean asynchrony indicates the average synchronisation error of the lead and follower relative to the metronome beat onset. The overall mean asynchrony was -10.3 ms; -1.7ms for the leads and -19.1ms for followers. The difference in the average synchronisation error between leads and followers was not significant ($p > .05$). However, the predicted difference for *Feedback Cue* was significant ($F(1,10)= 21.595$, $p<.01$, $\eta_p^2 =.683$). For all participants, LV conditions resulted in larger synchronisation errors relative to the metronome (-32.5 ms) whereas LNV conditions resulted in smaller synchronisation errors (11.76ms). To further investigate whether the main effect of *Feedback Cue* affected both the leads and followers, separate post-hoc t-tests were conducted (Figure 3.3.a). Post-hoc t-tests showed that leads and followers As were affected by the *Feedback Cue* ($p<.025$). Leads' A exhibited mean positive asynchrony (19.8 ms) for LNV conditions, whereas mean negative asynchrony (-23.2 ms) were found for LV. Similarly, for the group of followers, LNV conditions yielded mean positive asynchrony (3.7 ms) and LV produced larger mean negative asynchrony (-41.9 ms). The mixed analysis of ANOVA also revealed a main effect of *Trial Type* ($F(1,10)= 22.038$, $p<.01$, $\eta_p^2 =.688$) for which participants' synchronisation errors were larger for F-S (-17.0 ms) compared to S-F (-3.7 ms) trials.



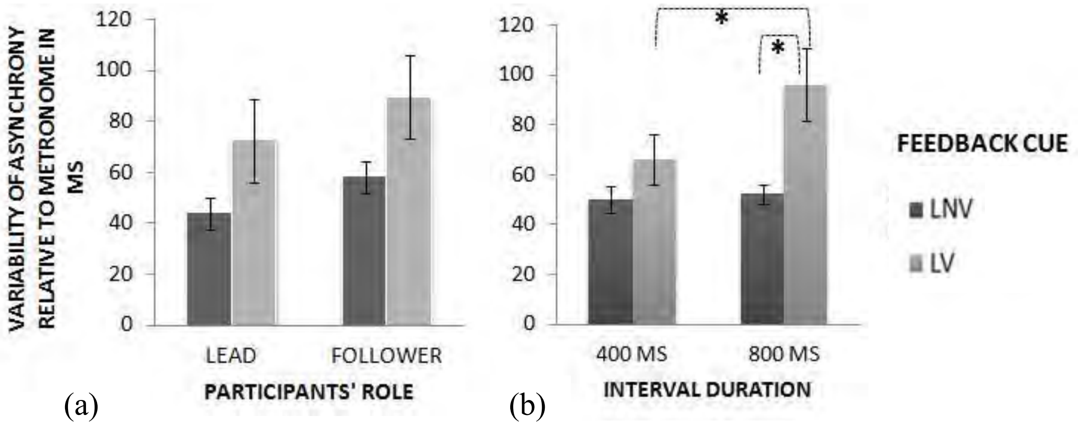
(a) (b)

Figure 3.3: ***Main effect of Feedback Cue on A***. Comparison between lead (N=6) and follower (N=6), for asynchrony relative to metronome (a). Interaction between *Feedback Cue x Interval Duration* (N=12) (b). * indicates significance differences for post-hoc t-tests. Error bars represent the standard errors of the means.

A significant two-way interaction between *Feedback Cue* and *Interval Duration* was also observed ($F(1,10)= 15.640$, $p<.05$, $\eta_p^2 =.610$) (Figure 3.3.b). Post-hoc multiple comparisons showed, that when participants performed longer interval durations, larger synchronisation errors were found for LV (-46.0 ms) compared to LNV (25.7 ms) conditions ($p <.01$). In addition, in LV conditions smaller synchronisation errors were observed for short interval durations (-19.0 ms) compared to long interval durations (-46.0 ms) ($p < .025$).

3.3.1.2. Standard Deviation of Asynchrony (sdA)

Mean standard deviation of asynchrony is a measure of participants' consistency in their synchronisation performance relative to the metronome. The greater the sdA, the more dispersion is there from the mean A and the less consistent are participants' synchronisation performance. The overall mean sdA was 66.1 ms; 58.2 ms for leads and 73.9 ms for followers. The difference in the average dispersion from the mean A between leads and followers was not significant (p >.05). However, the mixed ANOVA showed a significant main effect of *Feedback Cue* (F(1,10)= 7.382, p<.05, η_p^2 =.425)) and *Interval Duration* (F(1,10)= 6.69, p<.05, η_p^2 =.399). Synchronisation was more variable with visual feedback cues (81 ms) than without (51.2 ms). However, separate post-hoc t-tests revealed that the type of feedback cue did not significantly affect leads or followers on their own (p>.05) (Figure 3.4.a). The main effect of *Interval Duration* was due to less variability in the shorter interval (58 ms) compared to the longer interval (74.2 ms) condition.



(a) (b)

Figure 3.4: ***Main effect of Feedback Cue on sdA***. Comparison between lead (N=6) and follower (N=6), for sdA relative to metronome (a). Interaction between *Feedback Cue x Interval Duration* for sdA (N=12) (b). * indicates significance differences for post-hoc t-tests. Error bars represent the standard errors of the means.

In addition, a significant two-way interaction between *Feedback Cue* and *Interval Duration* was exposed F(1,10)= 13.419, $p<.05$, $\eta_p^2 = .573$) (Figure 3.4.b). Post-hoc multiple comparisons showed that for LV conditions, participants' synchronisation was more variable in longer interval durations (96.2 ms) compared to shorter interval durations (65.9 ms). In addition, synchronisation with longer interval durations resulted in more variable synchronisation performance for LV (96.2ms) compared to LNV (52.2ms).

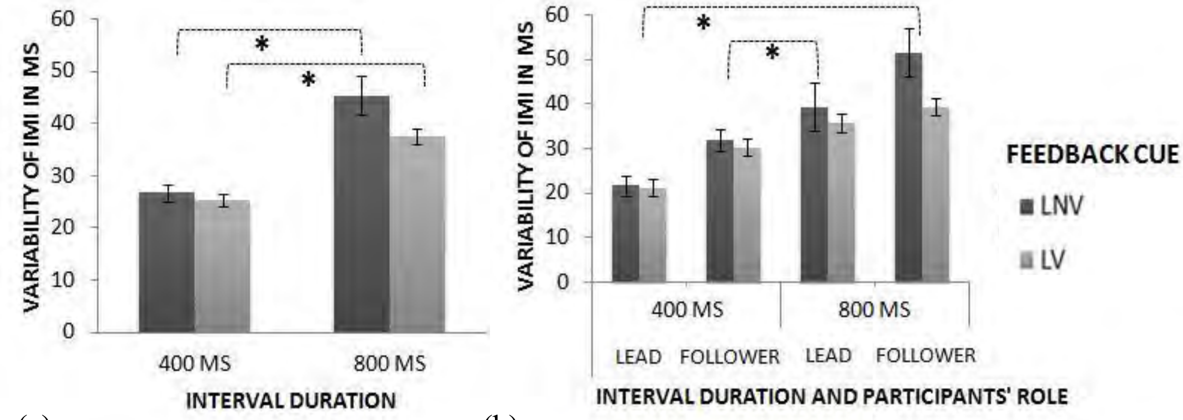
3.3.1.3. Mean Inter-Movement-Intervals (IMI)

The duration between participants' two successive downwards movements is referred to as an IMI. The difference of the average IMI performed by leads compared to followers was not significant ($p > .05$). The mixed ANOVA analysis exposed as expected, a main effect of interval duration (F(1,10)= 648.334, $p<.01$, $\eta_p^2 = .985$). Participants successfully reproduced the shorter interval duration of 400 ms (introduced by the metronome) with a mean IMI of 406 ms and the longer interval duration of 800 ms with a mean IMI of 771 ms.

3.3.1.4. Standard Deviation of IMI (sdIMI)

The mean sdIMI reveals the participants consistency of their IMI performance. The greater the sdIMI, the more dispersion is there from the mean IMI and the less consistent are participants' interval performance (reproduction). The overall mean sdIMI was 33.9 ms; 29.5 ms for leads and 38.2 ms for followers. The difference in the average dispersion from the mean IMI between leads and followers was significant (F (1,10)= 10.218, p=0.01, η_p^2 =.505) smaller sdIMI were performed by leads compared to followers. For the between factors, the mixed ANOVA found a significant main effect of *Interval Duration* (F (1,10)= 62.864, p<.01, η_p^2 =.863). The main effect of interval duration was due to less variability in the shorter intervals (26.3ms) compared to the longer intervals (41.5 ms). Surprisingly, an interaction between *Feedback Cue* and *Interval Duration* was exposed (F (1,10)= 5.412, p<.05, η_p^2 =.351) (Figure 3.5.a). Multiple post-hoc comparisons showed that for both feedback conditions, the performance with longer interval durations resulted in more variable IMI (p<0.01) compared to shorter interval durations (p<0.01). For longer interval durations (800 ms) a marginal significant effect of feedback cue was observed (p=0.06). Here, LV conditions resulted in slightly less variable IMI (37.6 ms) performance compared with LNV conditions (45.4ms).

To further investigate if this interaction was evident for leads and followers separately, multiple post-hoc t-tests were performed for each group. Findings showed that for both groups, shorter interval durations yielded significantly less variable IMI performance compared to longer interval durations irrespective of the type of visual feedback cue (p<.01) (Figure 3.5.b). For the followers only, a marginal effect of visual feedback cue was evident for longer interval durations (p=.06). Here, followers produced more variable IMIs for LNV (51.4 ms) compared to with LV (39.3 ms) conditions.



(a) (b)

Figure 3.5: ***Interaction between Feedback Cue x Interval Duration of sdIMI (N=12).*** Interaction for all individuals combined (a). Interaction between *Feedback Cue x Interval Duration* of sdIMI for leads (N=6) and followers (N=6) separately (b). * indicates significance differences for post-hoc t-tests. Error bars represent the standard errors of the means.

3.3.2 ANOVAs of Continuation Phase

Analysis of the continuation phase (CP) was performed to test if participants internalised the inter-movement-interval produced during the synchronisation phase. To test if leads' access to visual information of the followers' movements enhanced participants timing performances during CP, two DVs were analysed, the mean IMI and sdIMI.

3.3.2. 1. Mean Inter-Movement-Intervals (IMI)

Participants' closely maintained their target interval of 400 ms, with leads producing an average of 403.3 ms IMI and followers an average of 399.9 ms IMIs. The reproduction of 800 ms target intervals resulted in a slight drift away from the mean, as leads performed an average of 772.1ms IMIs and followers an average of 768.2ms. In addition, for target intervals of 800 ms a main effect of *Feedback Cue* was exposed (F (1,10)= 24.406, $p<.01$, $\eta_p^2 =.707$). Participants' reproduced IMIs significantly closer to the target IMI for LNV (802.4ms) compared to LV (737.6ms) conditions. Post-hoc t-tests exposed that for both, leads ($p<.01$) and followers ($p<.025$) LV conditions resulted in a drift away from the target IMI of 800 ms compared with LNV conditions (Figure 3.6).

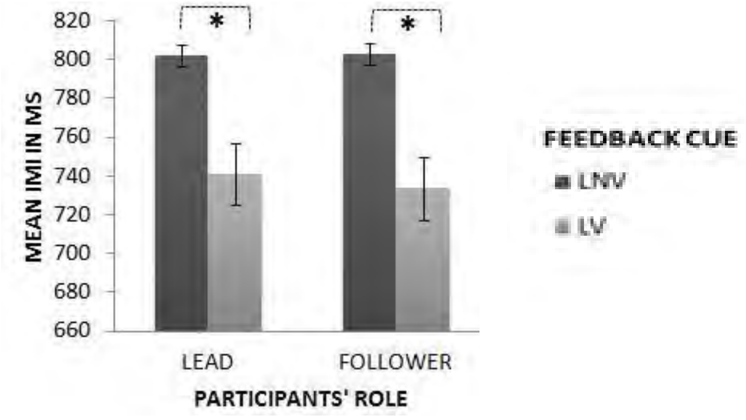


Figure 3.6: ***Main effect of Feedback Cue on IMIs.*** For leads (N=6) and followers (N=6) separately. * indicates significance differences for post-hoc t-tests. Error bars represent the standard errors of the means.

3.3.2. 2. Standard Deviation of IMI (sdIMI)

Participants' reproduction of 400 ms target intervals resulted in an average sdIMI of 19.1 ms; 17 ms for leads and 21.2 ms for followers. The difference in sdIMI between leads and followers was not significant. No main effects of interactions were found.

Target interval reproduction of 800 ms yielded in an average of 36 ms sdIMI; 31.1 ms sdIMI for leads and 40.9 ms sdIMI for followers. The sdIMI of leads were significantly smaller than those for followers (F(1,10)=9.310, p<.05. , η_p^2 =.482). In addition, a main effect of *Feedback Cue* was found (F(1,10)=5.993, p<.05. , η_p^2 =.375). Less variable IMIs were observed for LV (31.9ms) compared with LNV (40.2 ms) conditions. Post-hoc t-tests exposed that this main effect was only significant for the leads (p<.05) (Figure 3.7). Here, the leads performed less variable IMIs for LV (26.9 ms) compared with LNV (35.3 ms).

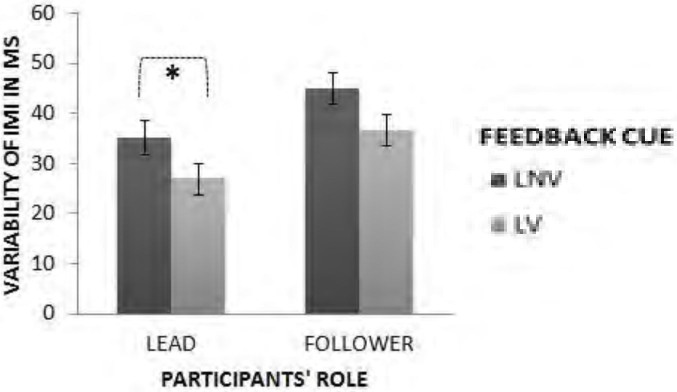


Figure 3.7: ***Main effect of Feedback Cue on sdIMI.*** For leads (N=6) and followers (N=6) separately. * indicates significance differences for post-hoc t-tests. Error bars represent the standard errors of the means.

3.3.3 Cross Correlation Analysis

Cross correlations were used to examine the relationship between the IMI's of the leads and followers. Figure 3.8 illustrates an example trial F-S showing the IMIs of one follower in relation to their lead. Based on visual observation the follower (grey) is one interval behind the lead's IMI (black) during the point at which the period shift was introduced (IMI number 32).

The largest (positive) cross correlations between the IMIs of leads and followers were found at Lag 0 and +1 for NVL conditions (see Figure 3.9). Visual observation of the cross correlation indicates a slightly stronger correlation for Lag 0. As with the NVL conditions, LV conditions showed similar positive cross correlations at Lag 0 and +1. However, LV cross correlations were found to be slightly larger at Lag +1. Interestingly, visual comparison indicates larger positive correlations for LV conditions during 800 ms intervals (r=.36) compared with LNV conditions of the same interval (r=.30).

Two separate repeated measure ANOVA with factor condition (LNV, LV), (F-S, S-F) and (400, 800 ms) were conducted, investigating cross correlations at Lag +1 and Lag 0. For the Lag 0 ANOVA, the overall mean correlation was r=.28 and no significant differences between conditions were observed. In comparison for ANOVAs of Lag +1, the overall mean was r=.26 and an interaction between *Trial Type* and *Interval Duration* was found (F(1,5)=96.349, p<.001, η_p^2 =.951). Post-hoc paired t-test revealed a significant difference between 400 and 800 ms durations in S-F trials (t(5)=3.935,p<.025) , with smaller correlations in 400 ms (r=.252) compared with 800 ms (r=.38). A further significant difference was evident for 800 ms durations in S-F compared with F-S trials (t(5)=4,238,p<.025), with significantly smaller correlations for 800 ms durations in F-S trials (r=.16) compared with S-F trials (r.=38).

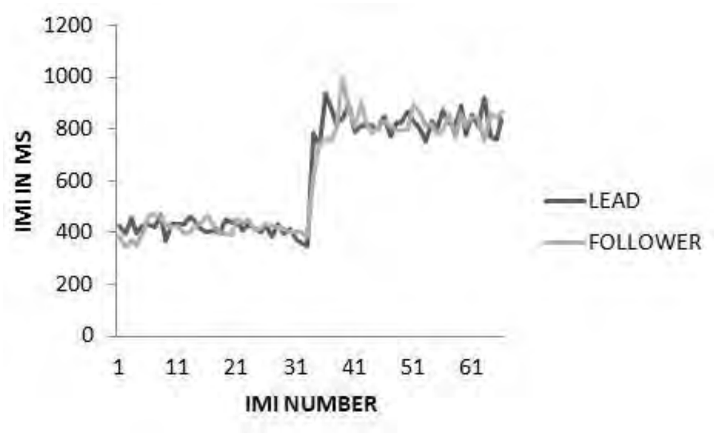


Figure 3.8: ***IMI Trajectory Example.*** Example trajectory for F-S trial, IMIs of follower in relation to lead are shown.

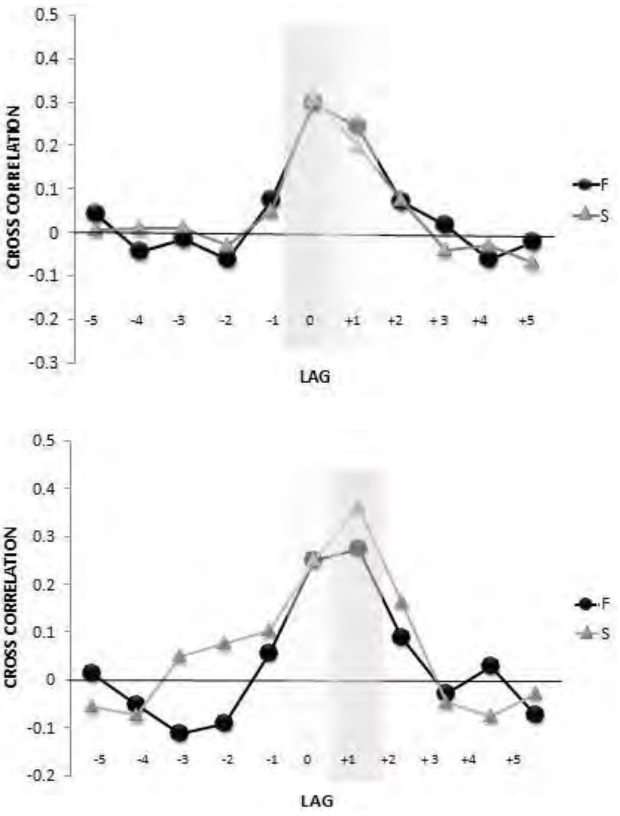


Figure 3.9: ***Cross Correlations.*** Top figure illustrates cross correlations of all participants' LNV conditions, comparing F (400 ms) and S (800 ms) durations. Bottom figure shows cross correlations of all participants' LV conditions, comparing F and S durations.

3.3.4 Post-Perturbation Recovery

On average for F-S trials followers corrected their IMIs one IMI after the leads introduced their new interval. This is in line with a first order linear error correction. In contrast, for S-F trials followers corrected their IMIs on average two IMIs after the leads. The latter is more in line with a second order linear error correction (Figure 3.10). A two way repeated measures ANOVA was conducted on the number of moves to attain a new stable IMI phase. Results revealed a significant main effect of *Interval Duration* (F(1,5)=67.232, p<.025, η_p^2 =.765), with faster recovery for F-S (1.4 moves after period shift) compared with S-F (2.3 moves after period shift) (Figure 3.11). No differences between the types of feedback cue were observed.

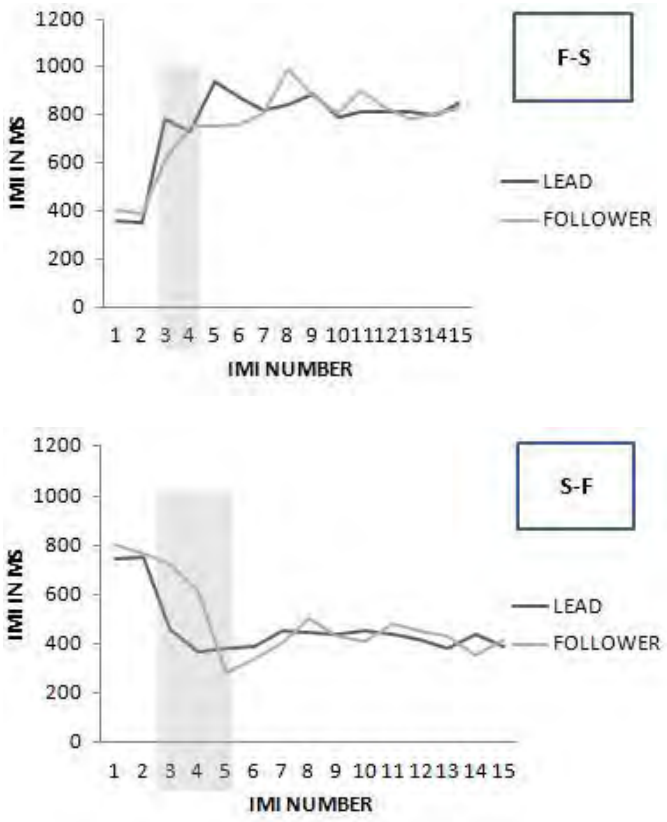


Figure 3.10: ***Post-Perturbation Recovery Illustration.*** Top figure illustrates lag +1 adjustment after period change at number 3 by the follower in F-S. Bottom figure shows a lag + 2 adjustments to leads' IMIs after period change.

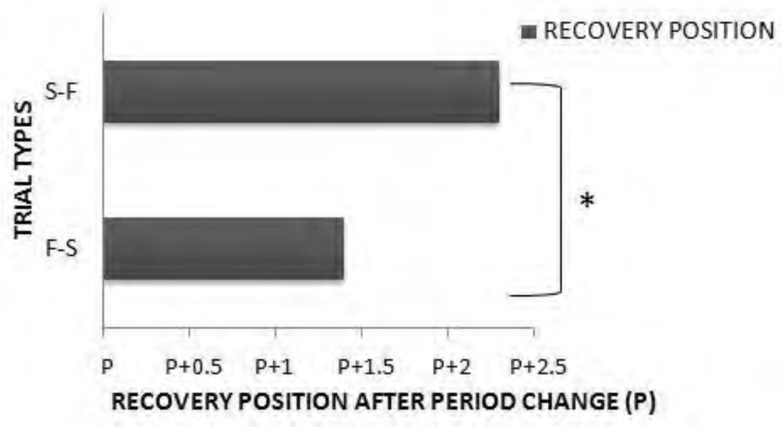
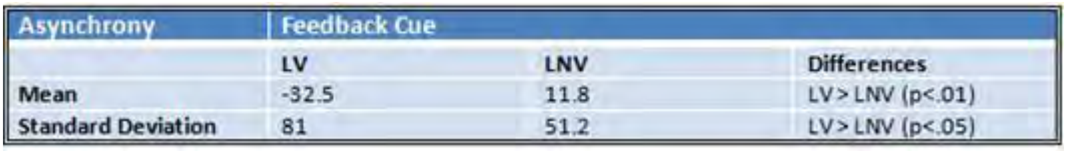


Figure 3.11: ***Post-Perturbation Recovery.*** For followers, N=6.* indicates significance difference. Recovery for F-S and S-F are shown.

3.3.5 Summary

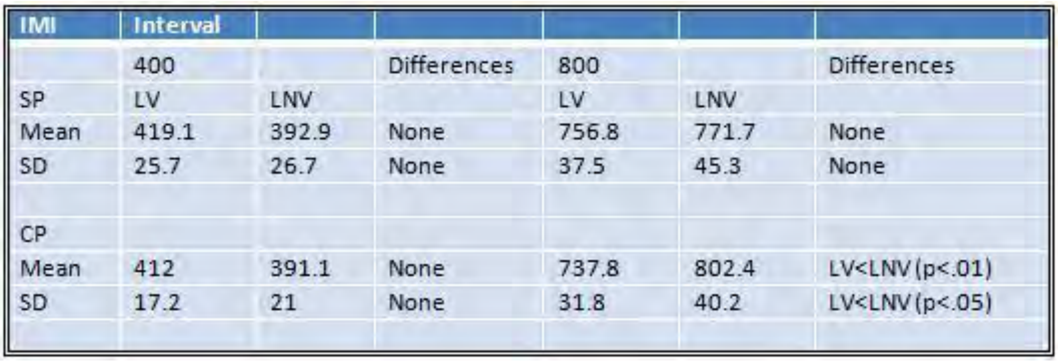
In summary, participants' combined values (leads and followers) showed an increase in the mean and variability of asynchrony for LV conditions compared to LNV (table 3.1). With respect to the interval reproductions (IMIs), they were found to be slightly more accurate and more variable in synchronisation phase, however slightly less accurate and less variable in continuation phase (table 3.2). Furthermore, cross correlation analysis showed a relatively small but consistent positive correlation between leads' and followers' IMIs. Lastly, after a period change, followers adjusted their period (IMI) with that of their leads on average one IMI after those of the leads in F-S and after two IMIs in S-F trials.

Table 3.1: ***Overall Mean A and sdA in Synchronisation Phase.*** Mean asynchrony and variability of asynchrony are shown for LV (lead visual cue) and LNV (lead no visual cue) (N=12).* indicates significance differences for ANOVA.



Asynchrony	Feedback Cue		
	LV	LNV	Differences
Mean	-32.5	11.8	LV > LNV (p<.01)
Standard Deviation	81	51.2	LV > LNV (p<.05)

Table 3.2: ***Overall IMIs for Synchronisation Phase (SP) & Continuation Phase (CP).*** Mean IMI and variability of IMI are shown for LV and LNV and 400 and 800 ms target intervals (N=12).* indicates significance differences for ANOVA.



IMI	Interval					
	400		Differences	800		Differences
SP	LV	LNV		LV	LNV	
Mean	419.1	392.9	None	756.8	771.7	None
SD	25.7	26.7	None	37.5	45.3	None
CP						
Mean	412	391.1	None	737.8	802.4	LV<LNV (p<.01)
SD	17.2	21	None	31.8	40.2	LV<LNV (p<.05)

3.4 Discussion

The present chapter adopted a theoretical framework of sensorimotor synchronisation from an information processing approach to investigate visually mediated timing between two individuals, based on feedback control. The core of the approach was the analysis of fluctuations in response timing of two performers relative to an external feedback cue provided to just one of them. Three research aims were set, with the first aiming to use mean, variability and dependence to characterise visually mediated timing between two individuals. The second aim was to investigate whether the visual access to the followers' movements affected the leads' timing relative to an auditory metronome. Lastly, the final goal was to provide evidence that the leads internalised the interval produced by the metronome.

In terms of the first research aim, to measure visually mediated temporal linkage between two individuals, a lead-follower paradigm was adopted. Interdependence, based on visual feedback cues perceived by the followers from the leads was established by the measures of asynchrony, inter-movement-intervals (IMI) and cross correlation. With respect to the former cross correlation analysis, followers' IMI were expected to correlate at lag 1 with those performed by the leads. A lag 1 correlation implies that the followers are one IMI behind the leads. Present findings showed relatively small, yet consistent positive cross correlations between the IMIs of the leads and those of the followers. In conditions in which the leads were accessing visual information of the followers (LV) positive correlations were observed for lag 0 and lag +1 with the largest for lag +1, as predicted. Similarly, in conditions in which the leads were prohibited visual information of the followers (LNV), positive correlations were also observed for lag 0 and lag +1, yet with the largest for lag 0. Positive lag 0 correlations suggest that followers timed their IMIs simultaneously with those performed by the leads. Significant correlation at lag 0 suggests that followers were able to detect and act on cues in the current cycle about how the leads were changing the interval duration. It may also be that lag +1 correlations were more evident for periods in which a new period change was introduced. Once the followers adjusted to the leads' new interval, predictions could be made, as the followers may be able to learn that only one period perturbation was introduced within each trial. With regards to the differences between the largest lag correlations between LV and LNV, the only difference may have been at the attentional level of the follower. In LV followers were observed by the leads and may have attended more closely followers' IMIs, which led to a larger correlation at Lag +1 as he or she was more likely to correct for changes. In contrast, in LNV conditions, followers were not observed by the leads and may therefore have less attended to each response time performed by the leads.

Post-Perturbation analyses confirmed the above made claim, as followers lagged behind the leads' IMIs during period changes. On average followers were one IMI (two response times) behind those of the leads for period corrections from a short to a long interval. In period corrections from a long to a short interval, followers were found to have been two IMIs (four response times) behind those of the leads. The former finding is supported by Repp (2001) who researched period corrections in synchronised finger tapping with an auditory metronome. In his study participants were adjusting to different magnitudes of period changes. For smaller magnitudes such as 4% differences to the pervious interval participants were able to correct within two response times, however for larger magnitudes an average of four response times were required to adjust to the new interval. In the present study the magnitude of the period change were larger compared with those used by Repp. Yet, participants were able to quickly adjust their timing from a slow to a fast interval. Perhaps the difference lies in the movement itself. Participants' in the present study synchronised with a moving visual pacing signal, whereas in Repp's study participants synchronised with an auditory tone. Participants within the current study may have been able to use the continuous feedback cue to speed up their correction process.

Interdependence, based on visual feedback cues perceived by the followers from the leads was also established by the measures of asynchrony and IMI. It was predicted that relative to the auditory pacing signal the followers would perform with larger mean and variability of asynchrony compared to the leads. This was hypothesised because the followers did not have the same external pacing cue (metronome) as the leads. Instead, followers synchronised to a more variable pacing cue introduced by the leads. Present findings showed that performances of the leads and followers were similar. However, there was a very consistent trend for worse performance by the followers, as predicted. Although one significant difference was found, the lack of overall significance may have been due to the small sample size. Thus the overall statistical power may have been decreased.

As mentioned above, one significant difference between leads' and followers' performances was observed for the measure of sdIMI. Here, longer interval durations of 800 ms, resulted in significantly larger sdIMIs produced by followers compared to those produced by leads. The increased variability in followers' IMI performances may have been due difference in the regularity within each perceived timing cue. Leads' auditory timing cues were highly regular (excluding the moment of period change), whereas the visual timing cues of leads' oscillatory arm movements perceived by the followers were irregular. Measures of leads' asynchrony and IMI showed that leads' performance was variable (e.g. sdA=58.2 ms). Variability in the perceived visual timing cue may have contributed to followers more variable timing performance in IMI. Although significant differences were only found for the measure of sdIMI, closer investigation revealed that the measure of asynchrony and the variability of asynchrony showed similar effects. Here an increase in followers' A and sdA in comparison to those performed by the leads were found.

Besides differences in the regularity of the perceived timing cues, another factor may have been contributing to the increased sdIMIs observed in followers' timing, such as the nature of the timing cue. Leads timed their movements with an auditory metronome whereas followers timed their movements with a visual timing cue. Thus, differences in variability may have arisen from the qualitative different nature of the timing cue. Support comes from research by Patel, Iverson, Chen and Repp, (2005) that investigated participants' sensorimotor synchronisation with visual and auditory timing cues. Their findings showed a significant increase in participants' variability of inter-response-intervals (equivalent to IMI of the present study) when they synchronised their finger tapping with a visual compared to an auditory metronome. Linking their results to the present ones, followers more variable IMI performance compared with the leads may have been caused by the modality difference of the perceived feedback cue. Taken together, the general trend of decreased timing performance of followers, may suggest that the variability and the nature of the visual feedback cue played a role in the present finding. However, it is yet unclear to what extent each factor may have contributed to this effect.

The second research aim was to investigate whether the visual feedback cue of followers' movements affected leads' synchronisation accuracy with the auditory metronome. Previous research by Kato and Konishi (2006) found that individuals' finger tapping in synchrony with an auditory cue whilst observing a visual or auditory distracter resulted in decreased timing performances. In line with their findings, it was predicted that leads' and followers' combined performances of the mean and variability of asynchrony would increase for conditions in which visual information of the followers' movements was made available to the leads. Indeed, present results confirmed this. Larger and more variable asynchronies were found for LV conditions compared to LVN conditions.

Leads' decreased synchronisation performance with an auditory metronome while perceiving a visual distracter cue may be explained by the effect of temporal ventriloquism. Temporal ventriloquism in timing, is the effect of multisensory integration in which in this instance, synchronisation may be biased towards the visual distracter cue (Welch, DuttonHurt & Warren, 1986). Aschersleben and Bertelson (2003) investigated the effect of temporal ventriloquism in synchronised tapping. They asked participants to time their finger-tapping with an auditory pacing signal, while perceiving a visual distracter. The timing of the distracter was varied. It either was presented ahead or behind the auditory timing cue. Results showed that when the visual pacing signal was presented ahead of the auditory beat, participants' tapped earlier, producing negative asynchronies. In contrast, when the visual signal was presented behind the auditory signal, they tapped later, producing positive asynchronies. This then was compared to synchronised tapping without a distracter cue. Overall significant larger asynchronies were observed when a visual distracter was present. Aschersleben and Bertelson concluded that their findings showed clear evidence for interference from the visual distracter cue in synchronised tapping.

Consistent with Aschersleben and Bertelson's findings, current results also revealed a interference from the visual distracter. Leads' asynchronies were on average behind the auditory pacing cue for conditions in which the visual information of the followers was available. More negative asynchronies were found when no visual information was provided. As the followers movement timing was on average slightly behind the auditory metronome and more variable, the integration of the delayed distracter, similar as in Aschersleben and Bertelson's study, may have led to positive asynchronies performed by the lead. However, followers' positive asynchronies were on average relatively small (3.7ms) and with that the discrepancy may not have been large enough to solely account for the positive asynchrony performed by the leads. It therefore, should be mentioned that the asynchrony only reflected the actual physical performance of the followers. Yet, leads may have perceived followers’ timings with a slight delay, based on the ‘Perceptual Centre’ hypothesis. The ‘Perceptual Centre’ hypothesis states that the perceived onset of a timing cue deviates from the physical onset (Vos, Bocheva, Yakimoff & Helser, 1993). Consequently, due to leads’ delayed perception of followers timing cue, the bias towards the visual cue may have been established.

Altogether, leads timing performance with an auditory pacing cue was significantly affected by the visually perceived timing of the followers, even when they were explicitly asked to not time their movements with those of the followers. Potential implications of the temporal ventriloquism effect in a dance ensemble scenario may be that dancers timing could drift away from the music towards the perceived timing of their dance partners. This may be of advantage to improve the visually perceived group cohesion by the audience, however at the cost of falling behind the music. Therefore dancers may adopt strategies to quickly correct for discrepancies between the auditory cues at a given threshold. However, it is not clear whether dancers would also show a ventriloquism effect and if so, whether they would use strategies to be less affected by visual distracters compared to non-dancers in order to maintain their timing with the music.

Lastly, the third aim was to investigate whether the interval produced by the metronome was internalised by the leads. If internalisation took place, leads’ synchronisation performance may have not only been solely based on feedback control, but internalisation of the temporal information may also have contributed to their performance. A continuation phase was introduced after a synchronisation phase. Continuation phases have been widely used to claim the existence of a central timekeeper (Wing & Kristofferson, 1973). It therefore, was predicted that leads could internalise temporal information about the metronome period. Indeed, results of IMI showed that leads were able to reproduce the target interval without an external pacing signal. This was found to be on average more accurate for shorter intervals than for longer intervals. For longer interval durations, leads speeded up their timing performances. Nonetheless after further investigation, the slight drift away from the longer target interval was only evident for conditions in which leads accessed followers' movement timing. The visual feedback cue of followers' rhythmical movements could have been unconsciously used as a pacing signal by the lead, even with explicit instructions not to do so. Supporting this explanation are the results of leads' sdIMI. Less variable IMI performance was found when leads accessed visual timing information of followers' movements compared to no access to the visual pacing signal. Such findings are consistent with research analysing participants timing performance during a continuation and synchronisation phase. Decreased variable inter-response-interval timing was observed when individuals timed their movement with an external timer, compared when no external cue was available (Semjen, Schulze & Vorberg, 2000). Thus, it has been concluded that the greater stability observed during the synchronisation phase, may have been due to a more precise temporal representation of the target interval.

Taken together, leads were able to internalise and accurately reproduce the target interval. Consequently, participants' synchronisation performance may have involved both feedback control and internal predictions. Support that internal predictions may play a role in sensorimotor synchronisation was recently provided by Repp (2011). He explored whether internal expectations were involved in synchronised finger-tapping after a phase shift. Participants were asked to tap with every second beat of the auditory timing cue. Phase corrections were introduced at every first beat of each rhythmic group of the timing cue. In agreement with traditional theories of phase corrections, the asynchrony between the perceived tone onset and the tap onset may cause the phase correction mechanism. Therefore, no or reduced phase corrections were expected due to the absence of asynchrony in Repp's study. In contradiction to his conception of this correcting mechanism, phase corrections took place in absence of the perceived asynchrony. Repp therefore concluded that phase corrections may be controlled by the asynchrony between the internally generated predicted tone onset and the onset of the phase shifted tone. Accordingly, in the present study both internal predictions and feedback corrections may have played an important role in participants' synchronisation performance.

3.4. 1. Summary

The present study successfully adopted an information processing framework to investigate three research aims. The first aim was to quantify visually mediated timing between two individuals. The second goal was to analyse whether the perceived visual feedback cues of the followers' movements affected the leads' timing with the auditory metronome and the third aim was to provide evidence that internal predictions, in addition to feedback control, may also contribute to individuals' synchronisation performances.

Quantification of the temporal linkage between the follower and lead was achieved by analysing the mean and variability of asynchrony and inter-movement-intervals. Clearly, results revealed that the followers closely matched the timing of the leads, based on visual feedback control. Thus, present measures were successful in quantifying interpersonal linkage in time. Interestingly, followers' timing performance showed an increase in the mean and variability of asynchrony compared with the leads. Followers' decreased performance may be explained by the nature of the pacing signal, visual pacing signal for followers and auditory pacing signal for the leads, and by the variability of the pacing signal compared with the regular auditory cue perceived by leads.

Leads' synchronisation performance with a metronome was significantly decreased when the rhythmical movements of followers were visible. The effect of temporal ventriloquism may explain the interference effect observed as bias towards the rhythmical timing of the follower was observed. Lastly, evidence for an internalisation of the target interval by the leads was evident. Therefore, it may be claimed that participants' synchronisation performance was not solely based on feedback control, but also on internal estimations of the following onsets of the external cue.

The results of the present study introduced several interesting new research questions. Two are particularly relevant to the research of dance ensemble synchronisation. The first is whether; in ensemble coordination, each individual's timing variability is carried over from one person to the next? In the next chapter, the idea of accumulating variability will be further explored by introducing multiple performers. The second question relates to the observed integration of cross-modally perceived rhythmical timing cues, even when participants were explicitly asked to time their movements according to only one cue. Can such integration be demonstrated when two rhythmical cues are perceived within the same modality and if so what are the potential advantages of this integrative process? The next chapter will answer this by introducing a paradigm in which individuals integrate two visual rhythmical movements simultaneously.

Chapter 4: Synchronised Timing with Multiple Performers:

'The Circle Paradigm'

4.1 Introduction

The preceding Chapter 3 proposed a paradigm to quantify visually mediated synchronisation between two individuals, emphasising feedback control. Strong evidence for temporal linkage between the followers and leads was established by measures of asynchrony, inter-movement-intervals and cross correlations. In addition, the lead's timing performance with the auditory pacing signal was negatively affected by observing the follower's rhythmic movements. Thus, the visual rhythmic information of the followers affected lead's error correction relative to the auditory pacing signal. Interestingly, Chapter 3 also revealed that the follower's inter-movement-intervals (IMI) increased in variability compared with those of the leads. However, for the variability of asynchrony (A) only trends were found. To explore this trend further and try to establish it on a more reliable statistical basis the bi-directionality of visual information exchange between two people has to be controlled. In addition, to examine whether variability is passed on from one person to the next, more than two, for example three or four persons' performance should be investigated. As the present study needs to control for the bi-directionality, the proposed multi-person paradigm limits the ensemble to a linear chain.

The proposed paradigm maintains the lead-follower relationship between individuals as introduced in Chapter 3. Two research aims were set. The first goal was to analyse whether an individual's timing variability may be carried over from one person to the next, due to feedback control. Secondly, integration of cross-modal timing cues was observed in the previous chapter, even when participants were explicitly asked to time their movements with only one cue. In the scenario of dance ensemble performances, dancers may not only time their movements to multi-modal external timing cues, but also to multiple cues within one modality. For instance, a dancer in a trio needs to time his or her movements with those of two other dance partners. Thus, the second aim of the current research was to examine how an individual integrates two separate external timing cues perceived unimodally.

4.1.1 Multi-Person Coordination

Research into multi-person coordination has begun to be more widely explored in the area of computer sciences and engineering, simulating interactive environments. For example, work by Ulicny and Thalmann (2002) introduced crowd behaviour simulation in time and space. The aim of their simulation was to introduce more variety in the currently rather scripted real-time computer games and virtual environments. By contrast, a surprisingly limited amount of research on multiperson timing has been conducted in the field of cognitive psychology.

Recently psychologists directed their attention towards exploring aspects of timing in music performances (Shaffer, 1984; Goebel & Palmer, 2009; Keller & Appel, 2010). Yet, research into music ensemble coordination has only explored solo or duet performances. For example, Goebel and Palmer (2009) investigated pianists' duet performances varying auditory feedback cues. Pianists' perceived either both parts, their own part, or one perceived their own part only whilst the other perceived both parts. Results showed less synchronous performance with decreased feedback cues. More interestingly, the less auditory feedback pianists perceived the more increased were their magnitude of their finger heights' above the piano keys and the more synchronous their head movements. The authors concluded that larger movement amplitudes were aimed to aid communication of the pianists timing to their duet partner. Considering the considerable amount of interest in music ensemble timing, it may be surprising that no research has yet investigated musicians timing between more than two ensemble members.

A further example of a real-life model of multi-person coordination was examined with multiple performers. Wing and Woodburn (1995) investigated timing between and within four rowers. The authors' idea was that rowers on each side of the boat work in a chain, from the back to the front. They examined performers' temporal dependencies between one another, using cross correlation analysis (see 4.2 method section). Cross correlation is an index of similarity between each rower's inter-stroke-intervals (similar to inter-movement-intervals). Surprisingly, results showed that in fact rowers integrated their peak correlation at lag zero, which suggested that they executed their stroke in synchrony with one another. Wing and Woodburn speculated that all rowers used the feedback information from the boat, rather than each correcting their current stroke on visual observation of the pre-ceding rowers previous stroke (which would have given a peak correlation of lag one). Nonetheless, these are speculations and it remains unclear how they achieved synchronous behaviour.

Unlike in Wing and Woodburn's (1995) study, the model that is proposed in this chapter controls for the amount of feedback perceived, emphasising visual feedback control. A lead-follower paradigm is adopted as in the previous chapter 3. Yet, similar to Wing and Woodburn's work, individuals perform in a chain in which they time their movements with those of a pre-ceding performer. Thus, they are expected to correct a current response on visual observation of the pre-ceding performers previous response time, which would result in peak correlation at lag one.

4.1.2 Sensory Integration of External Stimuli

In the case of dance, dancers' successful integration of visual (observing dance partners), auditory (music) and haptic (physical contact with dance partners) information is important for successful ensemble performances. Insights into how dancers' may integrate multiple sources of information come from research exploring how the central nervous system combines input of different modalities when interacting with objects in the environment (Violentyev, Shimojo & Shams, 2005; Guest & Spence, 2003). Several studies analysed how two sensory channels are integrated to achieve successful task performances. Two theories were proposed, one suggesting a winner-take-all integration, also often referred as 'Modality Precision' hypothesis (Welch & Warren, 1980) and another claiming a weighted integration of all sources (Bresciani, Dammeier & Ernst, 2006).

In respect to the former, the winner-take-all integration theory states that the most appropriate sensory channel for a given task dominates the less appropriate channels. For example in temporal judgement tasks, audition has shown to be more dominant and accurate than vision (Repp & Penel, 2002; Fujisaki & Nishida, 2005). The reverse was found for spatial judgement tasks, with vision being more precise in determining spatial information and thereby dominating audition (Bermant & Welch, 1976; Posner, Nissen & Klein, 1976). Support for this theory also comes from multisensory texture discrimination studies. Guest and Spence (2003) investigated the effect of visual-tactile integration on texture discrimination tasks. Participants were asked to discriminate the roughness of textures by focusing on only one sensory channel (visual or tactile) whilst perceiving a distracter of the opposite sensory channel. For visual assessment tasks participants' judgement was found to be modulated by information from the tactile channel. In contrast, tactile assessments have not been found to be influenced by visual information. The authors concluded that the more precise a source is the more its information may dominate in a given task.

Contradicting evidence comes from research into multi-modal integration in sensorimotor synchronisation (SMS). Kato and Konishi (2006), for example, investigated individuals' finger tapping in synchrony with a visual cue whilst observing an auditory distracter. Significant interference from the auditory distracter was observed in their timing performances. When the task roles were reversed; finger tapping in synchrony with an auditory cue whilst observing a visual distracter, also resulted in a bias towards the visual distracter however, of smaller magnitude compared with auditory distracters. In contrast to the winner-take-all integration theory each sensory channel may have been integrated in a weighted fashion. Weighted integration similar to the effects observed in Kato and Konishi's study were also observed in Chapter 3. Here, leaders' synchronisation with an auditory pacing signal was negatively affected by observing a visual rhythmic pacing cue. That is to say, a small bias towards the visual signal was found.

An increasing amount of evidence supports the theory of a weighted integration of all sensory sources. Johnston, Cumming and Landy (1994) showed that individuals combined motion and disparities of the image location signal when identifying the global shape of an object. The authors showed that integration occurred in a linear weighted fashion which has been modelled and referred as the Maximum Likelihood Estimate model (MLE). MLE aims to account for sensory integration in human behaviour and proposes that the central nervous system (CNS) weights sensory cues according to their statistical reliability (Ernst & Banks, 2002; van Beers, Sittig & Gon, 1999) to achieve an optimal estimate of the sensory information. The goal is an observable reduction in variance achieved through integration compared with the two or more individual estimates of each external source.

In SMS, research has explored whether multisensory cues enhance timing performances, testing the MLE model. Elliott, Wing and Welchman (2010b) asked their participants to synchronise their finger tapping with one or two external timing cues that varied in their reliability (audio, visual, tactile & audio-visual, audio-tactile and tactile-visual). Firstly, Elliott et al. compared participants' timing to one with two external cues and found an advantage of having two timing cues. More accurate tapping performances (smaller asynchronies) were evident for multisensory timing in contrast to unimodal timing. They then compared their behavioural data on multisensory integration with the data predicted by the MLE model. In general the behavioural data was consistent with the optimal use of the external signals, as predicted by the MLE model. However, the more unreliable one source compared to another source was, the less well the MLE model was able to account for participants' performances. The authors concluded that optimal integration of two sources may depend on a temporal window. Greater discrepancies between the timing of both signals may lead to a more independent processing therefore reducing optimal integration of two timing events.

Taken together, the present study explores how individuals integrate two external time cues that are perceived unimodally (visual). An integrator will be introduced at the end of two chains that are merging together. The task of the integrator is to combine both visually perceived rhythmical movements of the last person at the end of each chain.

4.1.3 Present Study

Previous literature that has been discussed introduced the idea of multi-person synchronisation within a chain (Wing & Woodburn, 1995) and the optimal integration of multisensory external timing cues (Elliott et al., 2010b). The present study aims to combine both ideas by introducing two linear groups passing timing information along a chain with one person at the end integrating the information of the two branches. Two research aims were set with the first aiming to analyse whether individual's timing variability may be carried over from one person to the next, using feedback control. A multi-person paradigm with six performers is developed. The lead-follower relationship between performers is maintained as previously introduced in Chapter 3. One individual is assigned the role of the lead, four the role of the follower and one the role of the integrator. The four followers are split into two chains, each consisting two followers.

One chain is placed on the left hand side of the lead, and the second chain is placed on the right hand side of the lead, each forming a half circle. In each chain of followers, the follower (follower 1) next to the lead synchronises his/her movements with those of the lead. The second follower (follower 2) who sits next to follower 1 synchronises his/her movements with those of follower 1. In line with findings in Chapter 3, an increase in followers compared with the lead's timing variability of asynchrony and inter-movement-intervals was expected.

In order to investigate the linkage between performers, cross-correlation analysis is used. A hierarchical structure in the temporal fluctuations between individuals' IMIs was predicted, as the directionality of the visual information flow is controlled. Fluctuations were expected to travelled across each chain of individuals; resulting in positive correlations at different lags. For example, follower 1 was predicted to be one interval behind leads' IMI (lag 1). This pattern was expected to continue across each chain.

Lastly, recent studies investigated multisensory integration in SMS. In the case of dance, performers' may time their movements with one or two dance partners with whom they are only visually linked (unimodal). Therefore, third aim was to investigate how individuals integrate two external timing cues perceived, focusing on visual feedback control. An integrator is introduced, closing the circle at the end of the two chains. Compared to the followers (Followers 1 and 2) who time their movements to one visual feedback cue, the integrator times his/ her movements to two visual feedback cues; one from follower 2 of the left chain and one from follower 2 of the right chain. It was predicted that the present results would support the MLE model. The integrator thereby was expected to optimally integrate both visual timing cues, leading to a reduction in timing variance compared with the predicted increase in variance (hypothesis 1) which was hypothesised when only one timing cue was provided. The currently introduced multi-person model is a lab model for dance formation.

4.2 Method

4.2.1 Participants

Six participants were recruited (N=6, all right handed) from staff and students at the University of Birmingham. Out of the six participants three were male and three were female (aged 30 – 40, mean 37.2 years). All participants provided informed consent, were naive to the purpose of the study and reported no neurological or auditory deficits.

4.2.2 Apparatus

Participants were seated on chairs arranged in a circle with participants facing outwards (Figure 4.1). The gap between chairs was 20 cm. Two 20 mm diameter spherical reflective markers were attached to each participant’s finger tips (left and right index finger tip) with double sided sticky tape. Two computers were used to run the study; one to present a metronome pulse to one performer, designated to the leads, and one to record the each participant’s kinematics. Metronome presentation was generated using the MatTAP toolbox (Elliott, Wing & Welchman, 2009) in Matlab (version 2009a; The Mathworks Inc., MA, USA) operating through a data acquisition device (USB-6229, National Instruments Inc., USA). Only the leads were listening to the auditory metronome via a headphone. The volume of the headphone was set to a level where other participants reported not to hear any sound. All other participants

wore soft ear plugs to further eliminate any external noise. Participants' movement kinematics were recorded at 200Hz using a twelve camera motion tracking system (Oqus, Gothenburg, Sweden).

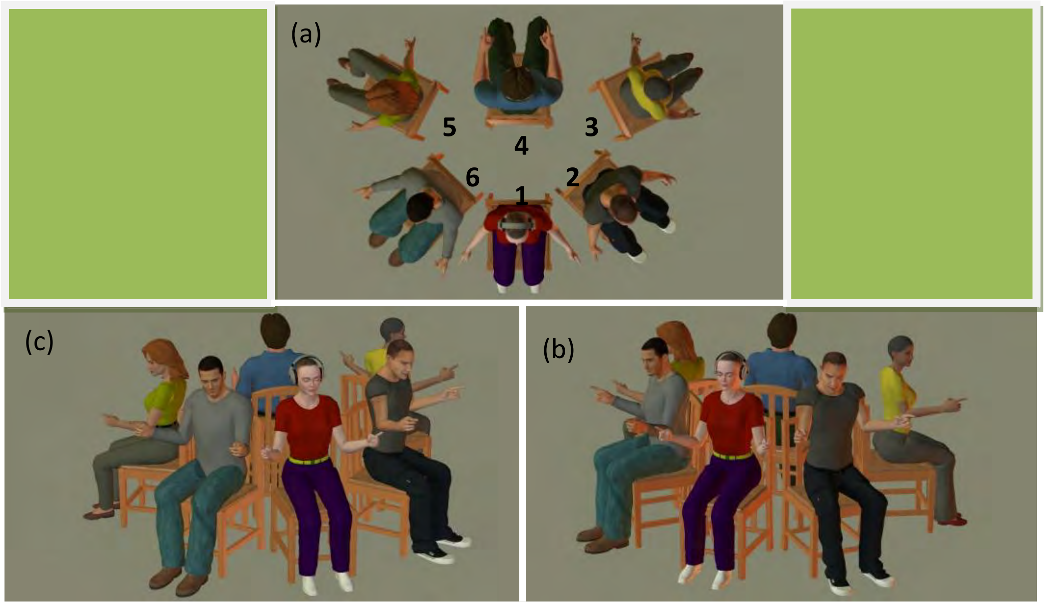


Figure 4.1***: Participants Seating Arrangements in the Circle*.** 1= Lead, 2=Left Follower 1, 3= Left Follower 2, 4= Integrator, 5= Right Follower 2, 6= Right Follower 1. (a) Top down, (b) right side and (c) left side view from lead's view. It should be noted that IT was slightly set into the circle, so IT could see 3 and 5 out of the corner of the eye.

4.2.3 Metronome Stimulus

The metronome stimuli followed a 2 x 2 experimental design with factors; *Trial Type* (F-S, S-F) and *Interval Duration* (500, 800 ms). Metronome trials consisted of one of the two *Trial Types*. *Trial Type* F-S (fast to slow interval), began with thirty metronome inter-onset-intervals (IOI) of 500 ms and continued with another thirty IOIs of 800 ms. In contrast, *Trial Type* S-F (slow to interval) started with twenty metronome IOIs of 800 ms and then continued with thirty IOIs of 500 ms.

Lastly, *Interval Duration* referred to the IOIs generated by the metronome. IOIs were on average either 500 ms or 800 ms with a spread of 5% around the mean IOI, for example an F-S trial could start with thirty IOIs of the interval duration of 510 ms followed by thirty IOIs of the interval duration of 790 ms. Similarly to Chapter3, IOI variations were randomly generated by Matlab and then hard coded into the MatTap toolbox to ensure that all pairs synchronised to exactly the same metronome IOIs. The variation of the IOI was intended to avoid anticipation by the leads and followers. Hereby, both leads and followers were required to actively pay attention to the target interval. Overall six F-S and six S-F *Trial Types* were generated, with a total of 12 metronome trials. Each metronome trial lasted around 40 seconds.

4.2.4 Procedure

Experimental testing was conducted in one session lasting 1.5 hours. At the beginning of the session participants were ask to fill in consent forms. The experimenter then demonstrated the oscillatory arm movement that participants were required to perform throughout the trials. Participants were asked to time their downwards movement with those performed by another person. After demonstrating that they could correctly perform the movement, the experimenter allocated the role each participant was designated to. In total there were three role; lead (LP), follower (of which there were four) and integrator (IT). The four followers consisted of Left Follower 1 (LF1), Left Follower 2 (LF2), Right Follower 1 (RF1) and Right Follower 2 (RF2) (see Figure 4.1). The four followers were split into two chains, each consisting two followers. One chain was placed on the left hand side of the lead, and the second chain was placed on the right hand side of the lead, each forming a half circle. LP was instructed to wear headphones and to time his/her downwards movements with the beat onsets of the metronome. In contrast, in each chain of followers, the follower (LF1, RF1) next to LP was required to synchronise his/her downwards movements with the downwards movements of LP's left or right hand. Similar, the second follower (LF2, RF2) who sat next to follower 1 synchronised his/her downwards movements with those of follower 1's left or right hand. Closing the circle, at the end of each chain sat the integrator. Compared to the followers who timed their movements to one visual feedback cue, the integrator timed his/her bimanual downwards movements to two visual feedback cues; the downwards movements of LF2's left hand and the downwards movements of RF2's right hand.

In total there were six testing blocks, each containing twelve trials. Each testing block differed in the role a participant was allocated to. Thus, each participant performed each of the six roles. For example person 1 performed the role of LP in block 1, RF2 in block 2, IT in block 3, LF1 in block 4, LF2 in block 5 and RF1 in block 6. The order of the roles was randomized for each of the six participants. Each block consisted of the twenty metronome trials (10 F-S, 10 S-F) previously introduced in the metronome stimulus section above, in a counterbalanced order. Each block lasted around 12 minutes with the overall session lasting around 1.5 hours excluding the break given after block 3.

4.2.5 Analysis

4.2.5.1 Kinematics

Participants' raw data were extracted from the motion files. The vertical axis of each participant's right and left index finger was selected for further analysis. Further analyses, except for the statistics were conducted in MATLAB. Each participant's trajectory data was digitally low-pass filtered at 1Hz (dual pass 8^{th} – order Butterworth filter). For each downwards movement of the oscillatory arm movement one peak detection algorithms was used to determine the lowest vertical value of the participants' index finger trajectory. In each trial a total of 60 minimum values (30 for short and 30 for long interval durations) were identified for each participants' left and right finger.

Four measures were derived; inter-movement-interval (IMI), variability of IMI (sdIMI), asynchrony (A) and the variability of A (sdA). IMIs were estimated by measuring the time duration between each participant's two successive downwards movements. This was performed for long and short interval durations within each trial, in separate. As a period change was introduced, the first three IMIs were excluded to avoid outliers. The overall mean value (IMI) and the mean standard deviation of the IMIs for short and long intervals were used for statistical analysis. As the focus of the present study is on visually mediated information, A was calculated relative to the downwards movements of the person with whom the participant was asked to time his/her movements. Thus, LF1's right finger data were aligned in time with LP's left finger data. LF2's left finger data were aligned with LP's right finger data. Similarly, LF2's right finger data was aligned to LF1's left finger, RF2's left finger data was aligned to RF1's right finger, IT's right finger was aligned to LF2's left finger and IT's left finger was aligned to RF2's right finger data. The first three asynchronies of each interval period were excluded, eliminating potential outliers introduced by period changes. The overall mean value (A) and the mean standard deviation of the As (sdA) for short and long intervals were used for statistical analysis. Statistical analysis was conducted in SPSS 18.

The dependent measure A and sdA were separately analysed with a 6 x 2 x 2 repeated measures ANOVA with the within-subject factors of *Participants' Role* (left side of the circle: LF1, LF2, ITr (IT right finger), right side of the circle: RF1, RF2, ITl (IT left finger)), *Trial Type* (F-S, S-F) and *Interval Duration* (500, 800 ms). With minor discrepancies in the levels of *Participants' Role* (LP, LF1, RF1, LF2, RF2, IT) IMIs and sdIMI were also separately analysed with a 6 x 2 x 2 repeated measures ANOVA. Non-significant results (p>.05) were not discussed and Greenhouse-Geisser corrections were made for sphericity violations where necessary. Post-hoc comparisons were performed using the Bonferroni t-test (Howell, 2002).

Cross correlations were calculated to examine the relationship between two individuals' IMIs. Cross correlation coefficient is a measure of statistical similarity between the IMI of for instance LP and the corresponding IMI of LF1 (further details please see chapter 3, section 3.3.5). This was calculated and averaged separately for the first and second phase of F-S and S-F. Peak correlations and their belonging lag values were identified. Correlations were examined by a two-way repeated measure ANOVA with factor condition (F-S, S-F) and (500, 800 ms). This was conducted for all visually mediated timing performances (LF1, LF2, IT, RF1, RF2).

Post-perturbation recovery analysis investigated how long it took for the followers to adjust their timing with those of their leads after period change. Here leads' IMIs from the start of the period change were compared with those of the followers. Followers' recovery was estimated by determining the first IMI value that was within 1, 5 standard deviation of the followers new target interval performance. Each second phase of F-S and S-F were used for this analysis (total 76 trials). Once recovery positions were identified, a 6 x 2 repeated measures ANOVA with factor condition (LP, LF1, LF2, RF1, RF2, IT) and (500, 800 ms) was conducted to examine if *Participants' Role* and *Interval Duration* affected followers' performances.

Lastly, to ensure that the ITs combined their timing with both external cues asynchronies of their bimanual performance was estimated (BiM). BiM asynchronies were compared with asynchronies relative to each external source (ITr-LF2, ITl-RF2). Statistical analysis was performed on A and sdA, conducting two separate three-way repeated measures with the factors *Synchronisation Cue* (BiM LF2, RF2), *Trial Type* (F-S, S-F) and *Interval Duration* (500, 800 ms).

4.3 Results

In the following section, the first analyses were conducted on the mean and variability of the asynchrony and inter-movement-intervals for all participants' roles combined. Analyses were performed to investigate whether follower' timing performances (A, sdA, IMI, sdIMI) decreased relative to their leads. Then, cross-correlations between leads' and followers' IMIs are reported, followed by post-perturbation recovery analysis. Lastly, the integrators' bimanual performances were compared with their synchronisation to the two external cues (LF2, RF2)

4.3.1 ANOVAs for Group

4.3.1.1 Mean Asynchrony (A)

The average group asynchrony showed negativity with -11.9 ms. The mean As for each role are illustrated in table 4.1. No significant main effects or interactions were found ($p>.05$).

4.3.1.2. Standard Deviation of Asynchrony (sdA)

Mean variability of asynchrony is a measure of participants' consistency in their synchronisation performance. The greater the sdA, the more dispersion is there from the mean A and the less consistent is participants' synchronisation performance. The overall mean sdA was 32.9 ms and the 6 x 2 x 2 repeated measures ANOVA revealed a main effect of *Participants' Role* ($F(5,25)= 23.195$, $p<.01$, $\eta_p^2 =.823$), illustrated in Figure 4.2. Post-hoc pairwise comparisons showed significant differences between ITrs' sdA (49.9 ms) in comparison with those performed by LF1s (21.9 ms; $p<.025$), LF2s (26.9 ms; $p<.025$), RF1s (22.8 ms; $p<.05$) and RF2s (29.2 ms; $p<.025$). Similar, significant differences between ITls' sdA (46.9 ms) in comparison with those performed by LF1s ($p<.025$), LF2s ($p<.025$), RF1s ($p<.025$) and RF2s ($p<.025$) were found to be significant. Overall, the integrators' sdA were significantly larger compared with all other performers. A further significant difference was found between LF1s (21.9 ms) and LF2s (26.9 ms) (p<.025). The variability of asynchrony was significantly smaller for LF1s compared to their followers LF2. However, the difference between RF1s (22.8 ms) and their followers RF2 (29.2 ms) failed to reach significance (p=.06). No differences between ITrs and ITls were observed. In summary, significant increases in sdA were observed between leads and followers, with only one exception of the lead-follower relationship between RF1s and RF2s.

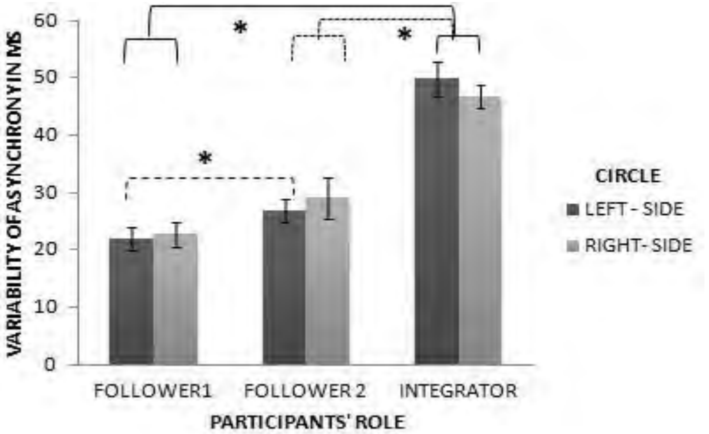


Figure 4.2: ***Mean deviation from the average synchronisation error (A)*** for each participant's role (N=6). * indicates significance differences for post-hoc comparison. Error bars represent the standard errors of the means.

4.3.1.3 Mean Inter-Movement-Interval (IMI)

To examine the accuracy of the reproduced interval with the target interval, separate two-way repeated measures were conducted for the short (500 ms) and long (800 ms) interval duration. The repeated measures ANOVA for short intervals resulted in an overall mean IMI of 499.4 ms. Here, the main effect of *Participants Role* was significant (F (5,25)= 4.522, p<.025, η_p^2 =.475) and post-hoc pairwise comparisons revealed a significant difference between the LPs (498 ms) and ITs (502.7 ms) (p<.05). LPs' IMIs were on average slightly shorter compared with ITs' IMIs. The repeated measures ANOVA for long intervals resulted in an overall mean IMI of 798.7 ms. No significant differences between *Participants' Roles* and *Trial Types* were found. Overall, regardless of the role of each participant, the target intervals were accurately reproduced.

4.3.1.4 Standard Deviation of Inter-Movement-Interval (sdIMI)

The average sdIMI reveals participants consistency of their IMI performance. The overall sdIMI resulted in 30.8 ms. A 6 x 2 x 2 repeated measures exposed two significant main effects, one for *Interval Duration* (F(1,5)= 40.195, p<.01, η_p^2 =.889) and one for *Participants Role* (F(5,25)= 19.865, p<.01, η_p^2 =.799). The effect of *Interval Duration* was due to smaller variability for short interval durations (24.2 ms) compared with long interval durations (37.4 ms). As illustrated in Figure 4.3 a rather linear increase in variability was observed from the LPs to Followers 2 (LF2 and RF2). Two separate post-hoc comparisons for short and long interval durations showed that the variability of the leads was significantly smaller compared to all other roles (p<.025). The second smallest variability was observed for Followers 1 (LF1 and RF1) which was significantly smaller compared to Followers 2 (LF2 and RF2) and the Integrators (p<.025). Greatest variability was observed by Followers 2 and Integrators, however significant difference between both roles was not found (p>.05). Overall, increases in sdIMIs were found along each chain (left and right) of individuals.

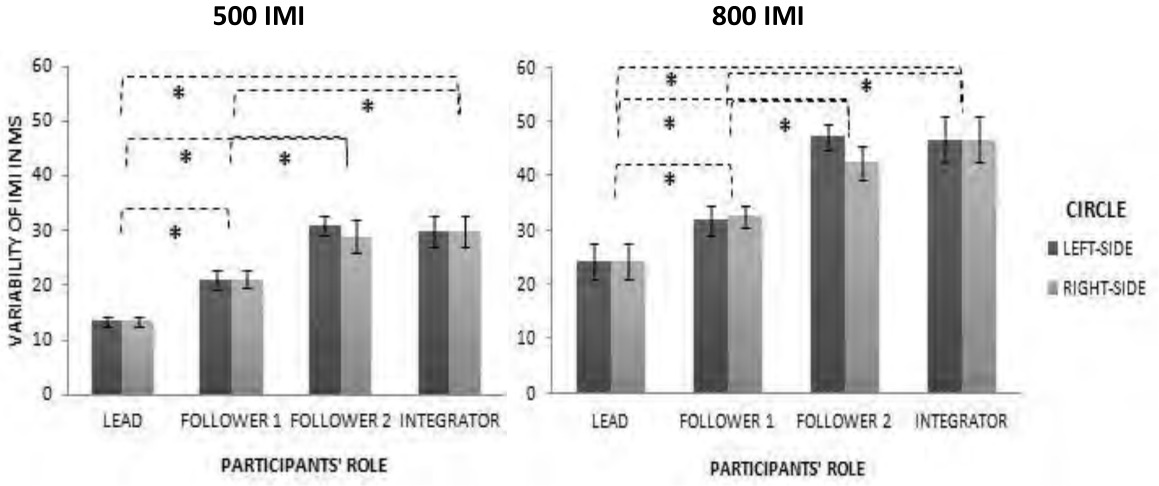


Figure 4.3: ***Mean deviation from the average IMI*** for each participant's role (N=6). Top left graph presents results for 500 ms and top right graph 800 ms target intervals.* indicates significance differences for post-hoc comparison. Error bars represent the standard errors of the means.

4.3.2 Cross Correlation Analysis

Cross correlations were used to examine the relationship between the IMIs of a given leads and followers. Figure 4.4 illustrates an example trial (F-S) of IMI performances for members on the left side of the chain. Visual observation of the graph below suggests a dependency between each member of the chain. This is highlighted by the period change adjustment from fast to slow. LP (red) introduced the new period, LF1 (blue) correct his or her period with a slight overshoot one interval after LP. LF2 (pink) corrected his or her performances one interval behind LF1 and IT (brown) corrected with a large overshoot his or her timing one interval behind LF2.

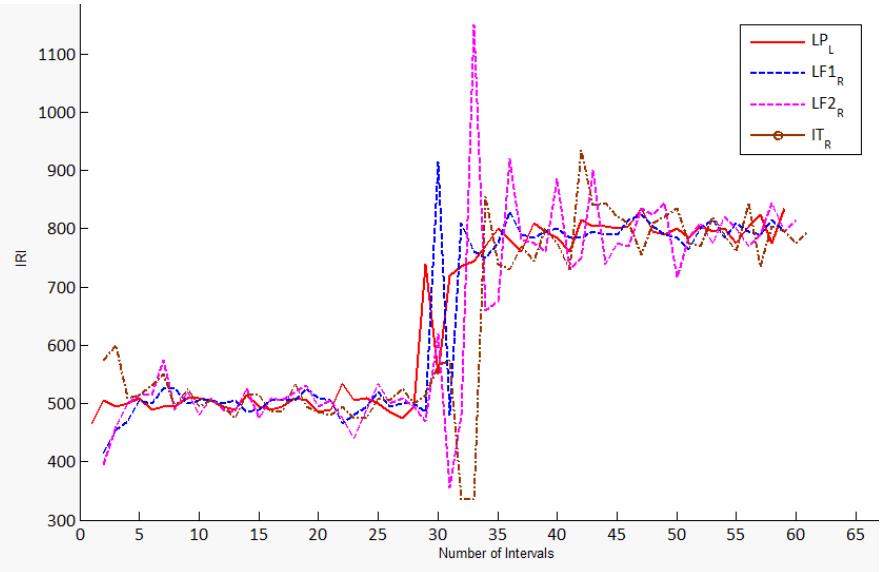


Figure 4.4: ***Illustration of IMI trajectory for F-S trial.*** In total 60 IMI for each member of the left side of the circle are presented.

The largest (positive) cross correlations between the IMIs of the leads and LF1s and between the leads and RF1s were found at Lag +1 (see Figure 4. 5). Two separate repeated measure ANOVA with factor condition (F-S, S-F) and (500, 800 ms) was conducted, comparing cross correlations at Lag +1. No differences were found between conditions.

The largest (positive) cross correlations between the IMIs of LF1s and LF2s and between RF1s and RF2s were found at Lag 0 (see Figure 4. 4). Two separate repeated measures ANOVA were conducted, comparing cross correlations at Lag 0. Again, no differences were found between conditions. Smaller positive cross correlations were also found for (Lag -1 and Lag +1).

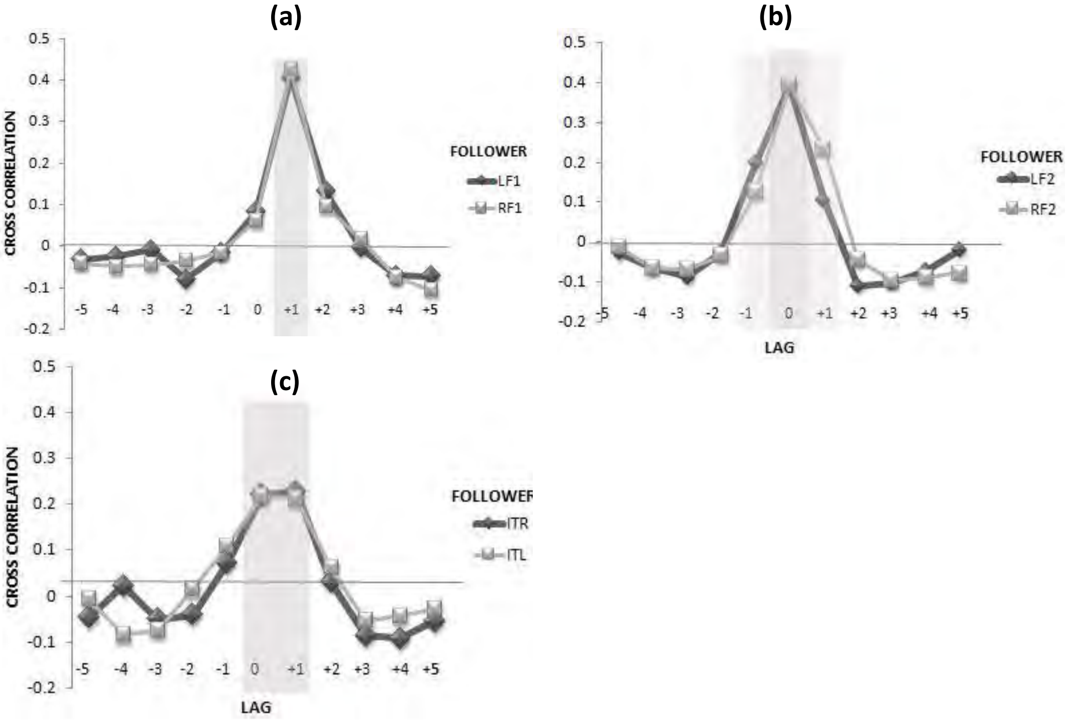


Figure 4.5: ***Cross Correlations*** between the IMIs of the lead and follower. Lag (0) indicates cross correlations between the current IMIs of lead and follower, whereas Lag (+1) shows correlation between followers' IMIs with the previous leaders' IMIs (Lag -1), with the next leaders' IMIs. (a) Shows Follower 1 with Lead, (b) Follower 2 with Follower 1 and (c) Integrator with Follower 2.

Lastly, between the IMIs of LF2s and ITrs and between RF2s and ITls largest (positive) cross correlations were found at Lag 0 and Lag +1 (see Figure 4. 4). Four separate repeated measures ANOVA were conducted, one each for Lag 0 and one each for Lag +1. Only for Lag 0, repeated measures ANOVA revealed for both (ITrs and ITls) a significant main effect of *Trial Type* (ITrs (F (1,5)= 17.207, $p<.01$, η_p^2 =.775); ITls (F (1,5)= 21.786, $p<.025$, η_p^2 =.813)). For both ITrs and ITls larger positive cross correlations were observed for S-F (r=.28, .26) compared with F-S (r=.15, .18).

4.3.3 Post-Perturbation Recovery

To examine how fast participants' adjusted their timing to the new interval duration, a post-perturbation recovery analysis was performed. A two way repeated measures ANOVA was conducted on the number of moves to attain a new stable IMI phase. Results revealed no significant differences between *Participants' Role* and *Interval Duration*. On average participants' were found to recover three IMIs after the intervals was introduced.

4.3.4 Bimanual Timing of the Integrator

To ensure that ITs integrated their performance bimanually, ITs' timing between their left and right hands were examined and compared with each hands timing relative to the designated visual timing cue (ITr-LF2, ITl-RF2). The present measure was conducted on the mean and variability of asynchronies. Separate three-way repeated measure with factors *Synchronisation Cue* (BiM (bimanual), LF2, RF2), *Trial Type* (F-S, S-F) and *Interval Duration* (500, 800 ms) were performed to compare mean and variability of asynchronies. The overall mean A was -6.2 ms and sdA was 34.4 ms. The repeated measures ANOVA of A, showed no significant differences between the conditions. In contrast, the repeated measures ANOVA for sdA exposed a significant main effect of *Synchronisation Cue* ($F(2,10)= 186.117$, $p<.01$, $\eta_p^2 =.974$). Post-hoc pairwise comparisons revealed a significant difference between BiM and LF2s, RF2s. Here, BiM resulted in significant smaller sdA (6.3 ms) compared with LF2s (49.9 ms) and RF2s (46.9 ms) (See Figure 4.6).

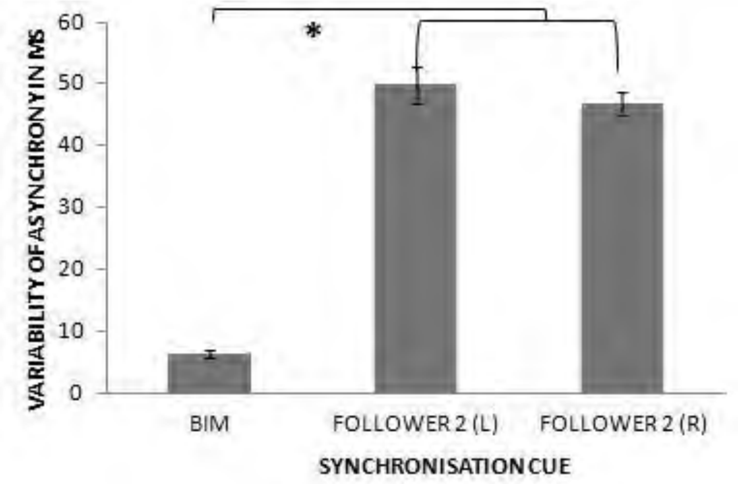
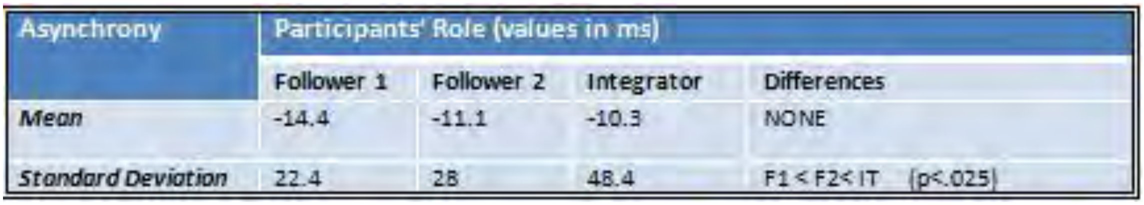


Figure 4.6: ***Integrators' sdA.*** Asynchrony relative to LF2, RF2 and Bimanual synchronisation.*indicates significance differences for post-hoc comparison. Error bars represent the standard errors of the means.

4.3.5 Summary

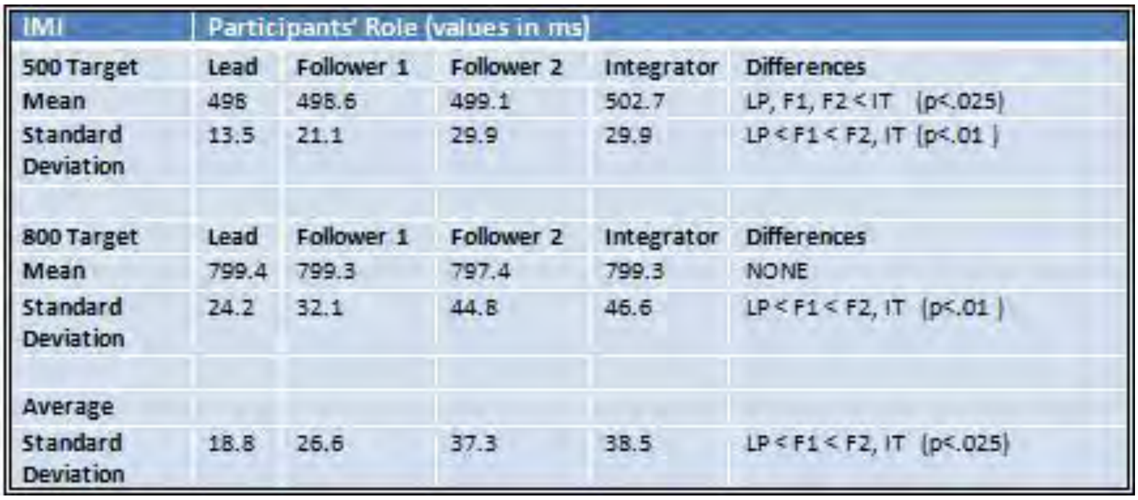
Taken together, an increase in the variability of asynchrony (sdA) relative from one person to the next and an increase in the variability of the inter-movement-intervals (sdIMI) were observed, with the Integrators (IT) as an exception (see table 4.1 and 4.2).

Table 4.1: ***Asynchrony of Followers and Integrator.*** Mean and standard deviation are shown. Statistical differences between members are presented in the last column.



Asynchrony	Participants' Role (values in ms)			
	Follower 1	Follower 2	Integrator	Differences
Mean	-14.4	-11.1	-10.3	NONE
Standard Deviation	22.4	28	48.4	F1 < F2< IT (p<.025)

Table 4.2: ***Inter-Movement-Intervals of Lead, Follower and Integrator.*** Mean and standard deviation for 500 and 800 target intervals are shown. Statistical differences between members are presented in the last column.



IMI	Participants' Role (values in ms)				
500 Target	Lead	Follower 1	Follower 2	Integrator	Differences
Mean	498	498.6	499.1	502.7	LP, F1, F2 < IT (p<.025)
Standard Deviation	13.5	21.1	29.9	29.9	LP < F1 < F2, IT (p<.01)
800 Target	Lead	Follower 1	Follower 2	Integrator	Differences
Mean	799.4	799.3	797.4	799.3	NONE
Standard Deviation	24.2	32.1	44.8	46.6	LP < F1 < F2, IT (p<.01)
Average					
Standard Deviation	18.8	26.6	37.3	38.5	LP < F1 < F2, IT (p<.025)

In respect to IITs' performances, larger variability was observed for A compared with IMI. Bimanual measures indicated that ITs integrated both visual external sources into one response time, as close synchronous timing between their left and right hands was observed. Lastly, a hierarchical ordering of dependencies between members within the circle was found.

4.4 Discussion

The present chapter introduced a new paradigm for the analysis of fluctuations in response timing of multiple performers relative to an external visual source of feedback. Participants were aligned into two linear groups passing timing information along a chain with one person at the end integrating the information of the two branches. Two research aims were set. The first aim was to research whether individual’s timing variability may be carried over from one person to the next, using feedback control. In line with trends reported in Chapter 3, it was predicted that performers’ timing variability would increase along each chain of participants. The second aim was to investigate how individuals integrate two external timing cues perceived via one sensory channel (unimodal). According to the Maximum Likelihood Estimation model (MLE), two external timing cues may be integrated in a weighted fashion to achieve a reduction in the variance of produced response timing (Ernst & Banks, 2002). Therefore, it was hypothesised that the integrator optimally combines both visual cues. Optimal integration would be reflected in a reduction of the integrators’ response time variance, in comparison with the estimated response time variance for each individual timing cue.

4.4.1 The Accumulation of Variability Effect

With regards to the first research aim, individual’s timing variability was predicted to increase from one person to the next. Evidence for an increase in variability was provided by the measures of variability in asynchrony (sdA) and inter-movement-intervals (sdIMI). With respect to the latter, results of sdIMI showed a significant increase from one person to the next across the chain of individuals. LPs (lead) sdIMI (13.5 ms) were significantly smaller compared with those of Followers 1 (average of 21.1 ms). Similarly, Followers 1’s sdIMIs were significantly smaller than Followers 2’s sdIMIs (average of 29.9 ms). No differences between sdIMIs of Followers 2 and Integrators were observed. This will be further explained section 4.4.2.

In line with the findings observed in sdIMI, sdA showed a complementary pattern of results. Followers 1's sdA (22.6 ms) were smaller compared with Followers 2's sdA (28.1 ms) and Followers 2's sdA were significantly smaller in respect to the Integrators (48.2 ms). However, this effect was only marginally significant for RF1s and RF2s. The lack of significance on the right hand side of the chain may have been caused by participants timing their non-dominant hand (left hand) with the external timing cue. The non-dominant hand may have produced more variance compared with the dominant hand. Support comes from several research studies that investigated bimanual timing in sensorimotor synchronisation (Helmuth & Ivry, 1996; Drewing & Aschersleben, 2003). Drewing, Stenneken, Cole, Prinz and Aschersleben (2004), for example examined bimanual advantage in a finger tapping paradigm. Their findings showed that participants' finger tapping was more regular for the dominant hand when participants performed bimanual compared with unimanual finger tapping. Therefore, it may be more appropriate for the measure of relative asynchrony to align followers' right hand instead of their left hand with those of their leads' right hand. Additional analysis (not reported here), confirmed this suggestion, as significant differences between RF1s and RF2s were found when the dominant right was selected for the measure of sdA for participants on the right side of the chain.

Taken together, the increase in variability of response time from one person to the next was observed. One person reproduced a target interval and adds his or her own noise on the top of this interval. This time information including the noise is then passed over to the next individual. Support comes from the field of psychology. For example, Elliott et al. (2010) asked participants to time their finger tapping with a variable metronome. Participants response time variability increased with an increase of variability perceived in the external pacing signal. Hereby, participants may have integrated or carried over the perceived variability of the external cue in their own response timing. Participants' variability was slightly larger than the variability of the timing signal. This is in line with present findings in which followers were found to perform larger sdA and sdIMI compared with the variance in the time cue. Reasons for the significant increase in sdA and sdIMI might be that participants found it difficult to track and with that estimate the variable moving timing cue. Another reason might have been that participants add their own motor noise on the top of the estimated perceived variability of the timing cue.

Lastly, within the circle a hierarchical structure in the temporal fluctuations between individuals' IMIs was predicted. The linkage between performers came from the rhythmical visual information of their designated leads. This would result in positively correlations between the leads and followers. As temporal fluctuations travelled across a chain of individuals, correlations at different lags were expected. For example, Follower 1 is behind Lead's IMIs (lag 1) and Follower 2 is behind Follower 1's IMIs (lag 2 in respect to the lead) and so forth.

The measure of cross-correlation revealed a hierarchical structure by estimating the linkage between members of each chain. Positive correlations were found for each lead-follower pair within each chain. Followers 1 were positively correlated with leads' IMI at lag +1. A positive lag 1 correlation indicates that the followers timed their IMI with the observed preceding IMI of the leads, one interval behind. This delay in response time may not be surprising as the followers' task was to follow the timing of the leads, based on feedback control. In contrast, Followers 2 were positively correlated with Followers 1's IMIs at lag 0, suggesting simultaneous timing. For example, if Followers 1 produced a longer IMI than the expected average, then the corresponding

IMI of the Followers 2 would also have been longer than the average. In reverse, if Followers 1 produced a shorter IMI than the expected average would have imitated a reduced IMI of Followers 2. The observed lag 0 correlations were rather surprising. One explanation may be that the Followers 2 were able to perceive rhythmical visual feedback cues of the leads in the periphery of their vision. Followers 2's integration of Followers 1's timing cue may have resulted in the lag 0 correlation. Thus, Followers 2 and 1 timed their IMIs with those of the leads at lag +1.

Positive, yet weaker correlations in respect to Followers 1 and 2 were observed between the Integrators and Followers 2 at lag 0 and 1. The lag 1 correlation is consistent with Followers 1's lag correlation, whereas the lag 0 correlation is consistent with Followers 2. Here the only similarity between Followers 2 and the Integrators were that both may have perceived more than one pacing signal. It might have been that in some trials the Integrators were able to anticipate the corresponding IMI of both pacing cues, suggesting a potential advantage of perceiving two compared to one external time source. On the other hand in other trials, the Integrators were unable to effectively predict the upcoming IMI produced by the two pacing signals, resulting in a lag 1 correlation. There are various reasons why the Integrators on some occasions may have been able to anticipate the IMI of the two pacing cues. For example, both timing cues of the Integrators have a common source (LP), yet as they travelled across separate chains, temporal discrepancies may have emerged. Consider, that throughout short sections within each trial one source (e.g. LF2) may have been slightly ahead of their timing compared with the second source (RF2). The Integrators then could have integrated the earlier perceived temporal information by LF2s and adjusted his or her response accordingly. Consequently, this could have led to a lag 0 correlation with RF2s.

Overall, a hierarchical structure in the temporal fluctuations between individuals' IMIs was observed. Followers 1 and 2 were one and the Integrators one to two intervals behind those of their leads.

4.4.2 Sensory Integration of the Integrator

The second aim was to investigate how individuals integrate two external timing cues perceived via one unimodal sensory channel. According to the Maximum Likelihood Estimation model (MLE), two external timing cues may be integrated in a weighted fashion to achieve a reduction in the variance of produced response timing (Ernst & Banks, 2002). It was hypothesised that the integrators reduced their response time variance compared with the estimates of each perceived individual timing sources.

Results for the integrators' performances of the present study appear somewhat contradictory. The measure of sdA showed a large increase in integrators' response time variance (48 ms) compared with the variance that may be have been performed with the two sources individually (estimated at 30 to 35 ms, based on the 5ms increase in sdA between LF1s and LF2s). This result suggests a failure to integrate the two sources of timing information. In contrast, the results of sdIMI indicated a successful integration of the two timing sources, as no increase in sdIMI was observed compared with the actual sdIMI of Followers 2.

One possible explanation for the apparently contradictory findings concerning integration comes from models of movement synchronisation that suggest that timing of movements is controlled by first-order linear phase correction (Vorberg & Wing, 1996).

Linear first- order corrections predicts that individual's next response is timed relative to the perceived error between the previous onset and the previous goal (i.e. auditory pacing signal) (see Chapter 2 for details). In SMS it has been suggested that individuals goal is to minimise asynchrony variability. Vorberg and Schulz, (2002) illustrated in their study that minimising sdA resulted in an increase in the variability of IRI (equivalent to IMI). Comparing the present results with Vorberg and Schulz's findings, the integrators goal may not have been to minimize their sdA relative to both external timing cues. Instead the integrators adjusted their internal timer to the average interval perceived by each individual time cue. Thus, the integrators' strategy may have been to minimize the variability of IMI to maintain in time with both external timing cues.

The fact that both external signals were spatially apart from one another may support the former interpretation. The MLE model suggests that large discrepancies, (which may also include spatial discrepancies in unimodal conditions) between external signals decrease the optimal integration of two timing sources. Due to the spatial distance between the two sources, simultaneous tracking may have been rather difficult. The spatial separation may have required focal attending (Jones & Boltz, 1989); a constant switch of visual focus between the two cues. Shifting focal attending may have resulted in the failure of the integrators combining both visual cues simultaneously. To avoid such failure, the integrators may have tracked both visual cues within the periphery of their visual field. However, peripheral tracking would make it hard to track the exact onsets of each cue, increasing the sdA relative to both visual timing cues.

Difficulties in tracking discrete time onsets have been found to reduce response time performances. Evidence comes from research by Elliott, Welchman and Wing (2009) who examined SMS with different finger tapping actions. In their study participants performed either discrete or continuous finger tapping with an auditory pacing signal. Results showed an increase in the variability of asynchrony when performing continuous compared with discrete finger tapping. The authors concluded that participants were unable to estimate the error between the pacing cue and the response, due to the lack of tracking an on or offset when performing a continuous movement. Similarly, integrators in the present study may have been unable to track the onsets of each external time cue which led to the increase in sdA.

To conform to the task demands, integrators had to adopt a strategy that aimed to minimise sdIMI. The integrators may have internalised the target interval, provided by the external cues. Once internalised, the process of 'prioritised integrative attention' may have taken place (Keller, 2001) in which priority was given to one's own consistent time performance, whereas less attention may have been given to the timing of both external cues. Prioritised integrative attention would have enhanced consistent performance within the integrators whilst being able to detect larger interval changes in the two pacing cues. The former was necessary in order to re-adjust to the new interval after a period change.

4.4.3 Summary

The present study introduced a circle paradigm to investigate linkage between multiple performers, based on visual feedback control. Two research aims were investigated. The first aim was to research whether individual's timing variability may be carried over from one person to the next, using feedback control. The second aim investigated how individuals integrate two external timing cues perceived via one sensory channel.

Clearly, results showed an increase in timing variability from one person to the next across each chain of individuals. The effect observed was referred as an accumulation effect in which an individual integrated the perceived variability in their own performance and added his/her own noise on the top (e.g. motor noise). This consequently resulted in an increase in response time variability. Such variability may increase linearly across a chain of individuals.

Measures of cross-correlations revealed a hierarchical structure of the dependencies between each member within the circle that arose from the paradigm applied. The directionality of the visual information flow controlled the linkage between members. On average followers were one interval behind of the leads' interval, with one exception of the Followers 2 which may have been caused by a lack of visual feedback control. Future research is required to confirm present results of the observed hierarchical structure. Increased experimental control may be achieved by introducing visual displays. Here, one individual may time his or her movement with recordings of his or her own previously performed movement presented on a visual display screen. This could simulate an indefinite amount of individuals within a chain, thereby providing a large data set that may be used for modelling ensemble timing, emphasising feedback control.

Lastly, individuals' integration of two visual timing signals resulted in an increase in variability of asynchrony, however in a decrease of variability in inter-movement-intervals. It was concluded that individuals adopted a process of prioritised integrative attention in which they focus on maintaining a consistent overall performance that on average matched the target interval of their external time cues. In contrast, less attention was given to reducing the asynchrony relative to both external timing cues. This method was potentially the most effective one as the two perceived visual cues were spatially too far apart from one another.

In summary, the present study introduced a paradigm that could be used to investigate timing in ensemble performances. The circle paradigm may also be of interest to social psychologist analysing how social factors may influence timing performances within an ensemble. Insight into how low level (feedback control) and high level factors (cognitive) affect multi-persons timing could provide a more in depth understanding of real-life ensemble dynamics.

Chapter 5: Expert Dancers' Synchronised Timing:

The Importance of Visual and Sensorimotor Familiarity

5.1. Introduction

Previous chapters examined how people use visual feedback control to synchronise their oscillatory arm movements with those of another person. Individual's synchronisation of rhythmical movements with those produced by another person showed strong dependencies between the movement timings of both individuals. In Chapter 4, when individuals were asked to synchronise with two compared to one person's rhythmical movements, strong linkages between the individual and the two visual feedback cues were found. So far, interpersonal synchronisation has been investigated using non-expert dancers. The present chapter moves the focus onto expert ballet dancers' synchronisation. Expert dancers' timing with another dancer was examined in the context of movement familiarity of dance poses.

Dancers' ability to synchronise their movements with another dancer is essential for successful ensemble performance. Synchronisation in dance requires keeping in time with the movements of other dance partners. For example, two dancers may start and finish a dance movement at the same time. Keeping together in time demands dancers to coordinate their movements to events that can be observed in another dancer's movement execution. Those events may be defined in terms of dance poses in space or dynamic cues derived from the velocity profile in moving to or from those poses.

Three research aims were set for the present chapter. The first aim was to provide quantitative data on expert dancers' timing performance, using visual feedback cues. The second aim was to examine how dancers time their movements to various alternative events within the visually perceived movements performed by another dancer. And lastly, the third aim was to investigate whether dancers' familiarity with dance poses contributes to their synchronisation skills. Within the present experiment,, dancers time their movements with familiar dance poses that are part of their own dance repertoire and with less familiar dance poses that are not part of their own repertoire. In order to achieve these three aims, low performance variability in dancers' timing is desired to reveal dancers timing variability produced by their own motor system. Studies in the two preceding chapters represent a progressive increase in experimental control but at the same time increasing validity in terms of dance material. In Chapter 1, the auditory cues controlled the mean rate of timing; however the lead's variability was partly influenced by the follower and hence not fully controlled by the experimenter. In experiment 2, the lead was more controlled as the visual feedback of the follower was withdrawn. Nonetheless, the lead introduced his or her variability. Therefore, in the present experiment the nature of the lead's variability is controlled by introducing a virtual lead person. The virtual lead introduces temporal perturbation, an increase or decrease in interval durations. The variability of the lead's performance is held constant, close to zero throughout the experiment.

An overview of previous research into dancers' timing performance is presented, followed by a discussion of potential features within visual cues that may assist dancers timing, based on research examining musicians' timing with conductors. Next, expert dancers' enhanced sensorimotor skills are compared to non-dancers, finishing with a summary of the current study.

5.1.1 Timing in Dance

Relatively few studies explored timing in individual and ensemble dance performances. For individuals timing performances, research by Bathalha and Macara (2007) compared the rhythm capacity and synchrony between professional dancers and dance students, using a set of questionnaires. They found that dancers' perception of rhythmic factors such as the organisation of time in performance was better when performing familiar compared to unfamiliar movements. However, as noted in chapter 1, using questionnaires to study timing in dance is subjective and, though useful as a starting point for insights into what dancers aim to achieve in dancing, it fails to provide data on the accuracy of dancers' movement timing.

Research that applied a quantitative measurement was conducted by Minvielle–Moncla, Audiffren, Macar and Vallet (2008). They were interested in how interference of attention to time affects dancers timing abilities. Dancers had to learn reference duration whilst walking which then had to be retained and transferred to different walking distances. Findings showed that during the transfer task, more accurate timing of the reference duration was achieved when dancers travelled longer compared to a shorter distances. The authors concluded that spatial contraction is therefore more costly in attention of time than spatial extension, as potentially less attention could be directed to time. Furthermore, dancers were asked to perform improvised walking as an additional transfer task. The results showed an increase in time variability for improvised walking compared with all other transfer tasks. Minvielle–Moncla et al. suggested that improvisation required dancers to be creative and creativity has often been associated with demanding attention. Thus, they concluded that improvisation required more attentional resources reducing the amount of attention given to the timing factor (For further details see chapter 1).

In traditional dance training, dancers rehearse their dance movements in time with music. To investigate how well dancers were able to internalise the timing of rehearsed performances, Stevens, Schubert, Wang, Kroos and Halovic (2009) asked contemporary dancers to perform a piece of choreography in an ensemble with and without music. Their analysis consisted of scaling and lapsing as an indicator of time keeping. Scaling refers to slowing down or speeding up within a given section of a dance piece and lapsing refers to an omission or insertion of a movement. Overall, dancers reproduced their choreography without music faster than with music. Timing errors without music were attributed to the omission (lapsing) of movements and not to timing errors per se. The authors therefore suggested that dancers' attuned internal clock may be the felt time between dancers moving together in time without music. However, there was no attempt to characterise timing relations between dancers in the ensemble.

A first step into exploring multi-person synchronisation in dance was made by Maduell and Wing (2007). They conducted their research was based on the case of flamenco dance, bridging the gap between solo and group performances. An observational approach to ensemble coordination was provided, introducing a theoretical control structure between ensemble members. However, as previously noted in Chapter 1, they did not provide quantitative data to support their proposed model of control. Yet, the introduced control structure led to the idea of measuring one person relative to another person.

Quantifying two individuals timing relative to one another was examined in Chapter 3. A lead-follower paradigm was adopted to examine interpersonal synchronisation, emphasising visual feedback control. Linkages between the lead and follower were estimated with the measures of mean and variability of asynchrony (A) and inter-movement-intervals (IMI). Results clearly showed that the follower closely matched the timing of the leader. Seemingly, the lead-follower paradigm would be suitable for researching interpersonal synchronisation between two dancers.

5.1.2 Timing to Visual External Cues

In dance and music ensembles, movements of other members provide a variety of potential features that might serve as cues to aid synchronised timing within ensembles. Some insights into which events within a visual feedback cue individuals may time their movements to, come from research into musicians timing. Music ensembles are often lead by a conductor. The conductor's role is to provide gestures that depict temporal information and details about how loud or quiet (dynamic information) musicians' should play. The beat of the music is commonly indicated by the conductor's right hand. The right hand performs continuous up and downwards movements in space. Each downwards movement indicates the beat of a musical bar. Luck and Nte (2008) investigated how well musicians and non-musicians time their movements with the gestures of a conductor. In this experiment, the gesture of the conductor was one continuous up and downwards movement (u-shaped), represented by one point light on a computer screen. Participants were asked to tap in time with the dynamic point light display on a desktop keyboard. No instructions were given to which event within the dynamic dot motion participants were supposed to synchronise with. Participants' taps were plotted on the trajectory of the point light display. On average participants timed their finger tapping to the lowest vertical point of the point light trajectory (half way through the movement). A similar study by Luck and Slonoda (2009) also suggested that the absolute acceleration (the derivative of the velocity) of a dynamic point light presentation was used as a synchronisation cue for musician's timing. Overall, it may not be surprising that musicians time their movements to the downwards movement of the conductors gesture, as this movement is known to indicate the beat of the music (Demaree & Moses, 1994). However, even non-musicians timed their movements to this event, which could suggest that the absolute acceleration may be a powerful cue for movement timing. This cue however, may be specific to the nature of conductors' movement performances.

In the scenario of dance, exploring the events of the perceived visual cues performed by another dancer is rather complex. Dancers observe the overall movements of their dance partners which not only include movements of one or two arms, but movements of other limbs such as legs. One way to simplify the complexity of dancers' performances is to split a dance sequence into sections of dance poses. To further reduce the amount of degrees of freedom involved in performing a dance pose, the present study focuses on upper body dance poses. Compared to the u-shaped timing trajectory of the stimuli used in Luck and Nte (2008) research, dancers perceive stimuli of linear upwards movements of the arms reaching a dance pose in space. Luck and Nte found that participants timed their finger tapping with the lowest vertical point of the u-shaped trajectory which occurred half way through the movement. In the present study dancers time their movements with a trajectory whose direction was primarily linear. If dancers synchronise their movement timing with event cues that appear half way through the movement, similar to Luck and Nte findings, then dancers might be expected to use the peak velocity as their timing cue. To test this hypothesis and at the same time compare it with alternative timing cues, analysis on peak velocity timing is conducted and compared to events such as target positions (the final attained dance pose). Furthermore, the velocity-shape function of dancers' movements was compared with those of the virtual performer to examine further dynamic cues dancers may time their movements with.

5.1.3. Visual and Sensorimotor Familiarity in Dance

Expert dancers' enhanced sensorimotor skills relative to non-expert sports men and women have been widely established. Better performance is observed in domains such as posture, balance and reaction times (Kattenstroth, Kalisch, Kolankowska & Dinse, 2011). Research by Ramsey and Riddoch (2001) found that expert ballet dancers upper limb position-matching was more accurate compared to non-expert performers. They concluded that dance practice improves dancers' proprioceptive awareness, enhancing dancers' movement reproduction. In addition to enhanced upper limb coordination, enhanced lower limb coordination was found in dancers compared to non-dancers (Kiefer, 2009). Similar suggestions that dancer' proprioceptive awareness is enhanced derives from research into their postural sway. Golomer and Dupui (2000) investigated dancer' control of postural sway by manipulating the access to external feedback cues, comparing vision with no vision. Findings revealed that dancers compared to non-dancers were less dependent on vision and more effective in using proprioceptive cues for sway control.

A considerable amount of literature into dancers' motor and cognitive control (Bläsinget al. 2012) has been conducted, highlighting the rather exceptional skills acquired by dancers. Yet, these skills are based on years of rigorous training, visual and motor. Dancers fine-tune their somatosensation and visual percept to perform complex movement sequences with and without multiple dance partners.

The question arises whether dancers' enhanced somatosensation, in specific proprioceptive awareness is particularly fine-tuned to their own dance repertoire. For example are dancers more accurate in reproducing dance poses that are part of their daily training routine compared to poses that are not rehearsed? And if so, do dancers enhanced performances in reproducing more familiar compared to less familiar dance poses contribute to dancers' temporal synchronisation with another dancer?

5.1.4 Present Study

The present study had three research aims. The first was to provide quantitative data of expert dancers timing skills, focusing on visual feedback corrections. Expert ballet dancers were recruited to synchronise a set of dance movements with those of a virtual dancer. The virtual dancer was presented on a large display screen. Dancers' kinematic data were recorded using a three dimensional motion tracking system (Oqus, Sweden). Kinematic data were aligned to the movements of the virtual performer, enabling the quantification of synchronisation errors and timing variability's between the expert dancer and the dynamic visual display. The second aim was to investigate various events within the visually dynamic movement display with which dancers may time their movements. Present movements were reduced to upper limb movements. The timing to two synchronisation events, the dance poses in space and the more dynamic measure of peak velocity were compared. Based on previous research on musicians' timing with visual cues of a conductor, it was predicted that dancers time their movements with the peak velocity perceived within the trajectory display of the virtual dancer. The final aim was to explore whether dancers' motor expertise might contribute to their synchronisation performance. Dancers' motor familiarity with the dance material they perform was manipulated. Synchronisation with the virtual performer involved performance of highly practised (ballet) and less practised (novel) dance poses. It was hypothesised that dancers' timing with familiar ballet poses would lead to more accurate synchronisation performances compared to less familiar novel dance poses.

5.2 Method

5.2.1 Participants

Twelve female right handed expert dancers (Mean age=23.6, range 17 – 32 years) took part in this study. At the time of recruitment, participants either danced in a professional dance company or trained for auditions. All dancers were pre-dominantly trained in ballet (M=12.5, Range 6- 20 years) and had varying experience in other dance styles, predominantly in contemporary dance (See Appendix 5. 1). All dancers had normal or corrected-to-normal vision and were screened to ensure that they could discriminate 1 arcmin of disparity in a briefly (300 ms) presented random dot stereogram. This was a test for stereopsis vision (depth perception from retinal disparity, similar to Lugtigheid, Brenner and Welchman, (2011)). Dancers provided informed consent and were naive to the purpose of the study.

5.2.2 Apparatus

Expert dancers performed a given dance sequence on a wooden platform, facing a 3D stereo display (Inition systems, 2.50m x 1.90m) which was placed 1.20 m in front of them (Figure 5.1). The 3D stereo display projected the virtual dancer with which expert dancers were asked to time their movements. Two computers were used; one which initiated the 3D virtual display and a second one which recorded the kinematics of the movement trajectories at 200Hz, using a twelve camera optical motion tracking system (Qualisys Oqus, Gothenburg, Sweden). Fifty two 20 mm diameter spherical reflective markers were attached to the dancer's body with double sided sticky tape. Markers were placed on the legs and feet (24 markers), hips (3 markers), on arms (16 markers), spinal bone C7 and shoulder plates (3 markers), collarbone (2 markers) and head (4 markers) (Figure 5.2). This number of markers used ensured their recordings as a point light display could easily be recognised as a human. Participants wore 3D anaglyph glasses (red-green separated) to perceive the three dimensional effect of the stereo display. A photo sensor was placed at the corner of the screen, allowing synchronisation of the stimuli recordings with the recordings of the participant's kinematic data.

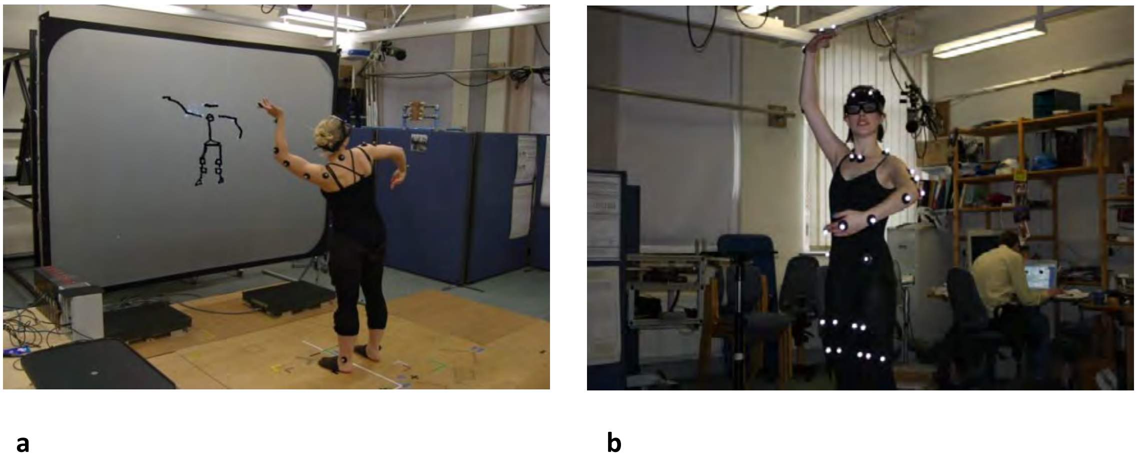


Figure 5.1: ***Experimental set up*** is shown **(a)**. The dancer performed on a wooden platform, facing a 3D stereo screen. The dancer on the right shows a frontal view, wearing 3D glasses and fifty two reflective markers on her body **(b)**.

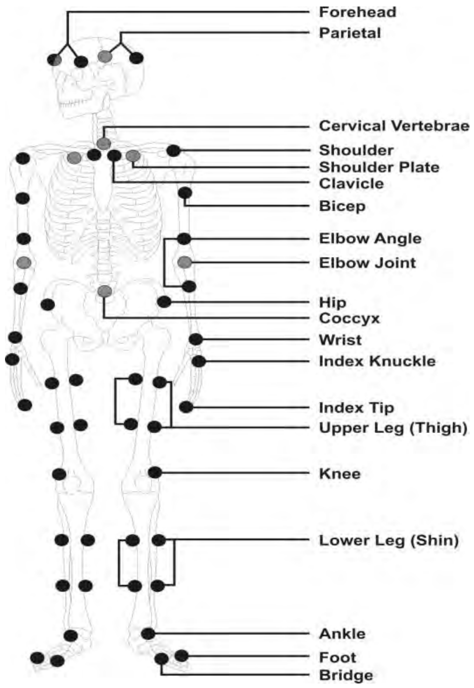


Figure 5.2: ***Marker placement.*** A total of 52 markers were attached to the dancer's body. Positions are illustrated on the skeleton above.

5.2.3 Stimulus Material

The stereo display presented a point light figure (52 points), performing a sequence of dance movements. The 'virtual dancer' was based on real motion capture recordings of an expert dancer that was displayed at a ratio of 2/3 (104.6cm) of the expert dancers' original height. Stereo stimuli consisted of three ballet and three matched novel dance sequences. All dance sequences were movements of the upper body. Ballet sequence one contained the 5th; ballet sequence two the 3rd and ballet sequence three the 4th arm position (latter with a slight twist of the upper body to the left) of the ballet vocabulary (Figure 5.4.a). Each dance sequence contained twelve repetitions of the specified ballet or matched novel arm movement in alternation with a downwards movement (Figure 5.3.b). The downwards movement was created by reversing the same upwards movement. This was done to ensure that the start of each dance position was the same across all trials.

Temporal modifications of the stimuli data were performed in Matlab, creating temporally perturbed and unperturbed dance trials. In order to control the time duration of each dance movement for all dance positions, a cubic spline interpolation was used to create fixed time durations. For trials that introduced no tempo change, called unperturbed trials, the time between the start and end of a dance movement was fixed to the duration of 1000 ms, followed by a pause of 500 ms. For brevity, the last frame of the dance movement was held for 500 ms (100 frames). The same movement was then reversed by a fixed duration of 1000 ms, again followed by a pause of 500 ms. This was repeated twelve times with a total trial duration of 36 seconds (Figure 5.3.b).

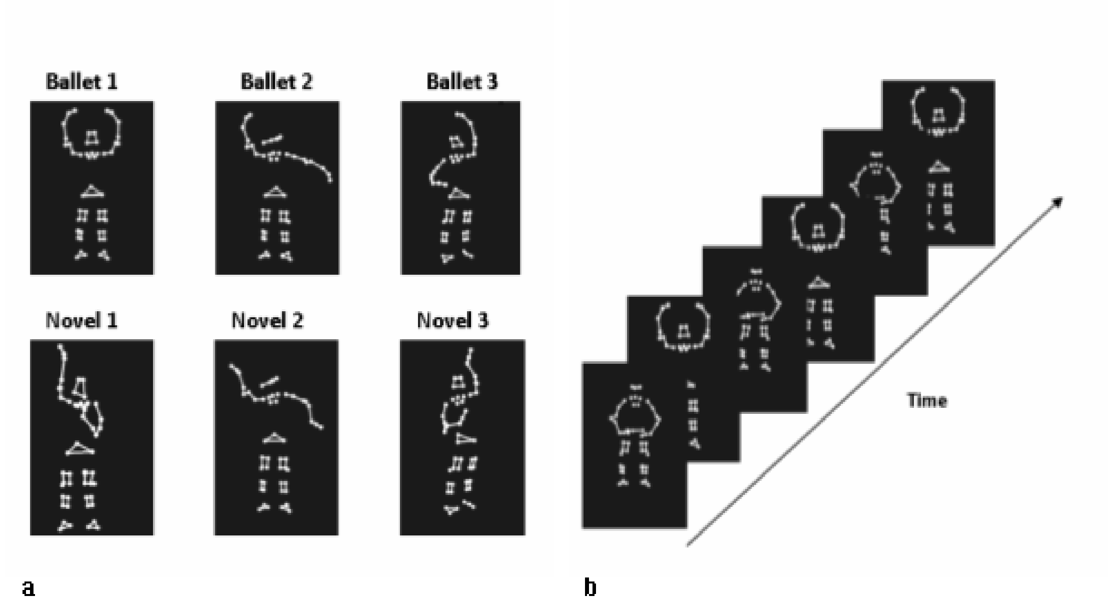


Figure 5.3: Stimuli Display; Three ballet and three matched novel dance positions introduced by the virtual dancer are shown **(a)**. Novel 1 was matched with Ballet 1 and so forth. An example of a ballet 1 dance sequence is illustrated with an alternation of dance and downwards movements **(b)**.

Trials in which a tempo change was introduced, referred as perturbed trials, contained temporal perturbations intended to avoid anticipation of the movement tempo by participants. Modifications were undertaken based on a 3 x 2 x 2 within participant design, investigating the effect of *Dance Type* (Ballet, Novel), *Tempo* (1000, 1200 ms) and *Trial Type* (Perturbation FSF, SFS) on dancers' synchronisation performance with another virtual dancer. Perturbation FSF contained two period changes; starting with a fast tempo (1000 ms), changing to slow (1200 ms) and then back to a fast tempo (1000 ms). For example, the time between the start and end of a dance movement and its reverse, was fixed to 1000 ms, this was repeated two or three times. Then a movement duration of 1200 ms was introduced and repeated three or four times, followed by a movement duration of 1000 ms which was then repeated five or six times. The duration of the pause after each reached target position was not affected by the tempo change and hold constant (500 ms) throughout all trial types. Perturbation SFS was the reverse of Perturbation FSF; slow (1200 ms) to fast (1000 ms) to slow (1200 ms). As for unperturbed trials, each dance position was repeated twelve times within a trial. The point of period change was introduced at varying positions and always at the start of a dance movement, in order to avoid anticipations of the point of period change by the expert dancers (Figure 5.4.).

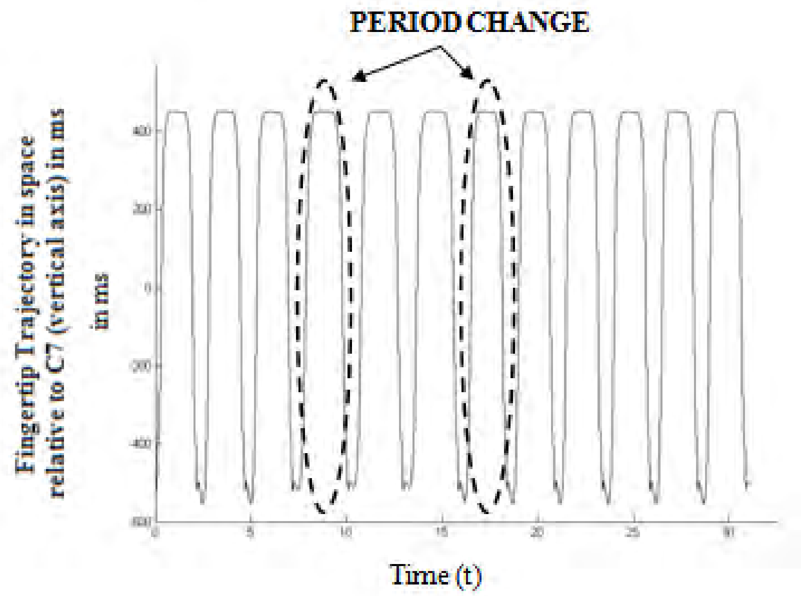


Figure 5.4: ***Stimulus Trajectory Profile***. Illustrates the trajectory profile of the fingertip of the stimulus (virtual performer) for perturbation condition FSF. Here the first period change was introduced at the 4th movement cycle and the second period change was introduced at the 7th movement cycle.

5.2.4 Procedure

At the beginning of each experiment dancers filled in a questionnaire designed to collect information of their dance background and years of dance experiences. Once filled in, 52 markers were placed on the dancer's body and the stereopsis test was undertaken. Dancers then were asked to wear 3D anaglyph glasses. Before the experimental phase begun, a training phase was conducted in which dancers practised all six dance sequences (three ballet and three novel sequences) after viewing a visual example of each dance sequence on the stereo screen. Once the training phase was over, the experimental phase began. Here, dancers were required to synchronise their timing as accurately as possible with those of the virtual dancer. Specifically, they were asked to synchronise their overall movement with those of the virtual performer. Before each trial begun the experimenter verbally announced which dance sequence dancers were about to perform.

In total, dancers performed each of the six dance sequences six times, twice for unperturbed trials (12 trials), twice for perturbed trial FSF (12 trials) and twice for SFS (12 trials), with a total of 36 trials. Each trial contained twelve dance movements, including its reverse movements, overall lasting approximately 40 seconds. To allow for a break, testing was carried out in two blocks of 18 trials. All conditions were randomised across dancers using an orthogonal Latin Square.

5.2.5 Kinematic Analysis

Stimulus and trial data were aligned in time, using the first peak onset of the photo sensor data. Out of the 52 markers the vertical displacement of the right index finger (rIF) of both the stimulus and trial data was selected for further analysis. The vertical position of the rIF was chosen as the performed movement was an up and downwards movement of the arms, moving along the vertical axis. A body centred coordinate system was used, selecting the vertebra prominens (C7) as a reference point to the chosen rIF. This relative measure of rIF was used for further analysis that consisted of two measures, target positions in space (TP) and peak velocities (PV) (See Chapter 2.2.3).

The attainment of the *target position* in space and time was defined by three rules. These three rules were set to identify the first velocity value closest to zero, with its five previous values being above the current velocity value which was only true if the value on the vertical axis was the first maximum value of the upwards movement and the first minimum value for the downwards movement. This allowed identification of the arrival at the target position in space and time. Target positions were determined for each movement (up and down), with a total of twelve upwards and twelve downwards target points per trial.

In order to identify the *peak velocity* values of the upwards movement (extension phase) and the downwards movements (flexion phase), the data of the rIF were digitally low-pass filtered at 2Hz (dual pass 8^{th}–order Butterworth filter) and then differentiated. A peak detection algorithm was used to determine the largest peak velocity value within each velocity profile of a performed movement. In total twelve peak velocity values for the upwards and twelve velocity peaks for the downwards movements were identified.

For both the *target positions* in space and the *peak velocities*, the mean *asynchrony* (A) and the mean *variability* of the asynchrony (sdA) to those of the virtual performer were determined. Values of the first movement of each new period phase were always excluded.

5.2.5.1 Unperturbed Trials

Unperturbed trials were analysed separately from perturbed trials. Analysis of unperturbed trials aimed to investigate whether dynamic cues within the visual stimuli are more powerful cues for dancers' synchronisation performance than more static cues such as target positions of a dance pose. Three measures were conducted, firstly comparing peak velocity (dynamic cue) synchronisation with target position (more static cue) synchronisation. And a third measure was introduced that investigated dancers timing to more than one dynamic cue, referred as velocity shape analysis. To compare dancers peak velocity to target position synchronisation of the perceived stimuli, a 2 x 2 x 2 mixed ANOVA measures was used; with *Synchronisation Event* (peak velocity ,target position) as a between subject factor and *Dance Type* (Ballet , Novel) and *Direction* (Up , Downwards movement) as within subject factors. In addition a correlation analysis was conducted to determine the relationship between the peak velocity and target position event.

Then the third measure of event synchronisation, shape analysis of the velocity-time functions was performed. The method of waveform moment analysis (similar to Ulrich, Wing and Rinkenauer, 1995) was used to quantify the shape of each velocity profile of a movement v*(t).* As the velocity profiles were unimodal, the first four moments M1, M2, M3 and M4 were selected as a parsimonious velocity shape description. These were calculated as followed

$$M_1 = \int t \times g(t)\, dt ,$$

$$M_2 = \sqrt{\int (t - M_1)^2 \times g(t) dt} ,$$

$$M_3 = \int \left[\frac{t - M_1}{M_2} \right]^3 g(t) dt ,$$

$$M_4 = \int \left[\frac{t - M_1}{M_2} \right]^4 g(t) dt - 3 ,$$

Where g*(t)* is the normalised function of v*(t) ;*

$$g(t) = \frac{V(t)}{\int V(t)\, dt}$$

The moments M1 and M2 are measures of the location and the spread of the v*(t)*, with a unit of milliseconds. The moments M3 and M4 are dimensionless quantities, providing indices. M3 is the index of skewness, if v*(t)* is a symmetrical distribution, then M3 = 0. Positive values mean that v*(t)* is skewed to the right, the opposite is true for negative values (Figure 5.5). The measure of kurtosis M4 is the index of peakedness. Zero (0) refers to a normal distribution, if M4 >0, the v *(t)* is more sharply peaked than a normal distribution. If M4 <0, then v *(t)* is flatter than a normal distribution (Figure 5.6).

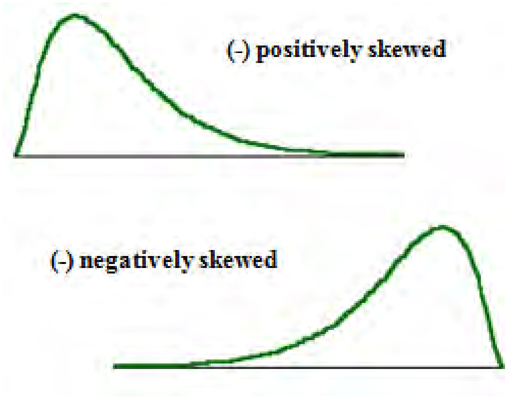


Figure 5.5: ***Skewed Velocity Profiles*.** Illustrates two v*(t)* shapes, one positively and one negatively skewed.

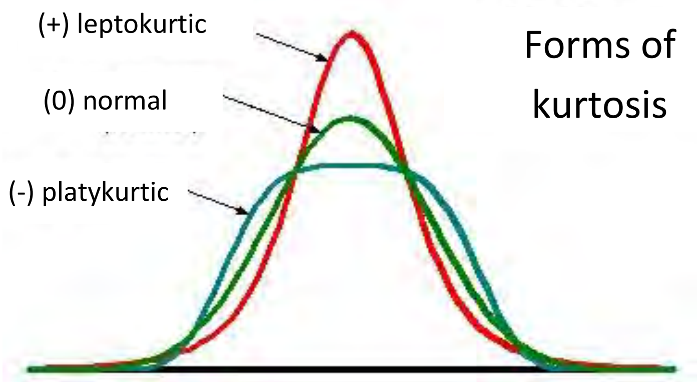


Figure 5.6: ***Three Forms of Kurtosis***. Leptokurtic (more peaked than normal), normal and platykurtic (flatter than normal).

Lastly, a 2 x 2 repeated ANOVA measures was conducted for each, the peak velocity and the target position event measure to investigate whether movement familiarity affected dancers timing performance which may have not been exposed by combining both measures in a Mixed ANOVA measures.

5.2.5.2 Perturbed Trials

Analysis of perturbed trials provided a larger amount of data to further analyse the effect of familiarity whilst reducing dancers' entrainment to the timing as a potential covariate. Here, analysis was only conducted on the peak velocity measure as it was found to be a less variable event cue for dancers timing (see results of unperturbed trials). Firstly, A 2 x 2 x 2 repeated measures ANOVA with *Trial Type* (Perturbed S2F , FSF) *Dance Type* (Ballet , Novel) and *Tempo* (1000 ,1200 ms) was performed.

Moreover, introduced period changes throughout perturbed trials allowed for the investigation of how fast dancers were able to adjust their timing post-perturbation and whether their recovery was affected by their visual or motor familiarity of the dance poses. Post-perturbation measure analysed dancers' asynchronies relative to the virtual dancer, from the start of the second period change to the end of each trial. Only trials in which the second perturbation was introduced at the ninth dance movement were examined, to allow for a larger data set to be analysed. In total, eight trials per dancer were analysed. A criterion was set to identify how many movements post-perturbation were needed until expert dancers' synchronisation performance was recovered. As an indicator of recovery, asynchronies (up and downwards movements' asynchrony in alternation) were grouped to investigate which three successive movements gave rise to the lowest mean asynchrony. All synchronies were made positive, measuring the absolute synchronisation error between the dancer and the virtual performer. There were ten possible recovery positions (Figure.5.7). The asynchronies were averaged for each pairing and the pairing with the lowest mean asynchrony was chosen as the position of recovery. For example, if pairing three gave rise to the lowest mean asynchrony, the 3rd asynchrony post-perturbation was selected. This would suggest that the absolute synchronisation error was lowest at the window staring at the 3nd to the 5rd movement. The position of recovery and the mean asynchrony value of each pairing were analysed using a 2 x 2 x 2 repeated measures ANOVA (*Trial Type x Dance Type x Tempo*).

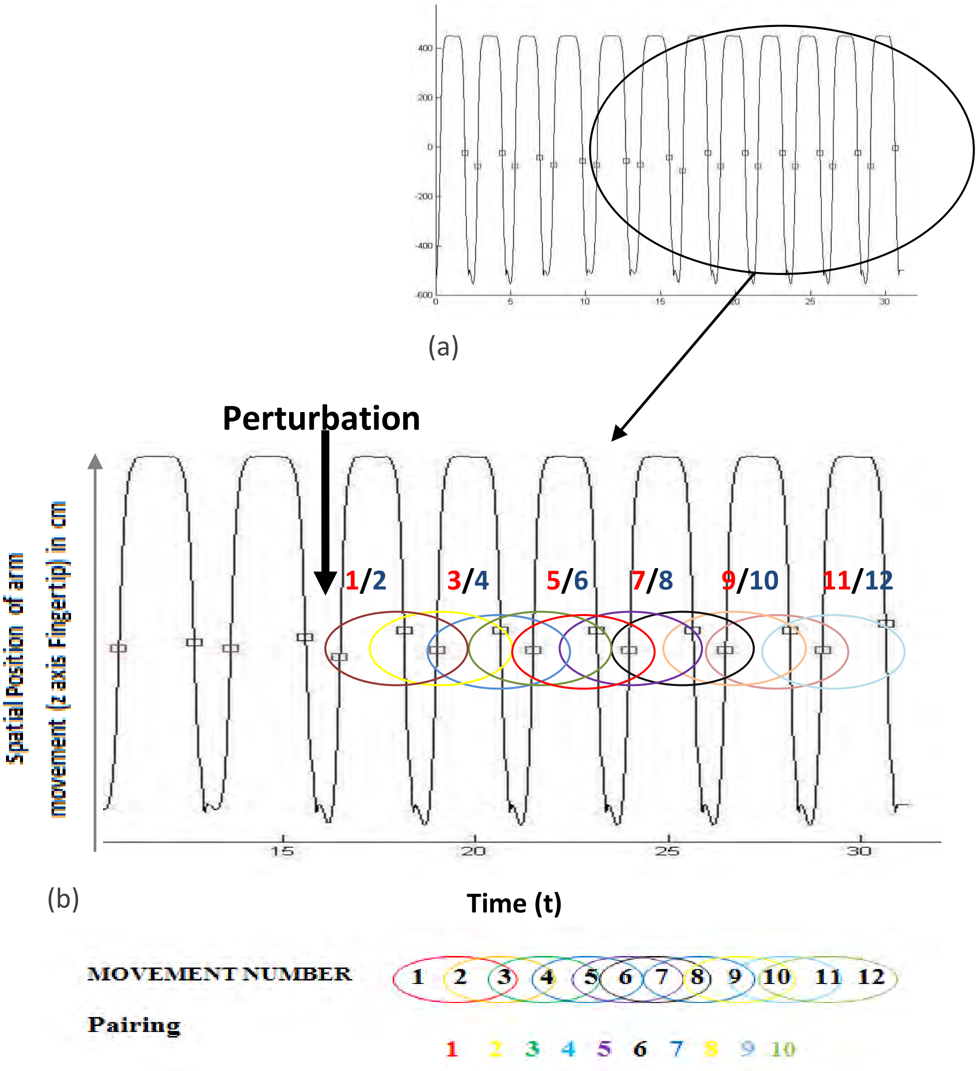


Figure 5.7: ***Post-Perturbation Analysis.*** An example trajectory of the stimulus is presented for FSF **(a)**. A close up is show in **(b)**, here the second perturbation was introduced at the 7th upwards movement. In both graphs the spatial position of the arm movement is shown. The peak velocity for up (red square) and down (blue square) are plotted on the trajectory. For the post-perturbation analysis, three successive peak velocities (asynchronies relative to stimulus) are grouped together as a pair.

Lastly, a correlation analysis was conducted, evaluating the relationship between dancers' synchronisation errors and the years of dancers' dance experience.

Overall, 3.4% trials had to be excluded due to noise in recordings or a missed movement production by the participant.

In summary, for the statistical analysis two dependent variables were evaluated. Separate repeated measures analyses of variance (ANOVA) were conducted for each DV. Non-significant results (p>.05) were not discussed. Where the assumptions of sphericity were violated, the degrees of freedom were corrected using the Greenhouse - Geisser estimates. Significant interactions were further investigated. For significant two-way interactions, paired t-tests were performed between the appropriate levels of the factors, using a Bonferroni alpha correction for multiple tests. For all synchronisation events a main effect of *Dance Type* was expected with ballet movements resulting in more accurate performance compared to novel movements. This would be reflected by smaller and less variable asynchronies performed by the dancer.

5.3. Results

Firstly, the results for unperturbed trials are presented in the following order; ANOVAs of the mean asynchrony and standard deviation of asynchrony followed by the shape analysis of the velocity-time function. Then ANOVAs of perturbed trials are shown; beginning with the mean and standard deviation of asynchrony, followed by the post-perturbation recovery analysis. Lastly, dependencies between years of training and dancers' synchronisation accuracy are briefly summarised.

5.3.1. ANOVAs of Unperturbed Trials

5.3.1.1 Mean Asynchrony (A)

A reveals information about the directionality and the magnitude of the average asynchrony (synchronisation error) relative to the virtual performer. The 2 x 2 x 2 Mixed ANOVA analysis exposed a significant difference between the two *Synchronisation Events* ($F(1,22)=7.392$, $p<.05$, $\eta_p^2 = .252$). Dancers' synchronisation errors were larger for target position timing (TP; 72.6 ms) compared with peak velocity timing (PV; 2.7 ms). No main effects were found, only an interaction between *Direction* and *Synchronisation Event* was observed ($F(1,22)=24.84$, $p<0.01$, , $\eta_p^2 =.530$) (Figure 5.8). Post-hoc comparisons revealed that for PV synchronisation, downwards movement resulted in significantly different mean A (-53.9 ms) compared to upwards movements (59.5 ms) ($p<.01$). In addition the downwards movements timing were significantly larger for TP synchronisation (98.8 ms) compared to PV synchronisation (-53.9 ms) ($p<.01$).

Pearson's correlation showed that both measures were significantly correlated with one another ($N=12$, $r=.639$, $p<.05$). Thus the larger the synchronisation errors in VP, the greater were the synchronisation errors in TP.

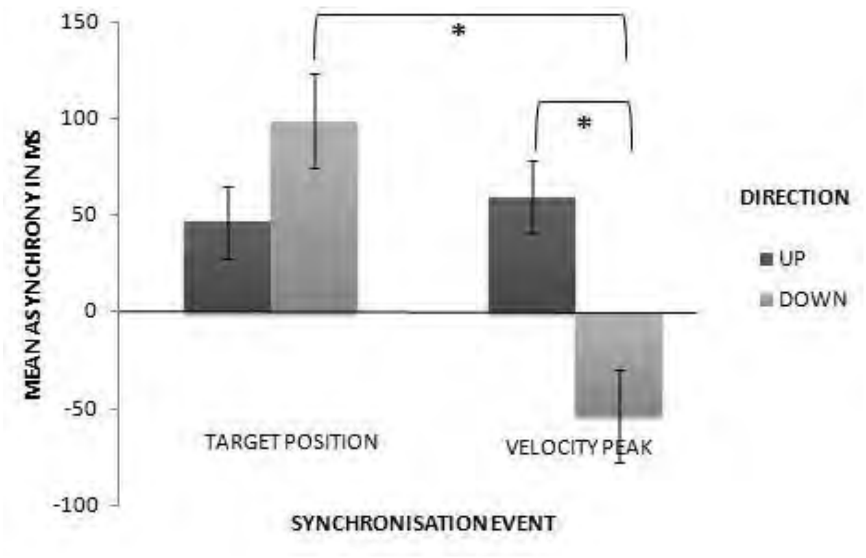


Figure 5.8: ***Interaction between Synchronisation Events x Movement Direction for A***. * significant post hoc t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

5.3.1.2. Standard Deviation of Asynchrony (sdA)

SdA reveals the dancers consistency in their synchronisation performance, measuring the dispersion from the mean A. The greater the sdA is the more dispersion from the mean A and the less consistent participants' synchronisation performance is. The 2 x 2 x 2 Mixed ANOVA analysis exposed a significant difference between the two *Synchronisation Events* (F(1,22)=19.984, p<.01, η_p^2 = .476). Dancers' synchronisation performance was significantly larger for TP timing (87.6 ms) compared with PV timing (55.3 ms). No main effects or interactions were exposed. Two separate post-hoc analyses on each synchronisation event (PV and TP) were performed, to investigate effects of familiarity, specific to the type of synchronisation event. One significant interaction between *Dance Type* and *Direction* for peak velocity timing was exposed (F(1,11)=23.652 p = 0.01, η_p^2 = .683) (Figure 5.9). This was further analysed by conducting two separate paired t-tests which revealed that for upwards movements only, dancers synchronisation performance was less variable for ballet compared to novel dance movements (p<.025). Pearson's correlation showed no relationship between PV and TP (N=12, r=.037, p=.908).

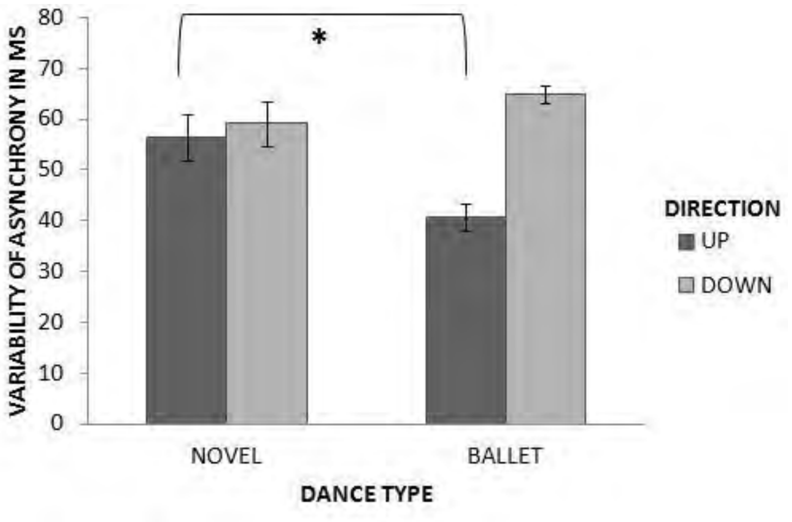


Figure 5.9: ***PV (peak velocity measure) interaction of Dance Type x Direction for sdA***. * indicates significance differences for paired t-test (Bonferroni corrected). Error bars represent the standard errors of the means.

5.3.1.3. Shape Analysis of Velocity–Time Function

Four defined moments within each velocity function of dancers movements were compared with those performed by the virtual dancer. Figure 5.10 illustrates ten velocity functions of one participant for novel, ballet and their reverse movements (downwards movements). The velocity profile of novel dance functions were slightly skewed to the left, whereas the velocity functions for ballet dance movements were more or less normally distributed with some trajectories performing a slight skews to the right.

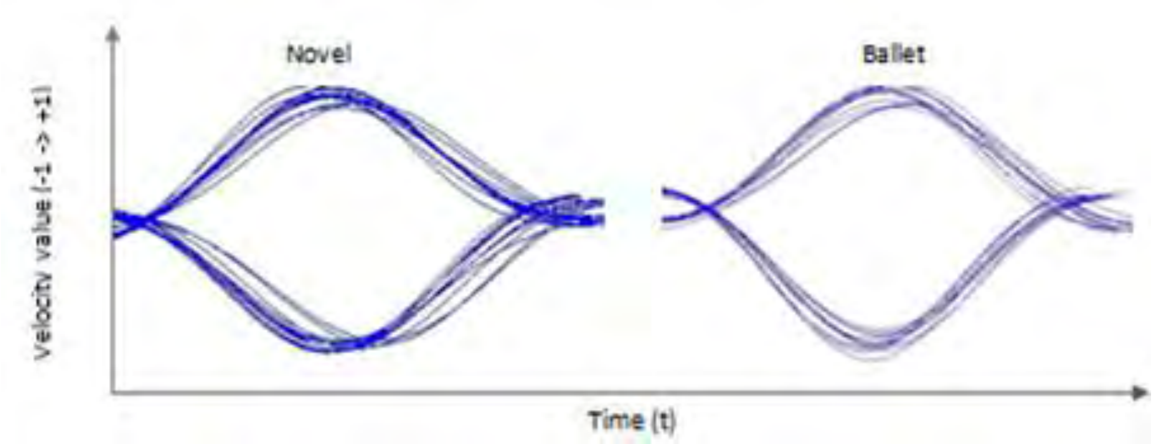


Figure 5.10: ***Example velocity-shape profiles*** of one dancer performing novel and ballet dance movements (velocity profiles overlapped within one trial).

The overall difference in the group mean of M1 (mean location) produced by the virtual stimuli and to those performed by expert dancers was 18.1ms. The repeated measures ANOVA found a significant interaction between *Dance Type* and *Direction* (F(1,11)=21.539,p= 0.001, η_p^2 = .662). Post-hoc paired t-tests exposed that dancers ballet movements M1 (0.4ms difference in M1) compared to novel dance movements M1 (37.9ms difference) were significantly closer to those of the virtual dancer (p<.01). The mean difference in M1 for downwards movements was significantly larger than for upwards movements (p<.05), this was more pronounced for ballet (p<.01) than novel dance movements (p<.05).

The overall difference in group mean of M2 performed by the virtual stimuli and those performed by expert dancers was 1.8 ms. The repeated measures ANOVA showed no significant difference between the expert and the virtual dancers' dispersion of produced velocity shapes.

Next, the overall difference in group mean of M3 performed by the virtual stimuli in and those performed by expert dancers was 0.04. The repeated measures ANOVA exposed a main effect of *Dance Type* (F(1,11)=56.302,p< .001, η_p^2 = .837) and *Direction* (F(1,11)=123.124, p< 0.001, η_p^2 = .918). Here, the difference in M3 between the expert and virtual dancer resulted in a greater skew to the right for ballet (.13) and a greater skew to the left (-.51) for novel dance moves. Expert dancers' compared with the virtual dancer's upwards movements showed a larger skew to the right (.135), instead downwards movements were slightly skewed to the left (-.06).

Lastly, the overall group mean of the M4 difference between the expert dancers and the virtual performer was 0.03. The repeated measures ANOVA only found a significant main effect *Dance Type* (F(1,11)=18.713,p<.001, η_p^2 = .6307), with expert dancers velocity shapes resulting in a greater peakedness for ballet (.008) compared with novel (-.003) dance movements.

5.3.2 ANOVAs of Perturbed Trials (Peak Velocity)

5.3.2.1 Mean Asynchrony (A)

The overall A was 63.5 ms. The repeated measures ANOVA exposed a significant main effect of *Dance Type* ($F(1,11)=15.208$ $p <.05$, $\eta_p^2 = .580$) and *Tempo* ($F(1,11)=52.088$, $p<.01$, $\eta_p^2 = .826$). Expert dancers mean A was lower when synchronising with novel (45 ms) compared to ballet movements (82 ms). The main effect of *Tempo* was due to lower mean A for 1200 ms (26.1 ms) than for 1000 ms (100.9 ms) movement durations. There was also a significant interaction between *Dance Type* and *Tempo* ($F(1,11)=13.047$,$p< .05$, $\eta_p^2 = .543$) which was further analysed by conducting post-hoc paired t-tests. Paired t-tests revealed a significant difference between ballet and novel movements for movement durations of 1000ms ($t(11)= 6.669$, $p<.001$), with ballet movements yielding significantly larger mean A than novel movements. For both, ballet ($t(11)= 5.376$, $p<.001$) and novel movements ($t(11)= 7.388$, $p<.001$) the movement duration of 1000ms resulted in greater mean A than 1200ms (Figure 5.11).

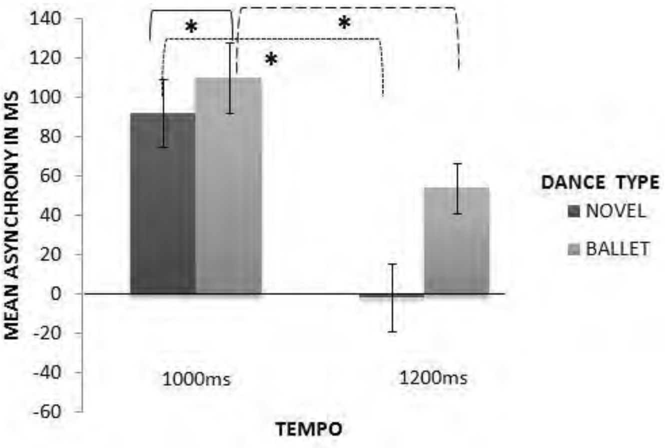


Figure 5.11: ***Perturbed Trials Mean A's interaction***. The graph shows the interaction between Dance Type and Tempo. * indicates significant difference for paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

5.3.2.2 Standard Deviation of Asynchrony (sdA)

The overall sdA was 57.1 ms. ANOVA exposed a significant main effect of *Dance Type* (F(1,11)=21.268, p=.001, η_p^2 =.659) and *Tempo* (F(1,11)=16.931, p<.05, η_p^2 =.606). Here, dancers' synchronisation resulted in smaller sdA for ballet (45.3 ms) than for novel (68.8 ms) dance movements. Moreover, movement durations of 1200 ms (64.2 ms) yielded in significant more variable A than movement durations of 1000 ms (49.9 ms).

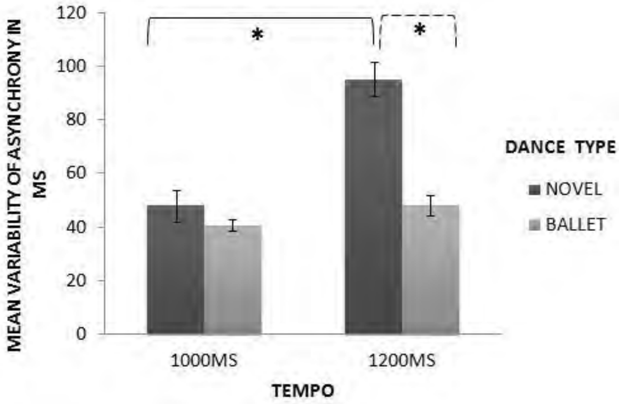


Figure 5.12: ***Perturbed Trials Mean sdA's interaction***. Illustrates the interaction of Dance Type and Tempo for FSF in perturbed conditions. Error bars represent the standard errors of the means. * indicates significant difference for paired t-tests (Bonferroni corrected).

Two two-way interactions were also found, one between *Trial Type* and *Tempo* (F(1,11)=14.33, $p<.05$, η_p^2 =.566) and another between *Dance Type* and *Tempo* (F(1,11)= 56.399, $p<.001$, η_p^2 =.837). In addition one three-way interaction between *Trial Type*, *Dance Type* and *Tempo* was exposed. As the three-way interactions was significant, interactions were analysed by separating the 2 x 2 x 2 ANOVA in two 2 x 2 ANOVAs, one for SFS and one for FSF.

For SFS repeated measures ANOVA revealed only a main effect of *Dance Type* (F(1,11)=9.324, $p<.05$, η_p^2 =0.459), with ballet movements resulting in less sdA compared to novel dance movements. No interactions were found. The ANOVA for FSF exposed a main effect of *Dance Type* (F(1,11)=24.136, $p<.001$, η_p^2 =0.687) and *Tempo* (F(1,11)=34.870, $p<.001$, η_p^2 =.760), as well as an interaction between *Dance Type* and *Tempo* (F(1,11)=48.708, $p<.001$, η_p^2 =.816). Here, dancers' sdAs were also smaller for ballet than for novel dance movements. The effect of *Tempo*, originally found in the 2 x 2 x 2 way ANOVA was only observed for FSF, with movement durations of 1000 ms yielding in less variable synchronisation performance, than movement durations of 1200 ms. The two way interaction between *Dance Type* and *Tempo* further exposed that expert dancers' movement synchronisation with ballet moves were only significantly less variable compared to novel movements for longer movement durations of 1200 ms (t(11)= 6.851, p<.001) (Figure 5.12.). No significant difference between Dance Types was found for movement durations of 1000 ms. In addition, larger sdAs of novel movements were observed 1200 ms compared to 1000 ms durations (t(11)=7.775, p<.001). In contrast, dancers' ballet movements were not affected by the movement interval.

5.3.3 ANOVAs for Post-Perturbation Recovery

A measure of period recovery was conducted to investigate whether expert dancers are faster in adjusting to temporal changes when synchronising with ballet compared to novel dance movements. Figure 5.13 illustrates one example trajectory of one dancer's peak velocity synchronisation, performing ballet dance movements. As the graph shows this dancer synchronised closely with the virtual dancers movement timing and adjusted nearly immediately his or her timing to those of the virtual dancer after a period change was introduced.

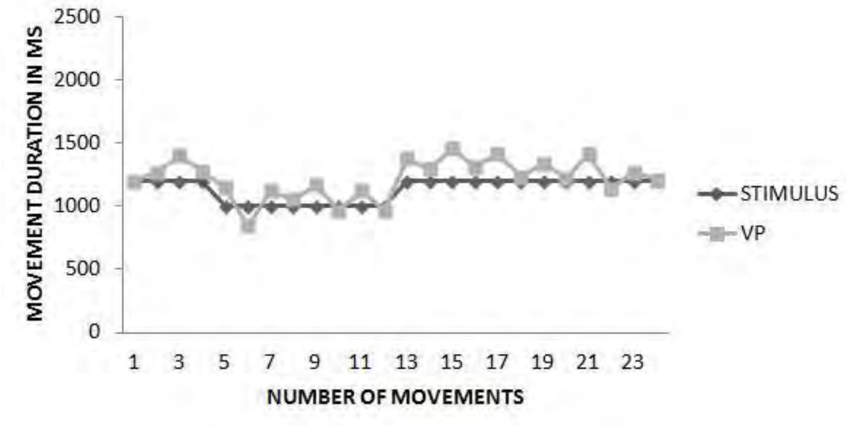


Figure 5.13: ***IMI Synchronisation Example Trajectory***. One dancer's peak velocity synchronisation performance relative to the target stimuli. Present example was taken from SFS trials.

The repeated measure ANOVA found no significant effects for the post-perturbation measures of recovery position and recovery value (p>.05). The average recovery position was 5.7 (6th to 8th movement post-perturbation, recovery value for this position was 67.7 ms).

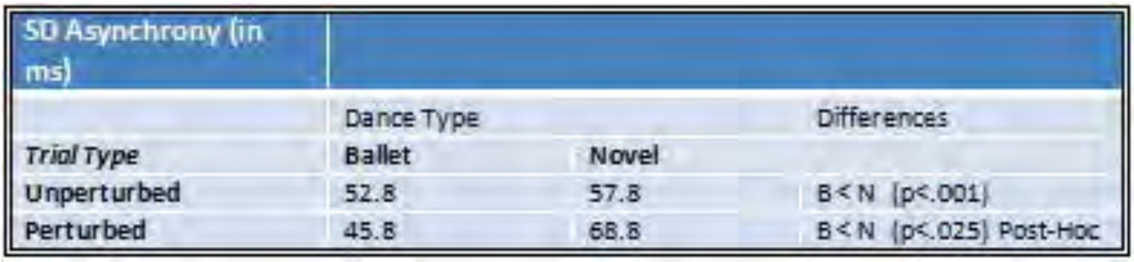
5.3.4 Dependencies between Years of Training and Dancers' Synchronisation Accuracy

The relation between expert dancers' years of overall dance experience and dancers synchronisation accuracy in terms of asynchrony and variability of asynchrony was evaluated using Pearson correlations, across all trials separately for unperturbed and perturbed Trials. The overall average correlation was r=.206 (N=12) and not significantly different from zero. No significant correlations between the average scores across all trials and conditions were found, nor were there any significant correlations found for particular conditions such a familiar.

5.3.5 Summary of the Results

Taken together, an effect of Dance Type was evident in the variability of asynchrony. Here, sdA were on average smaller for ballet compared with novel dance movements (see table 5.1).

Table 5.1: Movement Familiarity Effect on sdA. For both unperturbed and perturbed trials sdA values are summarized illustrating the effect of dance familiarity on dancers' synchronisation performances.



SD Asynchrony (in ms)			
	Dance Type		Differences
Trial Type	Ballet	Novel	
Unperturbed	52.8	57.8	B < N (p<.001)
Perturbed	45.8	68.8	B < N (p<.025) Post-Hoc

For dancer's mean synchronisation error (asynchrony), only one difference was observed in perturbed trials which revealed smaller A for novel than ballet dance moves.

Lastly, dancers' synchronisation accuracy in terms of synchronisation error and its variability was significantly better for the synchronisation event of peak velocity compared with the target position, as summarised in Table.

5.4. Discussion

In the present study there were three research aims. The first aim was to provide quantitative data of expert dancers timing skills, focusing on visual feedback control. The second aim was to investigate various events within the visual dynamic feedback cue with which dancers' may time their movements. And lastly, the final aim was to explore if dancers' visual and motor familiarity of highly rehearsed dance poses contributes to dancers' synchronisation performance. Expert ballet dancers were asked to synchronise upper body dance movements, ballet and novel dance movements with those of a virtual performer. The virtual dancer's performance included two trial types of highly controlled movement timings; unperturbed and perturbed trials. In unperturbed trials the tempo was held constant for each movement whereas in perturbed trials, two period changes were introduced to avoid dancers' anticipation movement timing.

The analysis of perturbed trials was conducted separately from the analysis of unperturbed trials. For unperturbed trials the factors of *Synchronisation Event* (peak velocity, target position), *Dance Type* (Ballet, Novel) and *Direction* (Up, Downwards movement) were investigated and for perturbed trials the factors *Trial Type* (Perturbation SFS, FSF), *Dance Type* (Ballet, Novel) and *Tempo* (1000, 1200 ms) were evaluated.

The first prediction made hypothesized that dancers will be more accurate at timing their movements to dynamic cues within the perceived movement trajectory of the virtual dancer, such as the peak velocity event compared to more static cues such as target position events. This would be in line with Luck and Nte (2008) findings that the dynamic cue that occurred half-way through the visual moving stimulus was found to be a powerful timing cue for musicians and non-musicians timing during a synchronisation task with a conductors movement. Increased mean and variability of timing errors for target position synchronisation in comparison to peak velocity synchronisation was expected as target positions may vary in space across performances, adding noise to the performance.

The second prediction hypothesized that dancers' high exposure, visually and in terms of motor practice, to dance movements that are part of ballet dancers' every day repertoire may improve dancers synchronisation performances. Therefore, it was hypothesised that dancers' timing would lead to smaller mean and variability of synchronisation errors for highly familiar ballet poses compared to less familiar novel dance poses.

5.4.1 Dancers Timing to Events within Visual Cues

In order to investigate to which events within the dynamic point light display expert ballet dancers synchronised their movements, three measures were evaluated; comparing the timing of the peak velocity (PV), target position (TP) and moments within the shape velocity time function performed by the expert dancers with those of the virtual dancer. Comparative statistical analysis on PV and TP synchronisation showed that dancers' synchronisation errors were significantly larger and more variable for TP synchronisation compared to PV synchronisation. The overall larger synchronisation errors for TP may be explained by the different distances travelled to reach each synchronisation event. Moving farther has been shown to result in greater inaccuracy in hitting targets (Schmidt, Zelaznik, Hawkins, Frank & Quinn, 1979). This was explained as more variability could be produced by force and time for farther distances compared to closer distances. Therefore, for synchronisation of TP events dancers had to move farther than for PV events, increasing the level of noise produced by dancers' movements.

Another source for an increase in dancers' synchronisation error for TP synchronisation may have been the qualitative different nature of the TP compared to the VP event. TP is a more static event with no fixed endpoint in space, whereas VP is a more dynamic event. Here, fluctuations of the reached TP in space may add to the level of increased synchronisation error and variability that was observed in the present data. If this would be true, target position synchronisation errors and its variability would perhaps have been expected to double in size as peak velocity events were found midway to the target position event. This however, was not found, as for synchronisation errors an average increase of errors of 70% (from PV to TP) and for the variability in timing an increase of only 32% was found. Hereby, the increase in timing errors was not shown to be additive and more interestingly the increase of synchronisation errors was of greater proportion than for its variability.

In addition to the comparative statistical analysis a correlation analysis was conducted, establishing whether there was any linkage between the timing of VP and the timing of TP. A positive relationship between the mean A of VP and TP was found. The larger the synchronisation errors were for PV the larger the synchronisation errors for TP. This is not surprising as VP timing is part of TP timing. However, no relationship between the sdA of VP and TP was found. This potentially would suggest that both events may be timed differently. For example, dancers increased synchronisation error for TP may mainly be due to difficulties in visually perceiving the start of the reached target position within the stimuli. Thus, consistently greater synchronisation errors were found. However, this rather visual discrepancy would not affect the consistency of this timing performance. Therefore, no relationship between the variability of PV and TP was observed. Overall, dancers’ timing to VP events resulted in less variable and lower synchronisation errors compared to TP.

A third measure was explored investigating dancers’ temporal and spatial matching of their velocity profile with those of the virtual dancer. The shape-velocity time function was used to identify four moments within the velocity profile, based on a method of waveform moments analysis (Cacioppo & Dorfman, 1987). Mathematical equations for calculating the present four moments of interest were based on Ulrich et al.’s (1995) research into force-time functions. This measure compared dancers speed at a given direction, exploring dynamic event cues. Results showed that dancers were able to closely time and match their mean location, dispersion, skewness and kurtosis within their velocity-profile with those of the virtual dancer. This measure was also sensitive to dancers’ familiarity of the dance movements performed and observed which will be discussed in the next section. Considering the close match of dancers velocity-shape function with those of the virtual performer the present measure may be a useful measure for future research that investigates dancers’ movement timing with dynamic cues that may be more continuous than those used in the present study. For example in contemporary dance, dancers often perform movements that flow from one dance pose to another without a pause. Identifying timing of more continuous movements potentially requires analysis of various dynamic cues for which the shape-velocity time function may be ideal.

To summarise, dancers were able to time their movements to both events, dynamic and more static ones. Nonetheless, dynamic timing cues compared to static cues may be more powerful and accurate cues to synchronise with. In comparison to musicians' timing with movements performed by a conductor, Luck and Nte (2008) suggested that musicians time their movements to the lowest spatial point of the perceived downwards movement of the conductor. The identified timing cue was the absolute acceleration, a dynamic cue which occurred half way through the trajectory. In relation to the present findings, dancers were also found to time their movements with a dynamic cue (peak velocity) half way through the perceived movement.. Nonetheless, this was one of various identified dynamic cues dancers were closely timing with (velocity-shape analysis). Perhaps, the rather specific finding of absolute acceleration as the dominant timing cue identified by Luck and Nte was due to the nature of the experimental paradigm. They tested musicians' and non-musicians' tapping in time with a dynamic dot display that represented the movement of a conductor. Participants' finger tap on a keyboard was recorded, tracking the endpoint of the downwards movement only. It is therefore unclear if participants were actually timing their overall finger movement with those of the conductor, with that matching the u-shaped trajectory of the conductors' movement. Motion tracking of participants' finger tapping may give rise to potentially more similarities between how dancers and musicians time their movements with ensemble members.

5.4.2 Movement Familiarity and Timing

Ballet dancers' high exposure to dance poses that are part of their own dance repertoire may contribute to the success of their movement synchronisation with another dance partner. To explore whether dance familiarity interacts with dancers timing skills, dancers were asked to synchronise highly practised ballet movements and less practise novel movements with those of a virtual dancers. Two measures, peak velocity synchronisation and moments within the shape velocity function were found to interact with dancers' familiarity of dance poses perceived and performed. The analysis of the shape velocity function showed that dancers timing of their mean location M1 was significantly closer to those of the virtual dancer for ballet compared to novel dance movements. And the analysis of peak velocity synchronisation found that dancers timing with ballet movements compared to novel movements was significantly less variable.

For perturbed trials in which temporal perturbations were introduced at varying positions, similar results were found in terms of dancers' timing variability. Dancers performed less variable timing with ballet compared to novel dance movements. This was more pronounced for longer movement durations of 1200 ms than for shorter movement durations of 1000ms. Results showed that dancers' synchronisation variability with ballet movements was not affected by tempo. This is surprising as research based on finger tapping paradigms found that tapping variability increased with increased interval durations (Ivry & Hazeltine, 1995). In contrast, dancers' synchronisation variability with novel movements, nearly doubled in variability for longer compared to shorter movement durations. Dancers less variable performance with ballet movements may be explained by dancers various timing experience of ballet movements. Typical everyday training involves dancers performing their own movement repertoire at various speeds. Such training may enhance their ability to reproduce rehearsed movements not only consistently in space (Ramsey & Riddoch, 2001) but also in time. Nonetheless, it is not clear whether dancers' motor practise or visual familiarity contributed to the less variable performance. Thus, no predictions can be made in terms of to what extent either motor familiarity or visual familiarity contributed to this performance. Future studies could examine this by manipulating dancer visual familiarity whilst keeping constant their motor familiarity during interpersonal synchronisation.

The increased timing variability that has been observed for novel movements could also have various reasons; firstly timing variability is known to increase with longer time durations (Ivry & Hazeltine, 1995). However, the proportion of increase (48.1 ms for 1000 ms to 95ms for 1200 ms) may be too large to be explained by this on its own. Perhaps, the increase may also be due to the design of the experiment. Dancers performed more dance sequences in which movement durations lasted 1000 ms; all unperturbed trials consisted of this duration. Furthermore, during the training phase dancers learned each movement by observing unperturbed trials (1000ms). Thus, more practised was given for novel dance movements at shorter than longer movement durations. Hereby, practise could have reduced dancers' timing variability for short compared to long movement durations.

In addition to dancers' synchronisation variability during unperturbed trials, dancers mean synchronisation error (A) was also affected by dancers' movement familiarity. Surprisingly, larger synchronisation errors were found for ballet compared to novel dance moves. Nonetheless, this was only significant for shorter movement durations of 1000ms in which dancers synchronisation error was overall larger than for 1200ms durations. Overall, expert dancers seem to time their movements closer in time with dynamic cues the more time is allowed for perceiving feedback information. Considering that the correction of visual feedback cues occurs on average after 200ms (Keele, 1968), observing longer durations may have provided more time for corrective mechanisms to take place. Thus, less asynchrony was found for 1200 compared to 1000 ms durations.

Another explanation for the overall larger synchronisation error for 1000 ms durations comes from the area of psychophysics. Research showed that when participants perceived shorter compared to longer durations of moving stimuli (range 0cm/sec to 40cm/sec), they overestimated their time duration (Brown, 1995). The opposite was found for longer durations. Consequently, dancers may have overestimated the timing of shorter durations, leading to larger synchronisation errors than when synchronising with longer movement durations.

One reason why dancers were found to produce larger synchronisation errors for ballet compared to novel dance moves in 1000 ms durations may be explained by two different ways of performing each type of movement. Ballet dancers arm movement repertoire consists of highly controlled movements (LaViers & Egerstedt, 2011) that are encouraged to be performed expressively (Sirridge & Armelagos, 1977). For music ensemble synchronisation, it has been suggested that asynchronies are part of expressive timing (Hove, Keller & Krumhansl, 2007). Expert dancers may use the same technique to ensure expressiveness of their own performance of ballet movements. In contrast to ballet moves, novel movements first have to be learned and encoded in the dancers' muscle memory before expressive timing may be able to have taken place.

The present study also analysed how well dancers adjust their timing after a temporal perturbation. The average position at which lowest synchronisation errors post-perturbation were found was between the 6th to 8th movement which was within the third and fourth movement cycle after the period shift was introduced by the virtual performer. Factors, such as *Dance Type* and *Interval duration* did not interact with dancers' temporal adjustment performance. Thus, dancers' motor and visual familiarity for ballet moves did not enhance their ability to correct for period shifts compared to less familiar dance movements. One reason why no advantage for familiar moves was observed may have been that dancers had enough time to use feedback correction at an earlier point within the movement. In order to examine this, dancers' timing at the peak acceleration (half way to the peak velocity) may provide a better measure to investigate this.

Lastly, dependencies between dancers' synchronisation performance and their years of dance experience were evaluated, however no relationship was found. Therefore, dancers who had more years of dance training were not necessarily better at their synchronisation performances. Perhaps, overall years of training may not be a sensitive measure to predict enhanced timing skills in synchronous expert dancers' performances.

5.4.3 Conclusion

The present study provides quantitative data on dancers' sensorimotor synchronisation to external events which so far has not been covered by the literature. In focus was dancers' timing with visual cues perceived by other dancers' movements. Dancers timed their moves more closely to dynamic cues such as the peak velocity than to more static cues such as the target position. Moreover, dancers were found to temporally match their own movement trajectory with those of the virtual performer. Dancers' synchronisation was also affected by their familiarity of the observed and performed dance movement. Timing variability was significantly reduced for ballet compared to novel dance movements. However, dancers' mean synchronisation errors were larger for ballet than novel dance moves. This finding may be interpreted as expressive timing as dancers rehearse their movements to be performed in an expressive manner, favouring asynchronous performance of ballet poses.

The present paradigm included the control of one dancer by introducing a virtual performer. This tool was successful in researching dancers' interpersonal sensorimotor synchronisation. It therefore may also be a useful tool to explore synchronisation of multi-person performances. For example, expert dancers' synchronisation with two virtual dancers could be explored. Here two dancers may be presented on a stereo display screen. Furthermore, other relevant external cues may be added, such as the auditory rhythm of the music or the haptic feedback of another dancer perceived through touch. This could provide a more holistic insight into dancers' timing in real life ensemble performances.

Chapter 6: Bottom-Up and Top-Down Modulation of Interpersonal Synchronisation

(In collaboration with Caroline Gillett)

6.1 Introduction

The preceding chapters described low level factors in sensorimotor synchronisation between two individuals, emphasising feedback control. Chapter 3 introduced a lead-follower paradigm that examined linkages between two individuals' rhythmical arm movements. In Chapter 4 temporal linkages were explored between multiple performers. Dependencies between chains of individuals were found and accumulation of variability across successive performers in a chain was evident. The previous chapter 5 investigated dancers' interpersonal synchronisation and the effect of familiarity on dancers' timing performances. Dancers' synchronisation was found to be affected by the familiarity of the observed and performed dance movement as the timing variability was significantly reduced for ballet compared to novel dance moves. This finding may be explained by an internal forward model. For example, more consistent predictions may have been made for dance movements that had more representations of sensory predictions stored within this model such as ballet moves. In contrast, novel dance moves lacked of a comparable amount of representations due to lack of exposure.

The present study has two aims. The first is to further explore whether the internal forward model is consistent with interpersonal synchronisation, adopting a more controlled paradigm. The paradigm used maintains the lead-follower relationship with the same virtual control of the lead as presented in Chapter 5. However, in contrast to the previous study, participants synchronise with visual recordings depicting their own and another person's movements. In line with the internal forward model, temporal predictions of observed movements that were generated by the one's own motor system were expected to be more accurate, compared to movements produced by another person's motor system.

The second aim of the present study is to shift attention from lower level timing control factors to higher level cognitive factors that may also influence synchronisation performances. For example, in Chapter 1 higher cognitive factors such as intentions, goals and beliefs were discussed as potentially affecting dance ensemble synchronisation. In the present study the effect of the cognitive factor belief, on interpersonal synchronisation is researched. Specifically, participants' belief about the identity of their performance partner was manipulated. Manipulating the belief about the identity was expected to affect the level of attention directed towards the synchronisation partner and one's own performance. On the basis of the idea that individuals may belief that synchronising with one's own movements would be more accurate, more attention will be directed towards one's own performance to fulfil this prediction. Thus, in the present study more accurate synchronisation performance was expected when participants believed to synchronise with their own compared to another person's recording. The results are considered both with respect to implications for internal models and for the common-coding hypothesis.

6.1.1 Processes involved in Interpersonal Synchronisation

In dance ensembles, dancers synchronise their movements to those of other dancers. The underlying mechanisms that are involved in interpersonal synchronisation are not well understood as noted in Chapter 2. One theory that may help explain how synchronisation is achieved is the internal forward model. As described in Chapter 1, the internal forward model involves predictions of one's own performance based on representations of previous motor actions. Research has indicated that the cerebellum stores representations of the motor command. Such representations may be sensory consequences, action contexts and body kinematics (Blakemore, Frith, & Wolpert, 2001). Evidence for the involvement of an internal forward model has been provided in psychophysical studies that investigated predictions of self-generated movements (Blakemore, Frith, & Wolpert, 1999). According to Blakemore and Decety (2001), it may be that the mechanism of internal forward control may also be used to predict other peoples' movements from action observation. The multiple stored representations of sensory predictions (Miall, Weir, Wolpert, & Stein, 1993) that have been formed by self-generated actions in the past may be used to derive predictions of other peoples' motor commands. This would require the simulation of another person's action and mapping them onto one's own stored representations for comparison.

Adopting the idea of internal models as an underlying mechanism in interpersonal synchronisation to the case of dance, dancers may simulate the movements of their dance partner during the performance in order to predict movement timings of ensemble members. However, simulated movements may carry traces of one's own individual way of executing a movement that would enhance predictions of self-generated moves. Simulating other dancers' movements may therefore be less accurate. Thus dancers' synchronisation performance may be expected to be better when it involves synchronising with movements produced by their own motor system compared with movements generated by another person's motor system.

Evidence for enhanced synchronisation performances when synchronising with actions that have been generated by one's own motor system compared with those of another comes from Keller, Knoblich and Repp (2007). They investigated pianists' synchronisation when playing a complementary part with their own auditory recording or another pianists' recording. The pianists, who were naive about who initially produced the part in the auditory recording, performed better when synchronising with their own than other pianists' recordings. The authors concluded that pianists may have simulated the accompanying part during the duet performance. As simulated parts may be expected to entail information of an individual's own idiosyncratic way of movement performances, pianists were able to perform better with their own recording (Knoblich & Flach, 2003).

A further theory for interpersonal synchronisation comes from research into performance perception and the idea that action and perception systems are closely linked (Hommel, Müsseler, Aschersleben, & Prinz, 2001). In interpersonal synchronisation, how we perceive another individual's performance may affect one's own synchronisation performances. Prinz (1997) has postulated a common coding theory for self- and other- produced actions, in which perceived events and planned performances share a common representational area.

This is partly due to the discovery of mirror neurons in monkey ventral premotor cortex, a mechanism known as direct matching. Direct matching refers to a process already seen in newborn infants, of imitating perceived human actions (Meltzhoff & Moore, 1983). Mirror neurons have been found to fire, either when the monkey executes a specific behaviour, or when it observes another monkey or human performing that same behaviour (Gallese, Fadiga, Fogassi & Rizolatti, 1996). A similar 'mirror neuron' system has also been hypothesised to exist in human brains, suggesting a common coding of motor execution and observation (Buccino, Binkofski, Fink, Fadiga, Fogassi, Gallese et al., 2001). Similar to the internal forward model, actions are encoded in terms of their sensory consequences.

The observed resonance within the pre-motor area identified with the mirror neuron system has been found to be modulated by individuals' own motor expertise. For example, Calvo-Merino, Glaser, Grèzes, Passingham and Haggard (2005) found that when expert ballet dancers observed movements within their own repertoire (ballet) compared with movements that were not part of their own repertoire (capoeira), greater activation within areas of the proposed mirror neuron systems was evident. The authors concluded that the increased activation reflected increased resonance and suggested that the level of resonance may be modulated by individuals' own past experience. In a further study the same research group found that the mirror systems resonate to motor familiarity and not purely to visual familiarity (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006).

In line with Calvo Merino et al's finding, evidence for a role of visual experience in perception of movements comes from research by Loula, Prasad, Harber and Shiffrar (2005). They examined the role of motor and visual experience in a visual recognition task, adopting the point light technique. Participants were asked to name the identity of a person in a video which depicted either, themselves, a friend or a stranger performing various activities such as dancing, and walking. Participants showed greatest accuracy in identifying themselves, this then was followed by a poorer performance of identifying a friend, which still was above chance. In contrast, identification of strangers was at chance level. The authors concluded that visual experience plays a significant role in action identification, as observing movements of friends led to greater accuracy in action recognition than observing the movements of strangers. Nonetheless, the role of motor experience also affected participants' perceptual identification, as they were significantly better in recognising their own compared to their friends' movements. Their results showed that neither theory by itself is sufficient to explain how humans observe the actions of others.

Taken together, there are several theories that could explain processes involved in interpersonal synchronisation, such as internal forward models or the common coding theory. An investigation of the role of internal simulation of another person's action in a music ensemble scenario, provided evidence for more accurate synchronisation performances when pianists played with their own auditory recordings compared with other pianists' recordings, as noted above (Keller et al., 2007). In Keller et al.'s study individuals synchronised with auditory performances, it yet has to be explored whether similar findings may be observed when synchronising movements with visual performances. The first experiment in the present chapter aims to examine this, by asking participants to synchronise their movements with visual recordings of their own previously generated performance or with those of another person. Participants are kept naive about the identity of the observed performer in the visual display. In line with the above described theories, internal forward model and the common-coding theory, temporal predictions of observed movements that have been performed by the same motor system may be more accurate, compared with those produced by another person. It therefore was hypothesized that participants' synchronisation would be more accurate when synchronising with their own compared with another person's recording.

6.1.2 Top-Down Modulation of Motor Control

Research into joint action provides evidence for the involvement of higher cognitive factors in cooperative performances. One factor that has been proposed to play a role in joint action is individuals' task representation of their partners' performances. In Sebanz, Knoblich and Prinz's (2003) study participants conducted a go-no go task, either alone or with a partner. In the joint action task, participants observed a human hand pointing to the left or the right. At the same time a red or green coloured ring was placed on the index finger. Participant A for example was instructed to respond to the colour green, whereas participant B responded to the hand pointing to the right. When the two targets for participant A and B spatially overlapped; e.g. index finger pointed to the right and green colour appeared also on the right, responses from both participants were required. Results indicated a slowing down in reaction times compared with conditions in which only one participant was required to perform a response. The authors suggested that this task conflict emerged because participants activated two task rules, representing one's own and the other persons' task instructions at the same time.

Recent research has found that anticipatory motor control may be modulated by the social relationship between two individuals. For example an EEG study (Kourtis, Sebanz & Knoblich, 2010) found stronger anticipatory motor control activity when an individual expected an interaction with a social partner compared with a third person with whom they had not previously interacted. Past knowledge of the social relationship may have acted on participant's expectations which consequently affected their predictive process of the other person's movement. Manipulations about individuals' expectations with regards to another person's actions could also be interpreted as a belief manipulation. Here, the fact that the third person did not interact with the participant before led to the belief that he or she will not interact with the third person in the near future.

Belief manipulation paradigms have been widely used to explore top down modulations of interference effects in movement imitations of congruent compared with incongruent movements. For instance, when participants were asked to execute a qualitatively different compared to exactly the same movement simultaneously with those observed by another person, less accurate spatial reproductions of the arm positions were observed. This interference effect was pre-dominantly found when participants performed with a human agent compared with a non-human agent (Kilner, Paulignan & Blackmore, 2003) and has been interpreted as a bias for human action in the 'mirror neuron' system (Tsai & Brass, 2007).

However, evidence for a human-specific direct matching system is ambiguous. Recent work by Stanley, Gowen and Miall (2007) showed similar interference effects triggered by a moving dot stimulus that followed a biologically plausible (human) or implausible velocity profile (non-human). Interestingly, when participants were made to believe that the actual human dot stimulus was computer generated, no interference effect was anymore observed. It therefore has been suggested that internal simulations may be prone to top-down influence. Specifically, Liepelt and Brass (2010) concluded the access to the 'mirror system' may be decreased when individuals observe non-human compared with human agents.

A literature search failed to reveal any publications relating to the effects of higher cognitive factors such as task representations or belief on interpersonal synchronisation performances. In the present study a belief manipulation paradigm, similar to the one described by Stanley et al. (2007) is chosen, to investigate the effect of top down modulations in a synchronisation task. In a second experiment, participants synchronise their movements with a visual recording of their own performance and with those of a match person. In comparison to the first experiment participants' belief about the identity of the person within the recording is manipulated. For example they could be told that they would synchronise with their own movement recording, yet they actually synchronise with the recording of another person. Participants may expect better performance when synchronising with their own movements compared with those of another because they were able to generate the exact movement before. It was therefore hypothesized that participants may perform more synchronously when they believed to synchronise with their own than with another persons' recording. Here, more attention may be directed towards the monitoring and predictive processes within the motor system for 'self belief'. It should be mentioned that the opposite may also be true. For example as individuals may expect worse performance with another person, more attention may be directed to the monitoring and predictive processes involved in motor control when synchronising with another compared with one's own recording.

Relating this to the scenario of dance, dancers may perform more synchronously when they believe they synchronise with another dancer that is predicted to perform well, for example a solo performer. Therefore, participants may direct more attention towards the timing of their dance partner. In contrast, when dancers perform with new ensemble members, a senior dancer may expect them to perform less accurately. Therefore, less attention may be directed towards the dance partners' timing, allocating more attentional resources to one's own performance. This consequently, could lead to less accurate synchronisation performances between two dancers.

6.1.3 Present Study

The present chapter set two research aims, each examined in two separate experiments. The first study aimed to explore whether the internal model theory is consistent with visually mediated interpersonal synchronisation. In line with the internal model theory, temporal predictions of observed movements that have been performed by the same system may be more accurate, compared to movements that have been produced by another person's motor system. To test this, a lead-follower paradigm is adopted in which participants execute arm movements in synchrony with those of a virtual partner, presented in a 3-d point light display based on kinematic data collected using a three dimensional motion tracking system. Executed movements involved a simple up and downwards movement of the right arm. Temporal perturbations in form of a period change were introduced as applied in pervious experiments. In line with Keller et al.'s (2007) study, participants were expected to synchronise more accurately with recording of one's own generated movements compared with those generated by another person. Synchronisation was estimated by the measures of asynchrony, as in Chapter 5. Smaller and less variable asynchrony was expected for synchronisation with one's own movement recordings.

Furthermore, the factors movement type (up, downwards movements) and trial type (F-S, S-F) were examined. No differences between the synchronisation of up compared with downwards movements were expected, as previous literature has yet not investigated time differences between these two types of movements. In addition, also no differences between trial types were expected as those were not evident in Chapter 3 and Chapter 4 which adopted the same type of temporal control. Lastly, post-perturbation recovery was expected to show faster adjustment to the new period when synchronising with one's own compared with another person's recording.

The second aim was to explore whether participants' belief about the agency of the performance partner would affect synchronisation performances. The term agency stands for the identity of the observed person. In a second study participants perform exactly the same task as in experiment one, with one exception. Participants' belief about the agent in the visual display is manipulated. For example they may be told that they would synchronise with their own generated movement recording, yet they actually synchronised with the recording of another person. If predictions of experiment 1 were found to be true, participants' may also predict and belief to perform more accurate when synchronising with their own compared with another person's movements. It therefore was hypothesised that participants perform smaller and less variable asynchrony when they believed to synchronise with their own compared with another persons' recording.

6.2 Methods

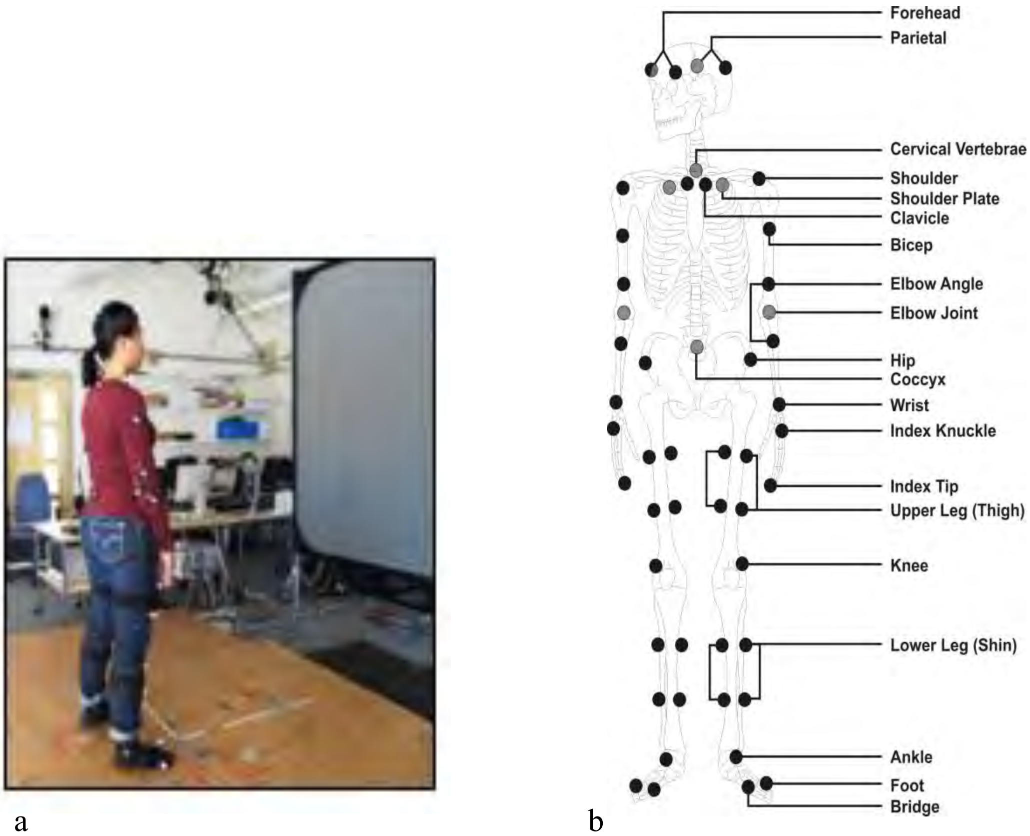
6.2.1. Participants

Twelve right – handed adults served as participants (Mean age 23.7 ± 2.6 (SD) yr; 6 females, 6 males). All participants provided informed consent, were naïve to the purpose of the study and reported no neurological or visual disorders. All participants were tested for stereopsis vision (depth perception from retinal disparity, Lugtigheid, Brenner and Welchman, (2011)). Participants were recruited via the University of

Birmingham Research Participation Scheme and either received £20 or research credits for their participation.

6.2.2 Apparatus

Participants performed a given arm movement whilst standing on a wooden platform and facing a 3D stereo display (Inition Systems, 2.50m x 1.90m) which was placed 1.20 m in front of them (Figure 6.1. a). Two computers were used; one which initiated the 3D virtual display and a second one which recorded the kinematics of the movement trajectories at 200Hz, using a twelve camera optical motion tracking system (Qualisys Oqus, Gothenburg, Sweden). Fifty two 20 mm diameter spherical reflective markers were attached to the participant's body with double sided sticky tape. Markers were placed on the legs and feet (24 markers), hips (3 markers), on arms (16 markers), spinal bone C7 and shoulder plates (3 markers), collarbone (2 markers) and head (4 markers) (Figure 6.1.b). This number of markers used ensured their recordings as a point light display could easily be recognised as a human. Participants wore 3D anaglyph glasses to perceive the 3dimensional effect of the stereo display. A photo sensor was placed at the corner of the screen, allowing synchronisation of the stimuli recordings with the recordings of the participant's kinematic data.

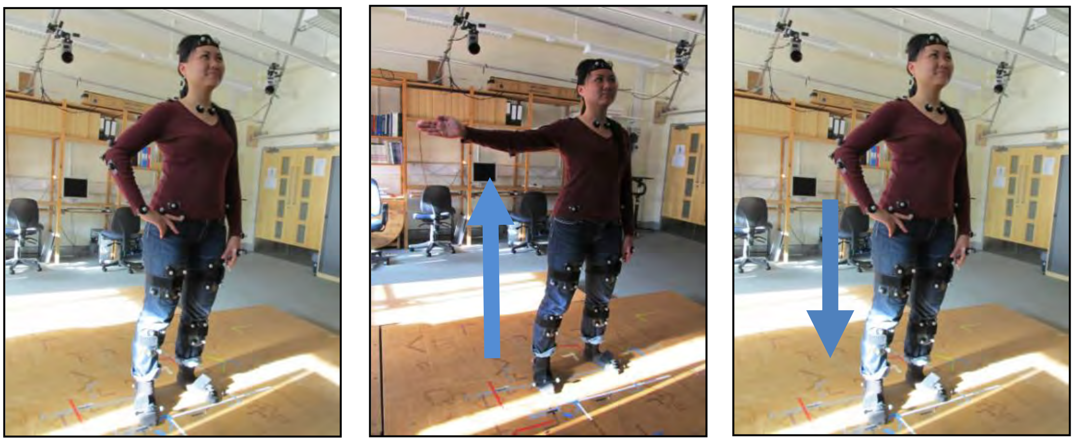


a b

Figure 6.1: ***Illustration of Experimental Setup and Marker Placements***. On the top left, a participant is standing on a platform, facing the 3D screen on which was displayed the virtual partner (a). On the top right, locations of the marker placement on participants is presented (b).

6.2.3. Stimulus Materials

The stereo display presented a point light figure (52 points), performing ten up and downwards movements of the right arm. The arm movement started from a resting position, in which the right arm rested on the right hip. Once the movement was initiated the final position of upwards movement was reached at shoulder level. A downwards movement was created by reversing the same upwards movement, to ensure that both movements did not vary in their execution. The virtual figure was based on real motion tracking recordings of the participants. It was displayed at a ratio of 2/3 of participants’ original body size (Figure 6.2). Temporal modifications of the stimuli were made in Matlab, creating temporally perturbed and unperturbed movement stimuli. Only one recording of the participants’ upwards movement (from the start of the movement up to its final position at shoulder height) was used to create the stimuli.



a b c

Figure 6.2: ***Movement Task.*** The starting position of the movement (a), followed by the upwards movement (b) then followed by the downwards movements (c).

In order to control the time duration of the upwards movement across participants a cubic spline interpolation was used to create fixed time durations, using the Matlab toolbox. The time durations of the stimuli for the unperturbed conditions consisted of three slow (1250, 1300, 1350 ms) and three fast tempo (950, 1000, 1050 ms) movement durations. The spread of durations was intended to avoid anticipation of the movement tempo by participants. Each movement was followed by a pause (holding the last frame) of 500 ms. The exact same upwards movement then was reversed, ensuring that the downwards movement contained the same movement dynamics as the upward movement. This again was followed by another pause for 500 ms. Each up and downwards movement was repeated ten times within a trial. In total six unperturbed stimuli recordings were created ranging from 29 to 37 seconds in trial length, due to varying tempo. Perturbed stimuli consisted of one period change; either starting with slow tempo movements followed by fast tempo (S-F) movements or the reverse (F-S). The magnitude of the period change was held constant (See table.6.1). The point of period change was introduced on either the 5th or 6th upwards movement, to avoid the participant attempting to predict its occurrence (Figure 6.3). In total twelve perturbed stimuli for participants own recordings were created ranging from 32.5 to 34.5 seconds in trial length. The exact same procedure of stimuli creation was done for a matched partner for each participant. Matches were done based on the similarity in height, weight, and gender and body configuration. Overall 12 unperturbed and 24 perturbed stimuli were created, from each the participants' and the matched agents' recordings.

Table 6.1: ***Stimuli Trials.*** The interval duration for unperturbed and perturbed trials are shown. Three fast and slow tempo variations for Unperturbed trials. Similarly, three F-S and S-F variations for Perturbed trials, for each period change at position five and six.

Unperturbed Trials				Perturbed F2S		Perturbed S2F	
	Fast		*Slow*	*Position*	*F > S*	*Position*	*S > F*
A	950 ms	A	1250 ms	5_A	1000 > 1350 ms	5_A	1350 > 1000 ms
B	1000 ms	B	1300 ms	5_B	1050 > 1400 ms	5_B	1400 > 1050 ms
C	1050 ms	C	1350 ms	5_C	950 > 1300 ms	5_C	1300 > 950 ms
				6_A	1000 > 1350 ms	6_A	1350 > 1000 ms
				6_B	1050 > 1400 ms	6_B	1400 > 1050 ms
				6_C	950 > 1300 ms	6_C	1300 > 950 ms
Total							
3		3		6		6	
Total Overall							
						18 trials per agent	

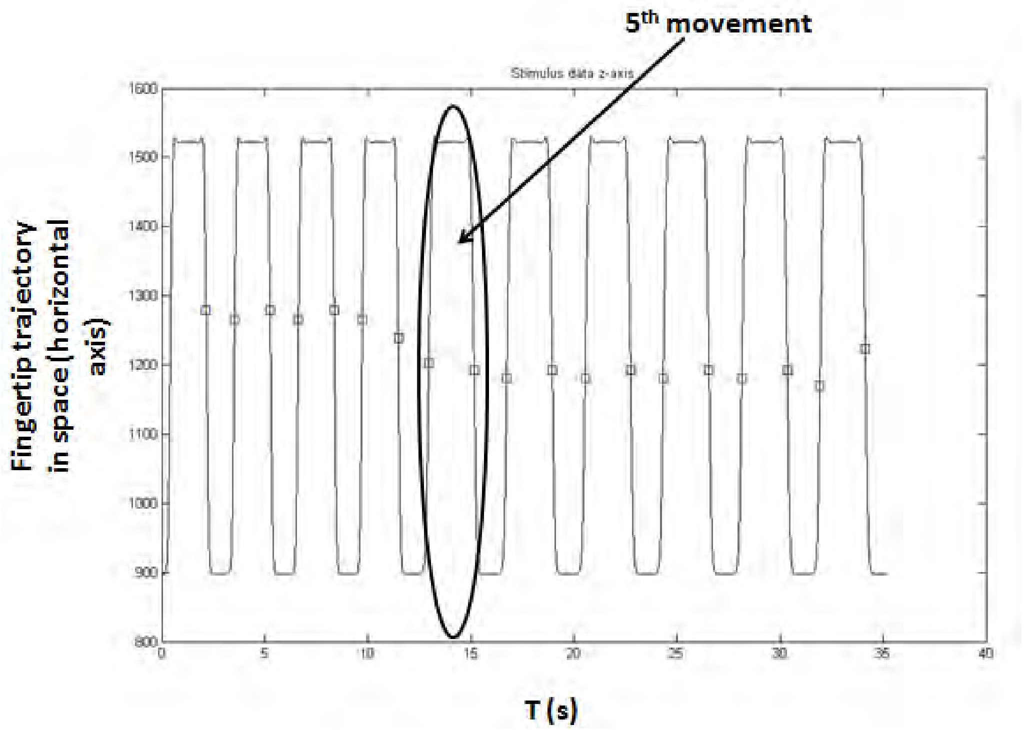


Figure 6.3: ***Illustrates Stimulus Trajectory Profile.*** The trajectory of the fingertip of the stimulus in which the periods change was introduced at the 5th movement cycle.

6.2.4 Procedure

6.2.4.1 Recording Session

Before starting the recording of the participants' movements, participants were told that this session tested their suitability for being a participant in this experiment and that potential unsuitability would lead to discontinuation of this study. This story was told in order to ensure that participants were naïve to the purpose of this study. After signing the consent form and reading the instructions, markers were placed on the participant and a stereopsis test was undertaken. The stereopsis test consisted of four video stimuli that were presented in two and three dimensions. Participants were asked to identify the dimensions of each video. All participants were able to identify the correct dimension of the video stimuli. One example recording then demonstrated the up and downwards movement which the participant had to replicate. Verbal corrections were given until the target movement was accurately replicated. Participants then had to perform the movement in synchrony with an auditory metronome, to ensure that all participants performed the movement at a similar duration. The movements performed to the metronome were recorded and used for stimuli creation. Lastly, a height measure was taken. Each recording session lasted on average 30 minutes.

6.2.4.2 Effect of Agency

The first experiment took place on average five days after the recording session. All 52 markers were again placed on the participant. Participants were instructed to perform the same movement as in the recording session. However, they now were required to synchronise the overall movement as accurately as possible with a point light visual display of a person performing the same action. The experimenter informed the participants that the visual display would consist of a series of dots which represented the human frame. No information of the identity of the person in the visual display was given. Participants then were asked to wear 3D anaglyph glasses. Two test trials were conducted before the actual experiment began. Session two consisted of 6 unperturbed and twelve perturbed trials of the participants' own recording (6 F-S, 6 S-F) and 6 unperturbed and twelve perturbed trials of a matched person, with a total of 36 trials and an average duration of 40 minutes per session. A break was given after 18 trials.

6.2.4.3 Effect of Belief

Experiment 2 took place on average three days after experiment 1. Again all makers were placed on the participant and the same instructions as in experiment one were given. Unlike in experiment one, participants were now given verbal and visual cues that they were either synchronising to themselves or to another person. This was done just before each trial, presenting either their name or the name of the other person in the middle of the screen. To ensure they were reading the names on the screen, the experimenter also read out to whom participants were synchronising with at the same time when the name was presented on the screen. The manipulation of the belief to which person the participant synchronised to was either true or false. In total, session three consisted of 72 trials (Figure 6.4). Two breaks were given, each after 24 trials. The recording session lasted on average 90 minutes

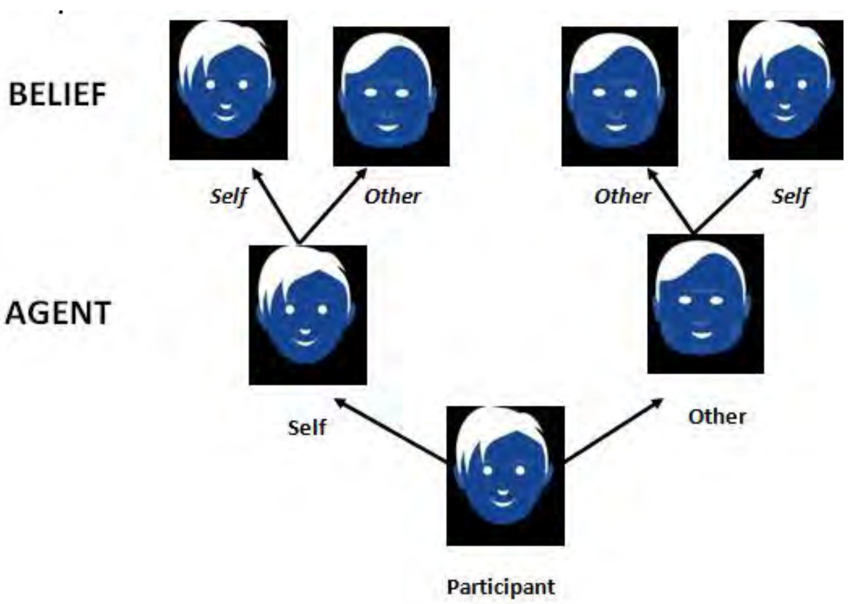


Figure 6.4: ***Paradigm of Experiment 2.*** Design of experiment three's belief manipulation.

After the recording, participants were asked to participate in a visual matching and identification task. In both tasks participants were asked to sit in front of a computer, watching video stimuli from the testing sessions. The visual matching task contained three video stimuli; one of themselves, one of their matched partner from the testing session and another new point light stimulus which was similar to both their own and their matched partner's point light stimulus in terms of height and body configuration. The movement duration was exactly the same for all three displays, 1000 ms per movement. During each trial two video stimuli were presented one after another, each presenting two up and downwards movements in alternation. After each presentation of the two videos, participants were asked to state whether both videos were the same or different. This task consisted of three blocks, containing nine trials which were randomized and counterbalanced across participants, with a total of 27 trials (Figure 6.5.a). Lastly, in the identification task participants were asked to identify themselves. After the presentation of one video stimulus of either their own, their matched partner or the new third point light recording, participants were asked to state whether they believed that the person in the video was their own recording or someone else's. The three video stimuli were presented in a randomized order and presented three times each, with a total of nine trials (Figure 6.5.b). Both tasks were conducted to ensure that participants were able to visually discriminate the video stimuli (visual matching task) and check whether a successful false belief was induced (identification task). At the end participants were debriefed about the belief deception. Overall, experiment 2 lasted around 2.5 hours.

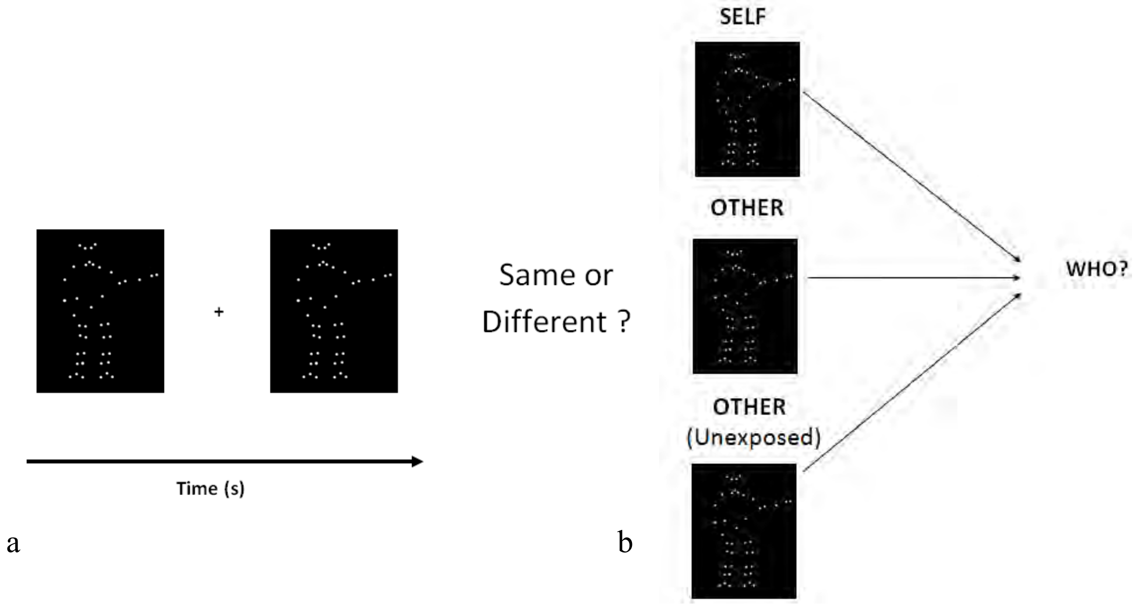


Figure 6.5: ***Discrimination Tasks.*** Two videos were presented, one after the other in the discrimination task (a), one video of participant's, their matched person or a new match person's recording was presented (b). After each presentation, participants were asked to make judgement about the agency of the person displayed in the recording.

6.2.5 Analysis

6.2.5.1 Kinematics

Stimulus and trial data were aligned in time, using the first peak onset of the photo sensor data. Out of the 52 markers the vertical movement component of the right index finger (rIF) of both the stimulus and trial data was selected for further analysis. The vertical position of the rIF was chosen as the performed movement was an up and downwards movement of the right arm, moving along the vertical axis. The analysis of rIF consisted of the measure of peak velocities compared with the measure of target positions, as this measure resulted in less variable and smaller synchronisation errors (see Chapter 5). In order to identify the *peak velocity* values of the extension phase (upwards movement) and the flexion phase (downwards movement) of the arm, the data of the rIF was digitally low-pass filtered at 2Hz (dual pass 8th –order Butterworth filter) and then differentiated. For each trial, a total of ten peak velocity times were determined for each upwards and downwards movement. The dependent measures of *relative mean Asynchrony* (A) and mean *variability of the asynchrony* (sdA) were determined. For both measures, the movement (5th or 6th upwards movement) at which the period changes were introduced and the 1st movement of each trial was excluded.

In experiment 1, the factor of most interest was *Agent*, the identity of the person with whom participants' synchronised their movements with. To compare participants' synchronisation performance with different stimuli recordings, a 3 x 2 x 2 repeated measures ANOVA was used; with the within-subject factors *Trial Type* (Perturbed F-S, Perturbed S-F, Unperturbed), *Agent* (Self-A, Other-A) and *Direction* (Up, Downwards movement). In experiment 2, an additional factor *Belief* (Self-B, Other-B) was added, for which a 3 x 2 x 2 x 2 repeated measures ANOVA was undertaken. Non-significant results (p>.05) were not discussed. Where the assumptions of sphericity were violated, the degrees of freedom were corrected using the Greenhouse - Geisser estimates. Significant interactions were further investigated. For significant two-way interactions, paired t-tests were performed between the appropriate levels of the factors, using a Bonferroni alpha correction for multiple tests. For significant three-way interactions, appropriate two two-way interactions were conducted and further significant effects were analysed using paired t-tests. Overall, in experiment 1, 3.7% and in experiment 2 2.7 % of trials had to be excluded due to noise in recordings or a missed movement production by the participant. Further analysis of IMI, sdIMI and absolute asynchrony was conducted but not presented in the present chapter (further details see Appendix).

Similar to the experiments in Chapter 4 and 5, period changes were introduced in perturbed trials to allowed the investigation of how fast participants adjusted their timing post-perturbation and whether their recovery was affected by the Agent and Belief manipulations. Post-perturbation analysis was exactly the same as in Chapter 5. This analysis was only conducted on trials in which the perturbation was introduced at the 5th upwards movement to allow for a larger data set to be analysed. In total 12 trials per participant were analysed in experiment 1 and 48 trials per participant in experiment 2. For further details of the analysis see Chapter 5. There were ten possible recovery positions (Figure 6.6). The position of recovery and the mean absolute asynchrony value of each pairing were analysed using a 2 x 2 repeated measures ANOVA (Agent x Trial Type) for experiment 1 and a 2 x 2 x 2 repeated measures ANOVA (Agent x Belief x Trial Type) for experiment 2.

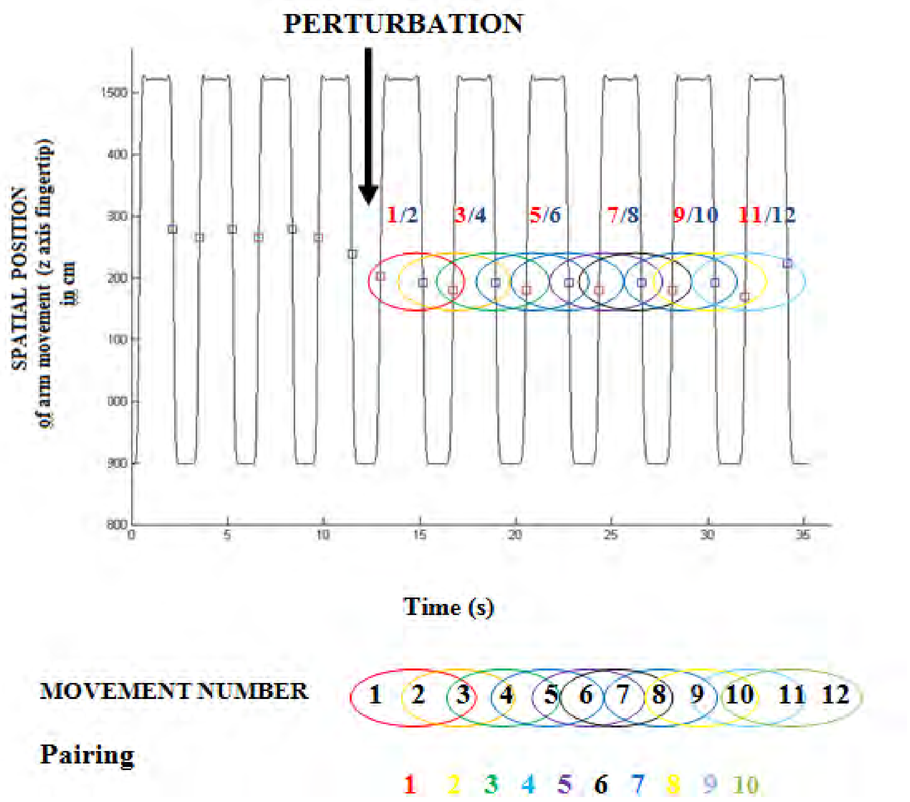


Figure 6.6:*Post-Perturbation Recovery Analysis*. In the graph spatial position of the arm movement and its peak velocity values of each up (red circles, numbers) and downwards (blue circles, numbers) movement are presented. Asynchrony values of the peak velocity for all movements post-perturbation were grouped in three and in order indexed by a pairing number.

6.2.5.2 Discrimination and Identification Scores

For the discrimination task each correct and incorrect answer was noted down. The percentage of correct answers was calculated for each participant (100% = 27 correct answers). The percentage of correct answers was correlated with the average value of each DV across experiment 1 and 2. Similarly, for the identification task the percentage of correct answers was calculated and correlated with the average of each DV across both experimental sessions. The latter analysis was not developed for statistical analysis and therefore any findings should be interpreted with caution. Instead, the identification task was conducted in order to test if the belief manipulation was successful.

6.3. Results

The results for experiment 1 are presented first in the following order, ANOVAs of mean asynchrony and standard deviation of asynchrony followed by the recovery analysis. Then ANOVAs of experiment 2 are reported; the mean and standard deviation of asynchrony, followed by the recovery analysis. Lastly, correlation analysis between the discrimination and identification scores and the asynchrony and the standard deviation of asynchrony are summarised.

6.3.1 ANOVAs of Effect of Agency (Peak Velocity)

6.3.1.1 Mean Asynchrony (A)

A reveals information about the directionality and the magnitude of the average asynchrony relative to the virtual performer. The overall mean A was 22.9 ms. A 3 x 2 x 2 repeated measures ANOVA revealed a main effect of *Trial Type* (F(1,33,1462) = 6.79, $p < .05$, $\eta_p^2 = .38$) with positive mean asynchronies of different magnitudes. The average mean A for Unperturbed Trials was 6.3 ms, 28.7 ms for Perturbation F-S and

33.5 ms for Perturbation S-F. A Bonferroni pairwise comparison exposed a reliable significant difference between Unperturbed trials compared to Perturbed Trials, F-S ($p < 0.01$) and S-F ($p < 0.05$). No difference was found between Perturbed F-S and S-F. A second main effect of *Agent* ($F(1,11) = 5.11$, $p < .05$, $\eta_p^2 = .32$) revealed positive mean asynchronies of different magnitudes. Participants' mean A were significantly larger when they synchronised with their own recording (Self-A, 30.3 ms) compared with another person's recording (Other-A, 15.4 ms) .Furthermore, a main effect of *Direction* ($F(1,11) = 30.94$, $p < .001$, $\eta_p^2 = .74$) was also found. Larger positive mean A were observed for upwards movements (59 ms) compared with a smaller negative mean A for downwards movements (-13.3 ms). Upwards movement were on average behind the virtual performers' upwards movements, whereas downwards movements were ahead of it.

Two significant interactions were found, a two - way interaction between *Trial Type* and *Agent* ($F(2,22) = 5.74$, $p < .05$, $\eta_p^2 = .34$) and a three – way interaction between *Trial Type, Agent* and *Direction* ($F(2,22) = 3.86$, $p < .05$, $\eta_p^2 = .26$). For the interaction between *Trial Type* and *Agent,* a series of paired t-tests indicated a significant difference between Self-A and Other-A for Unperturbed trials only, ($t(11)=3.05$, $p < 0.025$). Here participants' performances resulted in larger positive mean A for Self-A (25.5 ms) compared with smaller negative mean A for Other-A (-12.8 ms). As illustrated in Figure 6.7, only for Unperturbed trials participants' synchronisation with another person was on average ahead of the recording stimuli. This effect was found to have disappeared when period changes were introduced. In addition, the difference between Unperturbed trials and Perturbed F-S ($t(11)=4.24$, $p < 0.01$) and S-F ($t(11)=3.05$, $p < 0.025$) was significant. In Unperturbed Trials participants synchronisation with Other-A (- 12.8 ms) was significantly smaller and resulted in a negative mean A, compared with Perturbed F-S (27.30 ms; p < .01) and S-F (31.68 *ms*; *p* < .05) which resulted in slightly larger positive mean As. This difference between Trial Types was not evident for Self-A. Participants trailed consistently behind the point light stimuli display, regardless of the Trial Type.

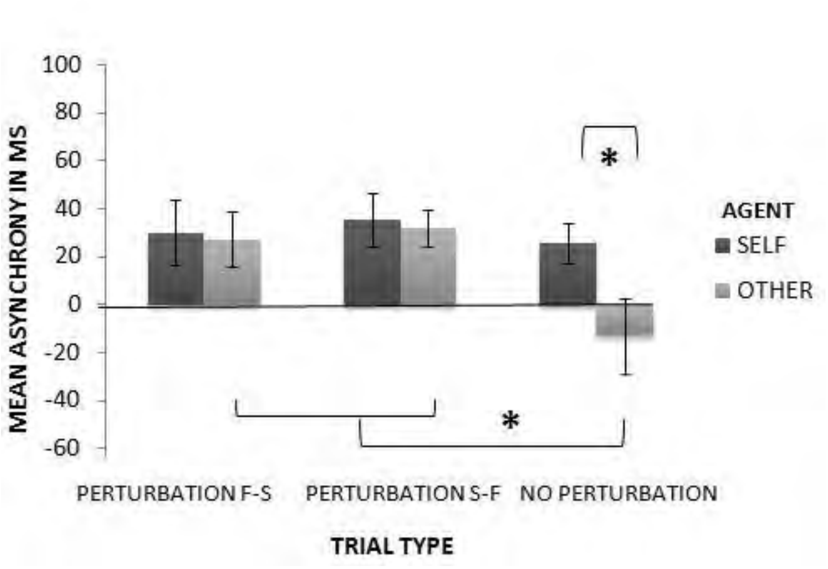


Figure 6.7: ***Interaction between Agent x Trial Type for mean A (Exp 1), N=12.*** * indicates if main effect was significant for separate paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

For the three way interaction between *Trial Type, Agent* and *Direction* two separate ANOVAs, followed by separate paired t-tests further revealed that the significant difference of Other-A's mean A (14.3 ms) compared with Self-A (61.9 ms) was only found for upwards movements in Unperturbed trials (t(11)= 4.98, p < 0.001). Figure 6.8 shows that synchronisation with one's own recording resulted in significantly larger positive mean As compared with synchronising with another person's recording. However, in both Self-A and Other-A, participants trailed on average behind the point light stimuli when performing upwards movements. In line with the two way interaction of *Trial Type* and *Agent* during Unperturbed trials, Other-A's mean A was significantly smaller compared with Other-A's mean A for Perturbed F-S ((*p* < .025; 67.8 ms) and S-F (*p* < .025; 74.6 ms). This was observed for upwards movements only. No significant differences between Agent and Trial Type were found for downwards movements (p>.05). Yet, overall a consistent main effect of direction was evident (p<.001).

Figure 6.8: ***Interaction between Agent x Trial Type x Direction for mean A (Exp 1), N=12.*** * indicates if main effect was significant for separate paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

6.3.1.2 Standard Deviation of Asynchrony (sdA)

SdA reveals the dancers consistency in their synchronisation performance, measuring the dispersion from the mean A. The greater the sdA is the more dispersion from the mean A and the less consistent participants' synchronisation performance is. The overall mean sdA was 58.2 ms. The 3 x 2 x 2 repeated measures ANOVA exposed a main effect of *Direction* (F(1,11) = 68.34, p < .001, $\eta_p^2 = .86$) which was due to less variability in upwards (50.5 ms) than in downwards movements (65.9 ms). Thus, participants' synchronisation performance with the stimuli was more consistent for upwards than for downwards movements.

A significant three-way interaction between *Trial Type, Agent* and *Direction* (F(2,22) = 3.88, $p < .05$, $\eta_p^2 = .26$) (Figure 6.8) was also exposed. Two-way ANOVAs analysis revealed no significant effect of *Agent* on *Trial Type* or *Direction* (p > .05). In line with the observed main effect of direction only significant effects of *Direction* were noted for all Trial Types (p<.05) during both Agent conditions (all p < .05).

6.3.1.3 ANOVAs for Post-Perturbation Recovery

A measure of period recovery was conducted to investigate whether participants are faster in adjusting to temporal changes when they synchronise with their own' movement recording compared with another person's recording. Figure 6.9 illustrates example recovery trajectories post-perturbation for six participants. Participants' recoveries for Perturbed F-S show some gradual adjustment from larger asynchronies converging to smaller asynchronies. In contrast, for Perturbed S-F trials fast recovery is shown. Some evidence of negative lag one autocorrelation was apparent in that as smaller asynchronies are often followed by larger asynchronies. Here smaller asynchronies were observed downwards movements, whereas the larger asynchronies illustrated upwards movements. This could imply that participants corrected faster movement durations with longer ones.

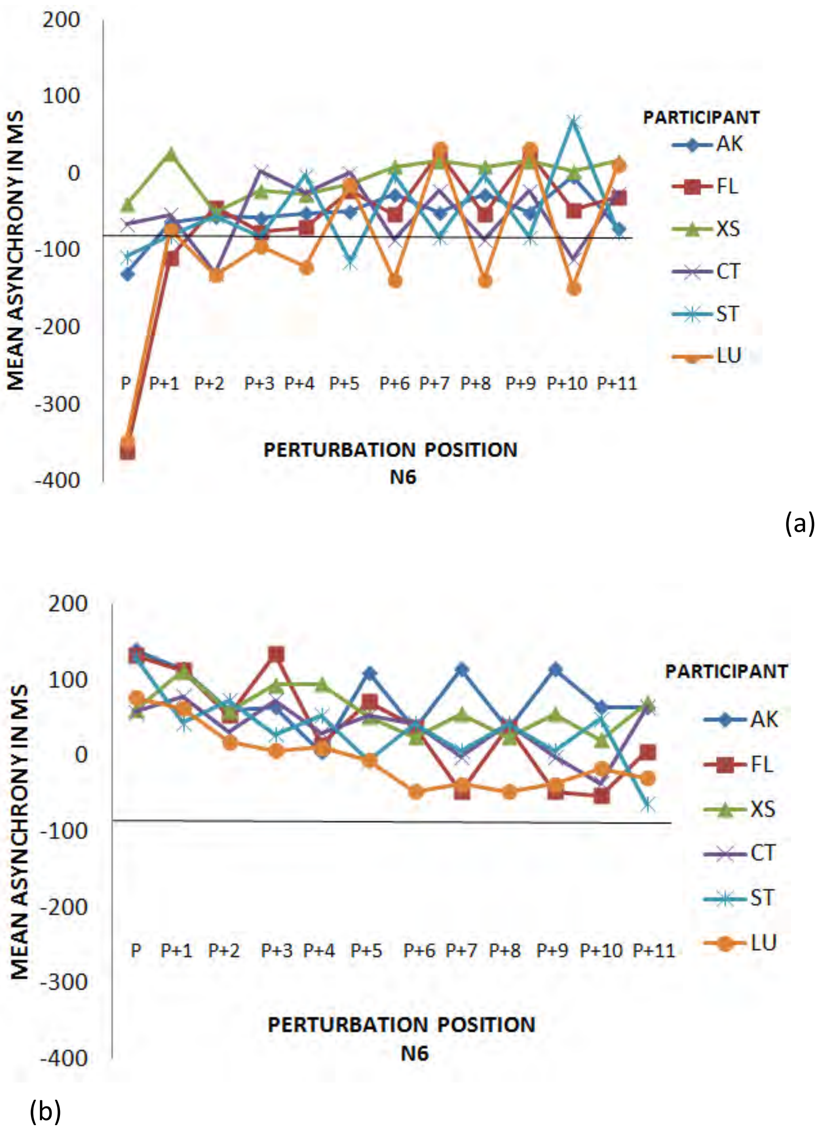


Figure 6.9: ***Example Recovery Trajectories.*** Example trajectories of six participants of asynchronies starting at the period change (P), followed by asynchronies after period change (P+1, P+2 ...). P = upwards A, P+1 = downwards A, P+2 = upwards up to P + 11. Perturbation F-S (a) shows a slowing down in tempo and Perturbation S-F (b) illustrates a speeding up in tempo during movement.

The mean position of recovery and the mean A value of the position were separately analysed. A 2 x 2 repeated measures ANOVA exposed a significant main effect for *Agent* ($F(1,11) = 11.31$, $p < .01$, $\eta_p^2 = .51$) for the recovery position.

Participants' were found to recover faster for Self-A (mean position: 4.8) compared with Other-A (mean position: 6.4). No significant main effect of recovery value was found ($p>.05$), suggesting that participants stabilised their movements on average four to six movements after a perturbation for Self-A and after six to eight movements for Other-A conditions.

6.3.2 ANOVAs of Effect of Belief

Experiment 2 manipulated the effect of belief in addition to the agency with which participants synchronised with.

6.3.2.1 Mean Asynchrony (A)

The mean A was 5.4 ms. A 3 x 2 x 2 x 2 repeated measures ANOVA only exposed a significant main effect of *Direction* ($F(1, 11) = 13.76$, $p < .01$, $\eta_p^2 = .56$). Similar to the findings in experiment 1, results of experiment 2 showed that smaller positive mean As were observed for upwards (26.5 ms) and larger negative mean As for downwards movements (-37.3 ms). Thus, upwards movement trailed behind the movements of the recording stimuli whilst downwards movements were on average ahead of the stimuli. No main effects of Agent and Belief were found.

6.3.2.2 Standard Deviation of Asynchrony (sdA)

The overall mean sdA was 60.5 ms. A 3 x 2 x 2 x 2 repeated measures ANOVA found a significant main effect of *Direction* ($F(1,11) = 24.50$, $p < .001$, $\eta_p^2 = .69$), as previously found in experiment 1. Participants' sdA were smaller for upwards (54.9 ms) than downwards movements (66 ms). In addition, a significant main effect of *Belief* ($F(1,11) = 8.26$, $p < .05$, $\eta_p^2 = .43$) was revealed.The average sdA was significantly smaller for Self-B (57.2 ms) compared with Other-B (63. 8 ms).

6.3.2.3 ANOVAs for Post-Perturbation Recovery

The mean position of recovery and the mean A value of the position were separately analysed. Unlike in experiment 1, no significant main effect for *Agent* was evident for the recovery position. In experiment 2, participant's recovered their synchronisation on average between the 5th and 7th movement post-perturbation. Nonetheless, a significant main effect of *Agent* was observed for the mean A value of the recovery position ($F(1,11) = 6.59$, $p < .05$, $\eta_p^2 = .38$). Participants' recovery position value was significantly smaller for Self-A (22.8 ms) than Other-A (32.5 ms). In experiment 2, participants showed no self-advantage when synchronising with their own' movement recordings in terms of faster recovery, yet their overall synchronisation error at the position of recovery was found to be smaller when synchronising with their own recordings.

6.3.3 Dependencies between Discrimination and Synchronisation Accuracy

Table 6.2 presents the average scores obtained across all participants (N=12) for the stimuli discrimination and identification task. The percentage of the correct responses was correlated against each participant’s performance of mean A and sdA, across all trials of experiment 1 and 2 in which the stimuli agent was their own or another person’s recording. One significant negative correlation was found between participants’ ability to discriminate stimuli and their sdA performance when synchronising with their own recording (r(12) = - 0.59, p < 0.05) (Figure 6.10).

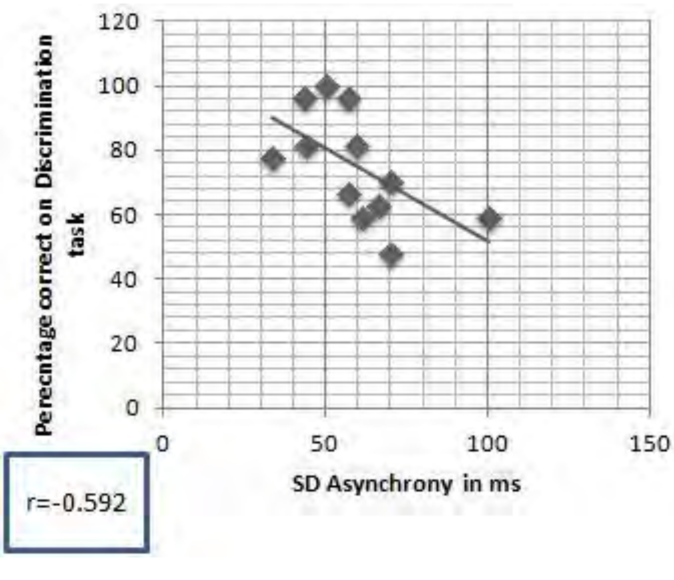
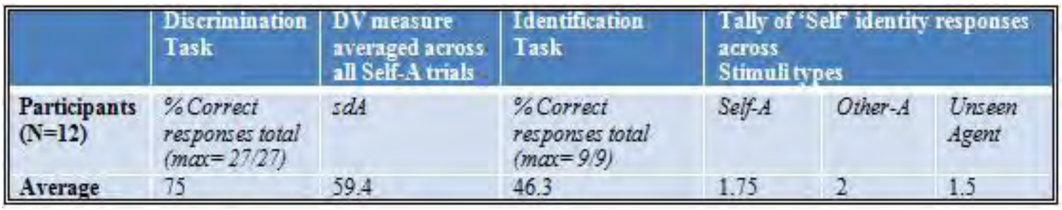


Figure 6.10: ***Negative Correlation between sdA for Self-A and Stimuli Discrimination Percentage (Exp 2).*** Trend line shows negative correlation. The more accurate the discrimination scores the smaller the sdA.

The greater the ability of a participant to discriminate the visual point-light displays was the less variable was his or her synchronisation performance.

Research by Keller et al. (2007) found that pianists who were better at recognising their own performance were also better in their synchronisation performances. Although our identification task was not designed for such correlations, to replicate these findings correlations between the percentages of correct responses of the identification task and participants synchronisation accuracy were also conducted. However no significant correlations were found. Therefore, participants who scored higher on identification scores for themselves were not associated with synchronising significantly better to their own recordings.

Table 6.2: ***Scores for Discrimination and Identification Task (N=12).*** Overall sdA value averaged across all factors.



	Discrimination Task	DV measure averaged across all Self-A trials	Identification Task	Tally of 'Self' identity responses across Stimuli types		
Participants (N=12)	*% Correct responses total (max= 27/27)*	*sdA*	*% Correct responses total (max= 9/9)*	*Self-A*	*Other-A*	*Unseen Agent*
Average	75	59.4	46.3	1.75	2	1.5

Lastly, to ensure that any discrepancies between the peak velocity values in stimuli generated from each participant and the stimuli to which they were paired with had no effect on their synchronisation performance, additional correlation between participants' DVs and the discrepancies between the stimuli velocity peak values were examined. No significant correlation between the discrepancies and participants' synchronisation performance were found. Therefore, differences in observed velocity profiles had no effect on participants' synchronisation performances.

6.3.4 Summary

Taken together, an effect of *Agent* was found for mean A in experiment 1 which suggested larger A when participants synchronised with their own compared with another persons' recording. In contrast to this, post-perturbation recovery analysis showed that participants recovered on average faster when they synchronised with their recordings (experiment 1). Similarly, the synchronisation error of the recovery position was found to be significantly smaller for Self-A conditions compared with Other-A conditions (experiment 2). Furthermore, the more accurate participants' ability was to discriminate between the point-light displays the less variable was their timing performance with their own recordings. The same or reverse was not found for Other-A.

Lastly, a main effect of *Belief* was exposed. Less variable synchronisation performance was observed when participants' believed to synchronise with their own compared with another person's recording, irrespective of the actual identity of the person presented on the display.

6.4 Discussion

The present chapter aimed to explore the role of an internal forward model in interpersonal synchronisation. Two research experiments were conducted, investigating two experimental questions. The first experiment aimed to examine if individuals' temporal predictions of observed movements that have been generated by their own motor system would be more accurate, compared with observing movements that have been produced by another person's motor system. In order to test this, participants synchronised simple up and downwards movements with visual point-light recordings that displayed their own previously performed movements (Self-A condition) or movements produced by another person (Other-A condition). Temporal perturbations were introduced that allowed for analysis of post-perturbation recovery. Current results were expected to replicate Keller et al.'s (2007) findings which revealed that pianists synchronised more accurately with auditory recordings that present one's own musical recording compared with recordings of another pianist. It therefore was predicted, that participant's synchronisation error would be smaller and less variable for Self-A compared to Other-A conditions. With regards to the post-perturbation recovery, faster recoveries were also expected for Self-A compared with Other-A conditions.

In a second experiment, attention was shifted from low level factors (bottom up) to high level cognitive factors (top down) that may influence synchronisation between two individuals. To test the effect of top down modulations, participant's belief about the identity of the performance partner was manipulated. Participants were told that they would synchronise with their own or another person's recording, which was either true or false. If the predictions of experiment 1 were found to be true, we might also expect participants to be more accurate when synchronising with movement recordings they believed were their own compared with recordings they believed to belong to another person. Consequently, this may affect their monitoring control of the motor system, and the amount of attention directed towards the visual recording. It therefore was hypothesised, that participants would perform smaller and less variable asynchrony when they believed they synchronised with a visual display that presented their own previous movement recording (Self-B) compared with those of another person (Other-B). An interaction between Agent and Belief was expected, as participants' synchronisation was expected to be more accurate when synchronising with Self-A, regardless of the belief. In respect to post-perturbation analysis, it was predicted that recoveries would be faster in Self-B than Other-B conditions. The results of the present chapter are now discussed in detail and their potential implications for dance ensemble performances are explored.

6.4.1 Effect of Agency on Visually Mediated Interpersonal Synchronisation

As noted above, results of the present experiments were expected to be in line with Keller et al.'s (2007) findings. It therefore was predicted that participant's synchronisation error (A) would be smaller and less variable (sdA) in Self-A compared with Other-A conditions. The current results provided rather limited support for the idea that internal simulations may have taken place. Evidence against the involvement of internal simulations that capture idiosyncratic characteristics of one's own movement comes from the results of A and sdA. In experiment 1, participants' synchronisation error was found to be significantly larger for Self-A compared with Other-A conditions. This potentially could suggest the reverse; synchronising with ones' own recording may be less accurate compared with synchronisation with another person's recording. Yet, after further post-hoc analysis this effect seemed to have been caused by two factors, the Trial Type and Direction which are discussed next.

Synchronisation with another person's recording was more accurate in unperturbed trials compared to perturbed trials. No differences between agents were observed in perturbed trials, as perhaps overall more attention was directed towards the stimuli when period changes were introduced. Instead the difference was only found to be evident for upwards movements in unperturbed trials. One explanation may be that participants may have perceived greater discrepancies between their own movement timings' and those of the stimuli of the Other-A at the beginning of each trial. They therefore, may have paid more attention to the visual recordings to continuously correct for the perceived error. However, if this had been the case, significantly larger sdA for Other-A compared with Self-A would have been expected. Yet, this was not found to be evident. Instead the sdA of Other-A was equivalent to Self-A conditions. Nonetheless different attentional strategies may have taken place for the Self-A and Other-A conditions. More attention may have still been paid to Other-A stimuli, resulting in smaller A and less attention may have been directed to Self-A stimuli. For the former, in Self-A conditions participants' may have perceived less temporal discrepancies at the beginning of the trial which resulted in less attentive performance with respect to the perceived stimuli. In order to examine this, future analysis should involve a measure that compares individual's synchronisation performances at the beginning of a trial with middle and end parts of the same trial.

Nevertheless, the finding above should be taken with caution, as the significant difference between Self-A and Other-A was not found to be a consistent finding across all Trial Types and moreover absolute asynchronies (see Appendix) also showed no significant differences. Furthermore, no effect of agent was found in experiment 2. Thus, this may suggest no role of internal simulation in interpersonal synchronisation. Instead, participants may only have used feedback control to correct for any temporal discrepancies. Therefore, another explanation of Keller et al.'s (2007) findings may have been that pianists found it easier to predict performance features affecting expressive timing, such as the style of rubato that they themselves produced. Thus, improved synchronisation with self versus other may have occurred, not because pianists internally simulated the performance of the accompanying part; but rather pianists may have adjusted their own tempo to match the style of rubato.

Yet, the post-perturbation analysis provided some evidence that may be in line with the internal forward model. In experiment 1, participants were found to recover faster post-perturbation when synchronising with their own recordings compared to when synchronising with another person's recording. This was also previously suggested by Daprati, Wiessnegger and Lacquaninti (2007) who predicted more precise detections of deviations when observing one's own movements than someone else's movements, if deviations are equally expected. However, in experiment 1, the observed advantage of synchronising with Self-A was not reflected in the actual recovery value. Equal synchronisation error values were found for the recovery position for both Self-A and Other-A conditions.

Besides the lack of significance for the recovery value, a significant difference for exactly that value was evident in experiment 2. Participants' recovery values showed a smaller synchronisation error for Self-A compared with Other-A conditions. Consequently, once participants adjusted their tempo to the new interval, more synchronous performance was observed when synchronising with their own recordings. Surprisingly, no difference in the recovery position was found, similar to that observed for experiment 1. This may have been caused by the additional factor Belief which potentially affected individuals' attention allocation to the target stimuli, allocating overall more attention to the stimuli displayed. Taken together, based on Daprati's (2007) assumption of individuals' more precise detection of deviations when observing their own movements, exactly this enhanced sensitivity may have facilitated participants' faster detection and adjustment in experiment 1 and led to closer synchronisation post-perturbation in experiment 2. Thus, internal simulations that are predicted to incorporate idiosyncratic ways of one's own movements may have resulted in more precise error detection and adjustment.

However, the advantage of perturbation recoveries for Self-A may also be explained by feedback control models. Once a new period is introduced faster adjustments may have taken place purely based on kinematic, joint and muscle similarities between the observed movements and the participants' movements. Here, participants may found it easier to recovery faster as exactly the same limb with its idiosyncratic constraints, executed the task as the one observed in the stimuli.

In light of the overall findings, the rather limited support for the role of internal simulation in interpersonal synchronisation may have been caused by the way the stimuli was experimentally controlled. To begin with, participants were trained to perform their upwards and downwards movements in a controlled manner, reducing idiosyncratic characteristics of individuals' own movements. Then movement recordings were temporally modified to ensure that each recording contained movements executed in exactly the same time duration across all stimuli, potentially further reducing individual characteristics. Evidence for this point of criticism comes from research on action identification. For example, Sevdalis and Keller (2011) showed that expression intensity of dance movements is important for self recognition amongst dancers and that the perception of personal movement kinematics plays a key role for self-recognition.

Controlled stimuli recordings were also matched for body configuration, thereby salient cues to distinguish the two agents displayed on the screen may have been removed and both recordings may have been treated as the same. However, if this would have been the case, it may have been reflected by generally poor discrimination scores between the stimuli which were not found. Instead, a correlation analysis revealed that participants who performed better at discriminating between the movement recordings were less variable in their synchronisation performance when synchronising with their own recordings. Perhaps, if participants who scored high on the discrimination task in the first place would only have been chosen to participate in the present study, stronger evidence for internal simulations during synchronisation would have been found. Lastly, the present study analysed only one marker. Instead, analysing multiple markers could have shown a more holistic performance, leading to slightly different results.

6.4.2 Top-Down Modulation in Interpersonal Synchronisation

Interpersonal synchronisation may be influenced by higher cognitive factors such as belief. To test the effect of top down modulations, participant's belief about the identity of the performance partner was manipulated. Participants were told that they synchronise with their own or another person's recording, which was either true or false. It was hypothesised that participants would perform with smaller and less variable asynchrony when they believed they synchronised with their own movement recording (Self-B) compared with that of another person (Other-B). With respect to the post-perturbation analysis, it was predicted that recoveries would be faster in Self-B than Other-B conditions. The results of experiment 2 exposed that participants timing variability was affected by top-down modulations. Participants' synchronisation performance was less variable when they believed they synchronised with their own' movement recordings compared with another persons' recordings, regardless of the actual identity of the displayed performer. However, the factor belief did not affect how fast participant's recovered from introduced perturbations.

Overall, the success of the top-down modulation on interpersonal synchronisation is consistent with previous literature in motor control. For example, past literature suggested that an automatic matching of observed movements only take place when observing another human compared to a non-human agent (Kilner et al., 2003). Stanley et al. (2007) investigated whether the human-specific direct matching system may be modulated by higher cognitive factors such as belief. Interestingly, when participants were made to believe that a human stimulus with which participants performed with was computer generated, the interference effect was no longer observed. Further evidence comes from motor priming experiments (Liepelt & Brass, 2010; Longo & Bertenthal (2009) which supported Stanley et al.'s (2007) findings.

Several explanations have been made; one interpretation involves a gating mechanism that controls the mirror neuron system, and another favours an attention hypothesis. For the former, Liepelt and Brass (2010) suggested a gating mechanism to explain their results of a motor priming task. In their study, participants believed they observed either a human or a wooden hand wearing a leather glove. Participants had to either lift their right index or middle finger in response to a number. The number was displayed together with a photograph of a right hand performing either a congruent or incongruent movement to the required response. Their results showed that a motor priming effect was evident for both human and wooden hand. However, the effect was significantly larger when participants believed the hand they observed was human rather than wooden. The authors therefore concluded that the belief about agency modulates the access to the mirror system, decreasing its access when the observer believes he or she observes a non-human agent. Instead, privileged access to the mirror system would be given when the observer believed they viewed a human agent.

In contrast to the gating theory, Longo and Berthenthal (2009) suggested that the level of attention may modulate automatic imitation of perceived actions. They interpret their results based on Ploanyi's (1966) distinction between subsidiary and focal awareness. The former refers to implicit awareness of the stimuli and the latter refers to focal attention to details within the stimuli. Longo and Berthenthal concluded that if individuals' attention is drawn to the artificial nature of the perceived stimuli; focal attention takes place, whilst subsidiary attention is the default regardless of the knowledge of the agent.

The present results may not be in line with a gating hypothesis. Firstly, overall rather limited and inconsistent evidence was given for the involvement of simulation in interpersonal synchronisation (experiment 1). Secondly, if the gating hypothesis, in line with the common coding theory were true, participants' synchronisation would have been expected to be significantly more accurate and less variable in Self-A and Self-B conditions compared to Other-A and Self-B conditions (similar to Liepelt & Brass, 2010). This would have been predicted as perceiving that one's own generated movements would resonate and facilitate the reproduction of that same movement. Even if the gating mechanism could have caused overwriting of the expected self-advantage effect during synchronisation, any interpretations may need confirmation by fMRI data to underline the biological basis for this.

Similarly, it could be argued that attention allocation affected internal forward models within the motor system. For example, participants may have directed more attention to the recording they believed was their own, as they expected better performance and to fulfil their expectations they allocated more focal attention towards the stimuli. In comparison, when participants believed they synchronised with another person's recording worse performance may have been expected. Therefore, less attention (subsidiary attention) may have been directed towards the virtual performer. Yet, recent theories of internal forward models as proposed by Blakemore and Decety (2001), would also predict better performance with one's own recording regardless of the belief, similar to the common coding theory. Thus, current results may only reflect a top down modulation of simple feedback control mechanisms, in line with the attention allocation interpretation stated above. Yet, it may also be true that the expected self-advantage effect when synchronising with one's own movements may have been completely overwritten by the level of attentional processes directed towards one's own motor system and the perceived stimuli.

Lastly, another explanation for the belief effect may be, that increased arousal caused by participants' hearing their own name (Carmody & Lewis, 2006) led to the present results. Thus, participants' increased arousal could have increased their attention towards the stimuli and their own monitoring motor control system, improving their synchronisation performances. Here, no internal beliefs about how well a participant may synchronise with a given partner would have been involved. However, considering that participants heard their name at least 30 times, it may have been expected that the level of arousal would have diminished across trials.

Taken together, overall findings clearly show top down modulations on interpersonal synchronisation. More attention was directed towards one's own believed movement recordings' compared to those of another person.

6.4.3 The Effect of Movement Direction in Interpersonal Synchronisation

Surprisingly, participants' synchronisation performance was also affected by the direction of movement. Participants were found to consistently synchronise more variably with the virtual person when executing upwards compared to downwards movements. Synchronisation with upwards movements resulted in mean positive asynchrony (A) whilst synchronisation with downwards movements resulted in negative A. Positive A suggested that the participants movement timings trailed on average behind those produced by the virtual performer. The opposite is true for negative A, with participants performing ahead of the movements observed. With regards to the present findings, participants were found to show more reactive behaviour for upwards movements, whereas for downwards movements more anticipatory behaviour was shown.

The difference in variability may be explained by the qualitative difference between the two types of movements. In the present study, upwards movements had no fixed physical target point in space, whereas downwards movements ended with the right arm being placed on the participant's hip (physical surface). It may therefore be suggested that upwards movements started with an acceleration phase (speeding up) followed by a deceleration phase (slowing down). In contrast, due to the physical surface at the end of a downwards movement, participants were not required to actively decelerate to control the reach of end position in space. Participants therefore engaged in less controlled movement execution, as downwards movements are mostly gravity driven. This could explain why downwards movements were more variable in their synchronisation performance than upwards movements.

With respect to the difference in the mean A, anticipatory behaviour of downwards movements in comparison to the reactive behaviour of upwards movements may be explained as followed: The Wing and Kristofferson Model (1973) predicts a negative lag 1 autocorrelation between IRIs. When individuals performed a shorter interval this then would be corrected by producing a longer interval and so on. This may have been the same in the present study; participants could have corrected for their faster downwards movements by producing slightly longer upwards movements.

Lastly, it was considered that the reversal of the upwards movement could also have resulted in the anticipatory timing of the downwards movements as observed. Upwards movements followed a trajectory of one quarter of a circle. Here, the peak velocity is predicted to occur half way through the movement. However, since participants' may not have needed to decelerate, the peak velocity may have naturally occurred later, thereby artificially creating the negative asynchrony.

6.4.4 Summary

The present study provided rather limited support that internal simulations may play a role in visually mediated interpersonal synchronisation. Evidence for faster recovery after temporal perturbations was found when synchronising with one's own recording compared with another person's recording. However, overall statistics on participants' synchronisation performance did not show more accurate synchronisation performance when synchronising with one's own movements. Yet, it cannot be ruled out that internal simulations may have been involved as the stimuli were largely controlled. This may have reduced idiosyncratic characteristics that were found to be important in recognising one's own generated movements compared with another person's generated movements.

Furthermore, the present results clearly show that higher cognitive factors, in this instance belief, modulated interpersonal synchronisation performances. Participants' synchronisations were less variable when they believed they synchronised with their own compared with another persons' recording, regardless of the actual identity of the person in the recording. Various possible interpretations may be drawn, focusing on the role of attention that may have modulated the influence of top-down information on lower level synchronisation processes. For example, one interpretation would be that more focal attention may have been directed towards recordings that were believed to depict the individual's own performances, as more accurate performance may have been expected in the first place. In contrast, worse performance may have been expected when synchronising with another person's recording, reducing the amount of focal attention directed towards the recording stimuli.

In respect to dance ensemble performances, dancers may synchronise equally well when performing with their own movement recording compared to another person's movement recording. Differences may rather have arisen due to factors such as motor expertise (enhanced somatosensation) or visual familiarity of the observed movement. And lastly, based on the present findings, dancers' interpersonal synchronisation may be also be modulated by higher cognitive factors such as the belief about how well dancers may expect to perform with another dancer.

In summary, present findings show stronger support for the role of feedback control mechanisms in interpersonal synchronisation that may not involve internal predictions in the form of simulations. In addition, top-down modulation of interpersonal synchronisation was observed which may be explained by the attention hypothesis.

Taken together, we cannot rule out that internal simulation took place as some evidence was found. Thus, future research is needed with less controlled movements to further investigate the role of internal simulation in visually mediated interpersonal synchronisation.

Chapter 7: General Summary, Discussion and Future Directions

7.1 Research Aim of this Thesis

The overall aim of this thesis was to provide the first step into exploring dance ensemble synchronisation. Focus was directed towards temporal aspects of visually mediated timing in dance, emphasising feedback control. Synchronisation between two or more individuals was investigated from an information processing (IP) perspective. The basis of this approach is the belief that a central timer produces time intervals and interacts with sensory and motor processes. The IP approach is concerned with identifying sources of variability in human motor timing, such as motor processes or the type of sensory channel used to perceive external time cues. Measures of fluctuations in response timing relative to an external time cue that is consistent with an IP framework were adopted and found suitable for investigating dancers' movement timing relative to other dancers.

This thesis firstly discussed previous research that focused on dancers' timing skills and introduced an empirically testable model of dance ensemble synchronisation. Methods and analyses were suggested to examine the aspect of time in dancers' interpersonal synchronisation (Chapter 1 & 2). Then, in the first two experimental chapters (Chapter 3 & 4) a lead-follower paradigm was developed to quantify the temporal linkage between two or more individuals. The effect of perceiving multisensory cues (Chapter 3) and the effect of integrating two unimodal cues

(Chapter4) on individuals' synchronisation performances were researched. The third experimental chapter (Chapter 5) developed a paradigm, in which the variability of the lead was controlled, by introducing a virtual three-dimensional performer. Dancers' interpersonal synchronisation and the importance of visual and sensorimotor familiarity were investigated. In the final experimental chapter (Chapter 6), two experiments were conducted. The first experiment examined the potential role of an internal forward model in visually mediated synchronisation and the second experiment investigated whether higher cognitive (top-down) factors modulate low level (bottom-up) processes involved in interpersonal synchronisation.

The present chapter will briefly describe the methods and analyses proposed to research dance ensemble synchronisation. It then, will summarise empirical findings of each experimental chapter and critically discuss the role of a feedback model, and the potential roles of an internal forward model and the 'Mirror Neuron' system, based on the present findings of Chapter 5 and 6. This is followed by a brief summary of the strengths and limitations of each experiment. Lastly, suggestions for future studies are provided, followed by a general conclusion.

7.2 Methodology and Analysis of Dance Movements

In order to research dance, dance movements had to be characterised. Such characterisation was conducted using motion tracking. Motion tracking has been suggested as a powerful and time efficient tool, as it can obtain objective detailed data of human forces and positions in time. A passive marker system was used in the present thesis to allow participants to move freely without physical constraints, as no wires or electronic equipments had to be worn. As noted above, measures in line with an IP framework have been adopted to analyse interpersonal synchronisation. Measures of the mean and variability of asynchrony, inter-movement–interval and cross-correlation analysis were used to quantify dependencies between two or more individuals within an ensemble.

In order to investigate how dancers synchronise their movements with those performed by another dancer, a lead-follow paradigm was developed similar to a paradigm used by Maduell and Wing's (2007). Maduell and Wing aimed to quantify one person's rhythmical timing in relation to another. Thus, in order to provide some control of the directionality of visual information flow, they assigned the role of a lead to one participant and the role of a follower to another participant. The lead-follower paradigm was further developed in the present thesis to ensure more control over the lead. Lastly, the studies in this thesis also introduced temporal perturbation in form of a period change. Introducing period changes had two benefits, firstly to avoid that participants anticipated the timing of the other dancer and secondly, to provide another measure of temporal linkage that was clearly visually mediated. In the former followers have been found to correct their timing to the new time interval that was introduced by the lead. The overall results showed that followers closely matched the timing with that of the lead. Thus the presented paradigms were successful in eliciting linkage between people.

7.3 Empirical Findings

7.3.1 Summary of Empirical Findings

The first experimental Chapter 3 introduced a paradigm that emphasised feedback control, to investigate visually mediated synchronisation between two individuals. This paradigm consisted of a lead and follower performing oscillatory arm movements together in time. The lead synchronised his or her movements with an auditory metronome and the follower synchronised his or her movements with those of the lead. Three research aims were set. The first aim was to quantify visually mediated temporal linkage between the lead and follower, using measures described earlier. Strong temporal dependence between the lead and follower was found, as mostly no differences between their synchronisation performances were observed. Interestingly, followers timing performances showed a trend of increases relative to the lead in mean and variability of asynchrony and inter-movement-intervals. Followers' less accurate performance may have been caused by the difference in the variability of the timing signal. Leads for example, synchronised with a regular auditory pacing signal, whereas followers synchronised with a more variable visual signal, depicting the rhythmical movements of the lead.

The second aim of chapter 3 was to investigate whether the interval produced by the metronome is internalised by the lead, a continuation phase was introduced. The lead maintained the interval without the availability of feedback information of the metronome, indicating that the internal timekeeper was adjusted to the correct interval. Therefore, sensorimotor synchronisation may not only be based on feedback control but may also involve internalised temporal information to reduce synchronisation errors.

Lastly, in real-life dance scenarios, dancers synchronise their timing to the beat of the music whilst observing the movements of their dance partners. Chapter 3 also researched whether leaders' synchronisation to the auditory pacing cue was negatively affected by perceiving visual information of followers' rhythmic arm movements compared to no additional visual information. Leaders' synchronisation performance with the metronome was significantly decreased when the rhythmical movements of the followers were visible. This interference effect was interpreted by the ventriloquism effect, which suggests that all sensory feedback cues were integrated in leaders' synchronisation performances. Thus, interference from the timing of the rhythmical information of the followers was evident.

Potential implications of the temporal ventriloquism effect in a dance ensemble scenario may be that dancers timing could drift away from the music towards the perceived timing of their dance partners. This may be of advantage to improve the visually perceived group cohesion by the audience, however at the cost of falling behind the music. Therefore, dancers may adopt strategies to quickly correct for discrepancies between the auditory cues at a given threshold. However, it is not clear if dancers would show a ventriloquism effect and if so, whether they would use strategies to be less affected by visual distracters compared to non-dancers in order to maintain their timing with the music. One strategy that may avoid dancers drifting away from the metronome is 'prioritised integrative attention', introduced by Jones (1976). According to Keller (2001), prioritised integrative attention is the mechanism that allows cohesion in musical ensemble synchronisation. Applied to dance, it would require divided attention in which one source is prioritised, for example musical sound, in relation to one or more other sources, e.g. the rhythmical movements of dance partners. This process of divided attention could therefore be a useful strategy adopted by dance ensemble members to maintain close synchrony with the music.

Chapter 4 is an extension of Chapter 3. It firstly aimed to further investigate the reliability of the effect of increased variability observed in followers' timing relative to the leads. Secondly, it also examined whether the previous effect of cross-modal integration, as found in Chapter 3, also takes place for multiple cues within one modality. A multi-person paradigm with six performers was developed. One individual was assigned the role of the lead, four the role of the follower and one the role of the integrator. The four followers were split into two chains, each consisting two followers. In contrast to the followers who synchronised with only one visual pacing signal, the integrator synchronised with two visual pacing signals. The results of Chapter 4 provided clear evidence for an accumulation of timing variability across each chain of followers. This was explained by individuals' adding their own variability to the timing signal that is then passed on from one person to the next.

Furthermore the integrators' performance of asynchrony relative to their two timing sources suggested a failure of integrating the two sources. In contrast the variability of integrators' inter-movement-intervals suggested the opposite, as no increase in variability was observed compared to the variability of inter-movement-intervals performed by the two timing sources on their own. This contradictory finding concerning the integration may suggest that participants adopted a different strategy of maintaining overall synchrony. For example, the two visual time sources were spatially slightly apart, which may require focal attending (Jones & Boltz, 1989); a constant switch of visual focus between the two cues. Therefore, the integrator had two options, either focusing on one source only which would have resulted in a failure of combining both signals, or adopting a strategy to minimize the variability of his or her inter-movement-intervals to maintain in time with both external cues. Thus the integrator may have internalised the combined interval perceived by both signals.

In dance, dancers also often coordinate their movements with two or more dance members. For example in the traditional *Swan Lake* ballet choreography, the black swan (solo performer) perceives in front of her to the right and to the left, a chain of white swans. To maintain synchrony (if no musical cues are available), the black swan has two options; either to attend to only one chain which would result in a failure of integrating both sources, or to time her movements with the overall tempo perceived by both chains. Once internalised, the same process as stated above, prioritised integrative attention could take place (Keller, 2001). The black swan may give priority to her own consistent time performance, whereas less attention may be given to the exact timing of both external cues (two chains). Prioritised integrative attention would have enhanced consistent performance within the integrator whilst being able to detect larger interval changes in the two pacing cues. The former would be necessary in order to re-adjust to new intervals introduced by external time sources.

The next Chapter 5 moved the focus onto expert ballet dancers' interpersonal synchronisation. Expert dancers' timing with another dancer was examined in the context of movement familiarity of dance poses. Two main research aims were set. The first aim explored how dancers time their movements to various alternate events within the visually perceived movements of the virtual performer. The second aim was to research whether visual and sensorimotor familiarity interacts with dancers' synchronisation skills. Findings showed that expert ballet dancers timed their movement less variably to the dynamics compared to the target position in space of a movement.

Furthermore, performing highly practised compared to less practised movements led to less variable synchronisation with the virtual performer. Therefore, visual and sensorimotor familiarity interacted with dancers' synchronisation performances. Yet it is not clear which of the two factors may have caused this effect. Research by Loula et al., (2005) suggests that both familiarity factors may have contributed to the interference effect on dancers' synchronisation performance. In their study, participants' performed a visual recognition in which they had to recognise either activities such as dancing when perceiving a point-light display that depicted their own, a friends' or a strangers recording. Their findings clearly showed that participants were significantly better in recognising their friends compared with strangers, whilst overall performing better when perceiving their own actions. Thus, it may be likely that both factors visual and motor experience, contributed to dancers' less variable timing performance when synchronising with ballet dance moves.

Finally, experiment 1 of Chapter 6 investigated whether an internal forward model may play a role in interpersonal visually mediated timing and could account for the results observed in Chapter 5. One previous study by Keller et al. (2007) suggested that some form of internal forward predictions may take place during musical ensemble synchronisation. Pianist who played with their an auditory recording that entailed their own previously generated performance, were better in their synchronisation performances, compared when playing with an recording produced by another pianist. Chapter 6 examined whether internal predictions generated by internal representations of a given movement may play a role in visually mediated synchronisation performances. Findings showed limited evidence for involvement of predictions in visually mediated interpersonal synchronisation. Nonetheless, participants were found to recovery faster post-perturbation when synchronising with their own movements recording than those of another person. Consequently, we cannot rule out that some form of internal simulation may have taken place, as a complement to simple feedback control mechanisms. Clearly, further research is required to explore the role of internal models in visually mediated synchronisation.

Lastly, previous experiments within this thesis focused on relatively low level factors affecting sensorimotor synchronisation. Interestingly, recent studies into joint action and motor control provide evidence for the involvement of higher cognitive factors cooperative performances (Sebanz et al., 2005; Stanley et al., 2007). Experiment 2 in Chapter 6 aimed to explore whether high level cognitive factors could affect visually mediated synchronisation between two individuals. The paradigm manipulated participants' belief about the visual cue with which they timed their movements. Individuals synchronised with movements they either believed to be their own or another person's movements. This was either true or false. Results showed that belief interacted with individuals timing performances, as less variable timing was observed when participants believed to time their movements with their own recordings compared with those of another person. Yet, it was not clear if belief was truly enforced as no measure was conducted to test this. Nonetheless, various possible explanations may account for this 'belief effect', such as an attention or arousal hypothesis. The former would suggest that focal attention (Ploanyi's, 1966) may have been directed to recordings participants believed to be their own whereas subsidiary attention may be directed to recordings believed to display other people's movements. In addition, the latter arousal theory concludes that when participants heard their name their arousal level increased (Carmody & Lewis, 2006). Thus, participants' increased arousal could have increased their attention towards the stimuli and their own monitoring motor control system, improving their synchronisation performances.

7.3.2 Underlying Mechanism in Dance Ensemble Synchronisation

Establishing interpersonal synchronisation requires some form of information exchange between two people which may be visual (Oullier et al., 2008). In dance synchronising with external cues such as the beat of the music or the perceived rhythmical movements of another person are used to maintain close synchrony with one another. In Chapter 3, evidence was provided that participants' internalised the target time interval. Such internalisation could help predicting the next response time. The question arose if some form of internal predictions may also be involved in dancers' synchronisation performances.

In Chapter 5, dancers' synchronisation performance was found to be affected by dancers' visual or motor familiarity. Clearly, this can be explained by simple feedback control. This model allows dancers to correct for any errors made and deduct it from its desired motor output. Dancers' less variable performance when synchronising with familiar compared with less familiar dance moves may have been caused by two factors. Firstly, ballet movements are visually more familiar to ballet dancers than novel dance movements. Thus, dancers may have been able to more accurately depict the timing cues when perceiving ballet compared with novel dance movements. Secondly, dancers were suggested to fine-tune their somatosensation to perform complex movement sequences with and without multiple dance partners (Bläsing et al., 2012). Therefore, dancers' enhanced somatosensation, in specific proprioceptive awareness may be particularly fine-tuned to movements of dancers' own repertoire. This consequently could have resulted in more precise motor timing when performing ballet compared with novel dance movements.

A second model, the internal forward model could also account for the findings observed above. The idea of the forward model is that in response to a motor command, the nervous system can be learn to predict the behaviour of the motor plan (Desmurget & Grafton, 2000). According to Blakemore and Decety (2001), it may also be that the mechanism of internal forward control could also be used to predict other peoples' movements from action observation. As ballet dance movements were highly practised by the dancers, ballet movements would be part of their internal representation that could aid predictive processes within the motor system. Thus, a dancer timing with ballet compared with less familiar movements would be expected to be more accurate, which is in line with the findings present in Chapter 5. Yet, only Chapter 6's experiment was designed for testing the role of internal simulation in synchronisation for which rather limited evidence was gathered (discussed later).

One way of testing if internal predictions were performed by dancers, is to re-examine dancers' synchronisation performance with novel dance movements across trials. As mentioned earlier the forward models suggest that the nervous system learns to predict. Thus, if throughout the experimental session, dancers' were found to improve their timing of novel dance movements, this then could potentially provide evidence that dancers learned to estimate the motor plan and that some form of internal predictions contributed to dancers' interpersonal synchronisation.

A third theory, the common-coding theory, could also account for dancers less variable synchronisation performance of familiar compared with less familiar dance moves. Interestingly, recent suggestions indicate that Mirror Neurons may be part of a predictive mechanism that involves internal models (Miall, 2003). In contrast to the internal forward model from a motor control point of view, the common coding theory suggests that movement observation leads to convert simulation of the motor program (Gallese, 2003). This would facilitate the use of that particular motor command set if obligated to act. When comparing this idea with the stimuli observed by the dancers, dancers synchronised exactly the same movements as performed by the virtual dancer. Thereby, dancers more accurate simulations of familiar dance movements could have led to more accurate synchronisation performances compared with less familiar movements. Further support comes from imaging studies that showed that dancers' so called mirror neuron system resonates stronger when observing familiar compared with less familiar movements (Calvo-Merino et al., 2006). In order to test if action simulations, in line with the common-coding theory took place, dancers' synchronisation performance in time with an observed qualitatively different movement of the same repertoire could be compared. As the observed movement is expected to lead to the simulation (resonance) of exactly that same movement, performing a different movement at the same time may decrease dancers' synchronisation accuracy. If this is true, it would provide evidence for the potential role of action simulation in dance ensemble synchronisation.

Chapter 6 aimed to test whether some form of prediction took place during visually mediated interpersonal synchronisation. Participants synchronised with either their own or another persons' recordings. As participants performed the movements before (in the recording session), in line with the internal forward model, they were expected to be more accurate at predicting the timing of movement when synchronising with their own compared to another persons' movements. However, the results were contradictive. Overall measures showed no improved synchronisation performance, whereas one measure found that participants recovered faster when synchronising with their own than with another person's recording. Yet, simple feedback control could account for both findings, the overall similar performance with one's own compared with other persons' movements and the advantage in the post-perturbation recovery. The latter may be due to the fact that participants' biomechanics matched the one of the perceived stimuli, facilitating faster recovery.

Nonetheless, both the internal forward model and the common coding theory could also account for the participants' faster recovery post-perturbation when synchronising with their own recordings. Perhaps, one reason why Keller et al.'s (2007) findings of their pianists' duet study could not be replicated in this study, was that the timing of the stimuli were too controlled. For example Knoblich and Flach (2004) showed that individuals' general tempo of performing a movement is an important cue for self-recognition. They manipulated the timing of participants' hand clapping, which resulted in a reduced ability to self-recognise one's own performance. Further limitations will be discussed in the next section.

Taken together, the present thesis clearly highlighted the importance of feedback control in establishing synchronisation between two or more people. Some form of internalisation may take place, yet this finding was only established within a continuation phase in which no external time cue was present (Chapter 3).

7.3.3 Strength and Limitations

The first experimental Chapter 3 successfully adopted an information processing framework to examine interpersonal synchronisation between two people. A lead-follower paradigm was introduced that controlled for bi-directional feedback compared to previous two person studies (Oullier et al., 2008; Helmuth & Ivry, 1996) that lacked such control. Furthermore, it controlled the timing of the lead by introducing an auditory pacing signal with which he or she synchronised with. However, one limitation of this study may have been the bi-directional feedback was not controlled during conditions in which the lead was provided access to the visual feedback of the followers' movement. At the same time exactly this limitation was useful to explore the interference effect of perceiving another person's movement on the lead's synchronisation performances.

Chapter 4 is the first study known that provides quantitative data of visually mediated synchronisation between more than two people, replicating ensemble performances. In contrast to the previous Chapter, leads' bi-directional feedback was fully controlled at all times. Overall, the visual information flow between ensembles was intended to be controlled. Nonetheless, this may not have been fully established. Followers 2 may have been able to observe not only their leads' movements (follower 1), but also could have perceived the feedback cues from the actual leads' movement. The latter would explain why followers 2 performed at lag 0 in relation to their leads, whereas follower 1 performed at lag +1 in relation to their leads.

Another limitation of both Chapter 3 and 4 was that the leads introduced their self-generated motor variability; therefore participants were consistently timing to a variable time source without having a control condition in which the visual time source was not variable. The latter could potentially provide details about individuals' average synchronisation error and their variability when synchronising with visual moving pacing signals performed by another human. To control for these limitations, Chapter 5 introduced a virtual performer as a lead.

Chapter 5 is the first of its kind, analysing dancers timing performances with those of another dancer. As noted above, it introduced the tool of using a virtual three dimensional performer, controlling the variability of the leads' performances. Meanwhile, by implementing a virtual performer, all dancers were performing with exactly the same lead, reducing between-participants variability that could be caused by perceiving slightly different timing cues. In addition, this study used real dance movements, compared to simple oscillatory arm movements, making this study more ecologically valid. Yet, one limitation may have been that the analysis was based on only one marker. Analysis of all markers may provide a more holistic understanding on how dancers time their overall movements with those of another dancer.

Chapter 6 introduced two experiments which to our knowledge are the first to investigate both whether internal predictions may play a role in visually mediated timing and whether belief interferes with individuals' synchronisation performances. The first experiment of this chapter adopted a controlled paradigm to investigate the role of internal predictions in synchronisation performances that has been successfully used by a previous research group (Keller et al., 2007). However, previous findings were not replicated. There may be several explanations: Firstly, the stimuli of the virtual performer were temporally controlled, which potentially reduced the ability of participants' to recognise their own performance. Secondly, the movement performed may have been too novel to allow synchronisation to be fully exploited. Thus, movements performed in common sports activities such as kicking a ball, may be less novel and more ecologically valid. Lastly, similar to Chapter 5, synchronisation analysis was only conducted on one marker.

7.4 Future Directions

Exploring dance ensemble synchronisation is just at its beginning. Each experiment on its own created new research questions that could be explored further. The empirically testable model of dance ensemble synchronisation, introduced in Chapter 1 aims to guide future research, by having identified potential components that could be first explored in isolation and then combined with other aspects to provide a holistic insight into ensemble synchronisation. This section will briefly state a few, of many potential future research studies.

With respect to Chapter 4, the introduced circle paradigm may also be of interest to social psychologist analysing how social variables such as attitudes and friendships, could influence timing performances within an ensemble. Insight into how social factors affect multi-persons timing could provide a more in depth understanding of real-life ensemble dynamics in dance and other types of group activities.

The same Chapter showed that variability of one persons' timing was passed on to the next person. Future research is required to confirm present results of the observed hierarchical structure. Increased experimental control may be achieved by introducing visual displays. Here, individuals may time their movements with recordings of their own previously performed movement presented on a visual display screen. This could be repeated continuously. Thereby it could simulate an indefinite amount of individuals within a chain, providing a large data set that may be used for modelling ensemble timing that emphasises feedback control. The model obtained then could be compared with real-life scenarios.

The paradigm used in Chapter 5 could be used to research dancers timing with multiple performers. For example similar as in Chapter 4 which included an integrator that had to time his or her movements with two visually perceived timing cues, a dancer may observe two dancers rhythmical movements presented on a virtual display. This paradigm may be modified further to examine if dancers integrate multiple unimodal cues in line with the maximum likelihood estimation model (see Chapter 4) that has been suggested for sensorimotor timing of smaller movements such as finger tapping. To test whether a similar integration takes place the virtual display could introduce one regular and one slightly variable performer simultaneously.

In real-life ensemble performances dancers synchronise with multisensory cues, such as the rhythmical beats of the music and the rhythmical movements of their dance partners. Again the paradigm used in Chapter 5 may be ideal to explore this. For instance, in addition to the virtual dancer, an auditory pacing signal may be introduced at the same time. This paradigm could provide insights into how dancers maintain overall synchrony in an ensemble, testing Jones (1976) postulated prioritised integrative attention theory.

Further research is also needed to provide stronger evidence that internal predictions as proposed by the internal forward model may have contributed to dancers' synchronisation performances. One way of examining this is to manipulate dancers' predictability of upcoming time cues. For example, Villing, Repp, Ward and Timoney (2011) manipulated participants perceived centre of their tap onset and the auditory pacing signals' onset combined, by introducing complex and less complex vocal syllables. Complex syllables compared with shorter sharp syllables were predicted to negatively affect participants' estimation of the onset of the perceived centre of asynchrony. In a task in which participants were introduced to a phase shift, participants responded quickly to the more predictable synchronisation cues of shorter syllables, whereas for complex syllable cues, participants were found to rely more on a continuation of their interval timing. This provides some evidence for the role of predictions in sensorimotor synchronisation for finger tapping. A similar paradigm may be used to explore if dancers use predictions for their interpersonal synchronisation. For instance the noise level of the perceived virtual performer may be increased or decreased. Then a perturbation could be introduced to test if dancers were able to adjust to both. If not it would provide evidence for the role of predictions in visually mediated sensorimotor synchronisation in dance.

7.5 Conclusion

This thesis comprises novel explorations of dance ensemble timing between two or more people. Dancers' movements were captured using motion tracking tools which provides an excellent tool to characterise dance movements as a means of exploring sensorimotor timing. An information processing approach to timing was used that provides a powerful instrument of quantifying temporal linkage between two dancers and to identify hierarchical structures within ensembles. Experimental paradigms were introduced that provided progressively more control of one person to explore more closely his or her influence on the other person. Throughout this thesis, individuals' use of feedback control was emphasised. Paradigms to investigate interpersonal dance performances with one or more dancers were first tested with non-dancers. Several findings observed could be translated to dance performances. One study that involved expert dancers revealed that their synchronisation performance with another dance partner was affected by their motor and visual experience. Furthermore, underlying mechanisms such as the internal forward model as a complementary to feedback control were considered and examined. Yet, results were found to be inconsistent. Although feedback control could account for mostly all findings of the present study, some evidence for the involvement of internal predictions in visually mediated interpersonal synchronisation was provided. Additionally, after pre-dominantly considering low level factors, the cognitive factor belief was also found to influence low level synchronisation performances between two people, by potentially changing the level of attention directed to their synchronisation partner and towards their own motor system. Altogether, the present thesis provided a starting point to research dance ensemble timing, providing powerful paradigms and analysis approaches, and the application of suitable tracking tools. A variety of ideas for further research were discussed and could also be applied to other ensemble performances that emphasis synchronous timing, such as in music ensembles, rowing, synchronised swimming, trampolining or diving.

Appendix A: Further Measures of Exp. 1 and 2 of Chapter 6

This Appendix presents unreported data from Chapter 6.

Analysis

For each trial, a total of ten peak velocity times were determined for each upwards and downwards movement. In addition to the dependent measures of *relative mean Asynchrony* (A), mean *variability of the asynchrony* (sdA); the absolute asynchrony (absA), the mean difference of the *Inter-Movement-Interval* (IMIdiff) in comparison to the IMI performed by the stimuli and the mean *variability of the Inter-Movement-Interval* (sdIMIdiff) were also determined. The averages were calculated as for A and sdA, excluding the first movement of each new interval duration.

In experiment 2 all absA, IMIdiff and sdIMIdiff were analysed using a 3 x 2 x 2 repeated measures ANOVA with *Trial Type* (Perturbed F-S, S-F and Unperturbed trials), *Agent* (Self-A, Other-A) and *Direction* (Up and Downwards movement) as within-subject factors. For experiment 2 an additional factor of *Belief* (Self-B, Other-B) was introduced, for which a 3 x 2 x 2 x 2 repeated measures ANOVA was undertaken.

Lastly, discrimination and identification scores were also correlated with the absA, IMIdiff and sdIMIdiff.

Effect of Agency

Absolute Asynchrony (absA)

The measure of the mean absA informs about the absolute synchronisation error performed between the participant and the stimulus. Unlike the measure of mean A, all asynchronies are made positive to avoid values from cancelling each other's out. The average absA was 82.1 ms. For the repeated measures analysis of absA, only a main effect of *Trial Type* was observed ($F(2,22) = 3.97$, $p < .05$, $\eta_p^2 = .27$). The effect of *Trial Type* was due to larger absA for F-S (90 ms) than S-F trials (83.5 ms). However, Bonferroni pairwise comparison showed no reliable difference across Trial types ($p > 0.05$).

Mean Inter-Movement Interval difference (IMIdiff)

The measure of IMI is the duration between two successive peak velocities, for example the duration between the peak velocity of the upwards movements and the following downwards movement. Two types of IMI's were analysed; upwards and downwards IMIs. The upwards IMI is the duration between the peak velocity of the downwards movement and the peak velocity of the following upwards movement. Downwards IMI is the duration between the peak velocity of the upwards movement and its following downwards movement. This was conducted for both, the virtual display and the participant. The difference between the IMIs of the participant and the IMIs of the virtual dancer were calculated for each trial. Lastly, all values were made positive (absolute difference of IMIs) for further analysis.

The mean IMIdiff was 83.4 ms. Repeated measures ANOVA identified a significant main effect of *Trial Type* (F (2,22) = 8.39, p < .01, η_p^2 = .43). Less IMIdiff were found for S-F (75.8 ms), followed by Unperturbed trials (81.1 ms) and F-S trials (93.3 ms). To further investigate the main effect of *Trial Type*, a Bonferroni pairwise comparison was undertaken, unveiling a significant difference between F-S and S-F trials only.

Equivalently to previous findings in measures of asynchrony, a main effect of *Direction* F(1,11) = 22.60, p < .01, η_p^2 = .67) was found. IMIdiff were significantly smaller for upwards movements (78.5 ms) than downwards movements (88. 3ms).

Moreover, an interaction between *Trial Type* and *Direction* (F(2,22) = 4.35, p < .05, η_p^2 = .28) and *Trial Type, Agent* and *Direction* (F(2,22) = 3.60, p < .05, η_p^2 = .25) was also significant (Figure A.1). To interpret the agent component of the three-way interaction, two two-way ANOVAS were carried out, followed by paired t-tests. No effect of Agent on Trial Type and Direction was found (p > .05). Instead, Trial Type showed an effect on Direction for Self-A conditions only. Here, when participants synchronised downwards movements to Self-A, significant smaller IMIdiff were revealed for S-F compared to F-S trials (t(11) =3.196, p < 0.025) . In addition, the same was found for downwards movements (t(11) = 2.761, p < 0.025).

Consistent with the finding of the main effect of Direction, participants' upwards movements were significantly closer in their IMIs to those of the stimulus, with one exception. In F2S trials for Other Agent only no difference between up and downwards movements was evident (p <.05).

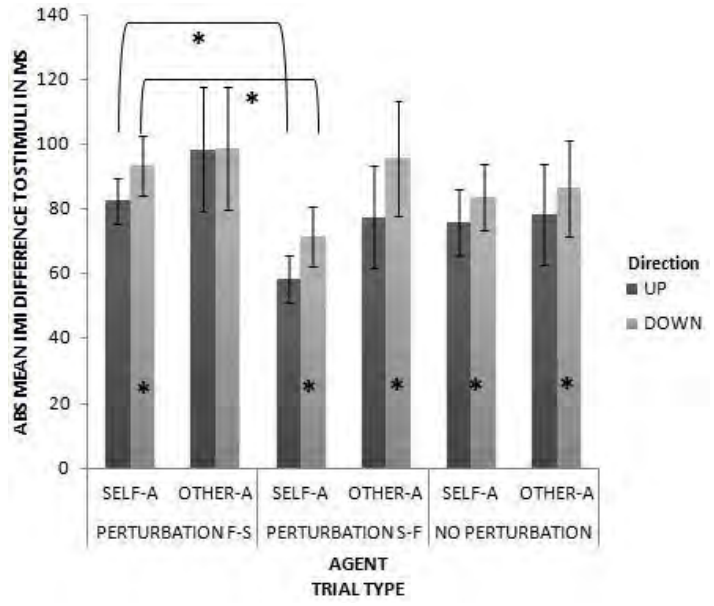


Figure A.1: ***Interaction between Trial Type, Agent and Direction on IMIdiff.*** * indicates significant difference for paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

Standard Deviation of Inter-Movement Interval difference (sdIMIdiff)

The mean IMIsd reveals the participants consistency of their IMI synchronisation performance, measuring the dispersion from the participants' mean IMI. The greater the mean IMIsd , the more dispersion from the mean IMI and the less consistent is participants' IMI synchronisation performance to the IMIs of the stimuli. The mean sdIMIdiff was 80.6 ms. A repeated measures ANOVA identified a significant main effects of *Trial Type* (F(1.32,14.54) = 5.15, p < .05, η_p^2 = .32) and *Direction* (F(1,11) = 18.94, p < .01, η_p^2 = .63). The effect of *Trial Type* was due to less variable IMIdiff of Unperturbed trials (72.5 ms) and S-F trials (75.8 ms) compared to F-S trials (93.3 ms). A Bonferroni pairwise comparison, found a reliable difference between S-F and F-S trials (p<.01). The findings of the main effect of *Direction* are in line with the findings in the measure of sdA, with significantly less variable IMIdiff for upwards (77.3 ms) than downwards movements (83.8 ms).

The interaction between *Trial Type* and *Direction* was also significant (F(2,22) = 5.59, $p < .05$, $\eta_p^2 = .34$) ,however not of interest to the proposed hypothesis. Therefore no further analysis was conducted.

Effect of Belief

Absolute Asynchrony (absA)

The measure of the mean absA informs about the absolute synchronisation error between the participant and the stimulus. Unlike the main effect of Trial Type found in experiment 1, no main effects or interactions were found for experiment 2. Therefore, the absolute synchronisation error showed no difference when synchronising with Self-A compared with Other-A.

Mean Inter-Movement Interval difference (IMIdiff)

In line with the observed main effect of Direction in experiment 1, a main effect of *Direction* (F(1,11) = 22.55, $p < .01$, $\eta_p^2 = .67$) was also found in experiment 2. Participants upwards movements (78.8 ms) were significantly smaller than their downwards movements (87.7 ms). A hypothesised main effect of *Belief* (F(1,11) =

7.29, $p < .05$, $\eta_p^2 = .40$) was also exposed, with a significantly smaller IMIdiff for Self-B (77.8 ms) than Other-B (88.6 ms) (Figure A.2).

Interestingly, an interaction between *Agent* and *Belief* was found ($F(1,11) = 5.84$, $p < .05$, $\eta_p^2 = .35$) (Figure 3.10). Paired t-tests analysis was used to investigate different effects of one factor on another. Significant differences in Belief conditions were only evident for Other-A trials (*t(11) = 2.92, p < 0.025*). Here, Self-B (84.3 ms) resulted in smaller IMIdiff than Other-B (87.7 ms) (Figure .3).

In contrast to experiment 1, no interactions between Trial Type and Direction and Trial Type, Agent and Direction were evident.

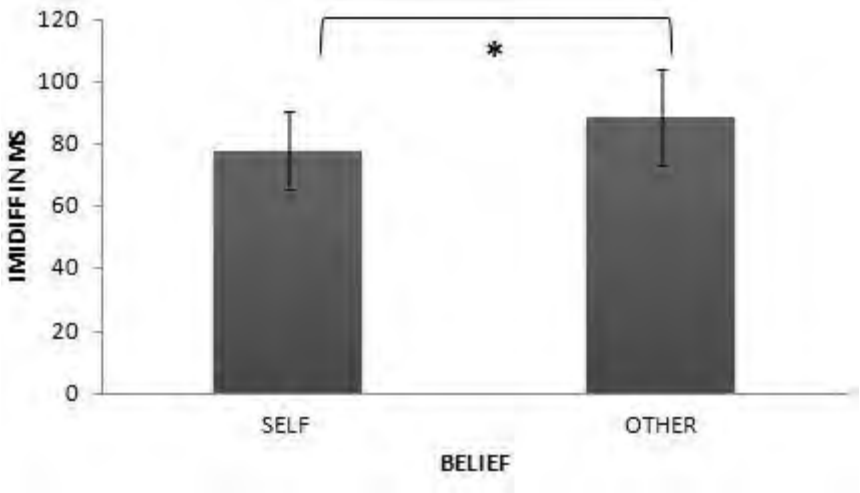


Figure A.2: ***Main effect of Belief on IMIdiff.*** * indicates significant difference. Error bars represent the standard errors of the means.

Figure A.3: ***Interaction between Belief and Agent on IMIdiff.*** * indicates significant difference for paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

Standard Deviation of Inter-Movement Interval difference (sdIMIdiff)

Unlike findings in experiment 1 no main effect of *Trial Type* and *Direction* were found. Instead, a significant main effect of *Belief* was observed (F(1,11) = 15.35, p < .01, η_p^2 = .58) which revealed that the mean sdIMIdiff was significantly smaller for Self-B (67.2 ms) than Other-B (77.6 ms) (Figure A.4).

An interaction between *Belief* and *Direction* (F(1,11) = 11.17, p < .01, η_p^2 = .50) was also significant (Figure A.5). A paired t-test exposed a significant difference between Self-B and Other-B for upwards movements only (t (11) = 4.18, p < 0.025). For Self-B, less variable IMIdiff were found for upwards (65.9 ms) than for downwards movements (81.5 ms).

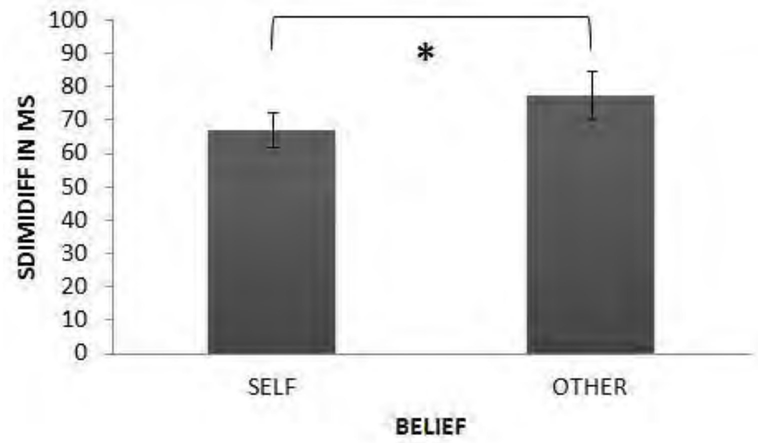


Figure A.4: ***Main effect of Belief on sdIMIdiff.*** * indicates significant difference. Error bars represent the standard errors of the means.

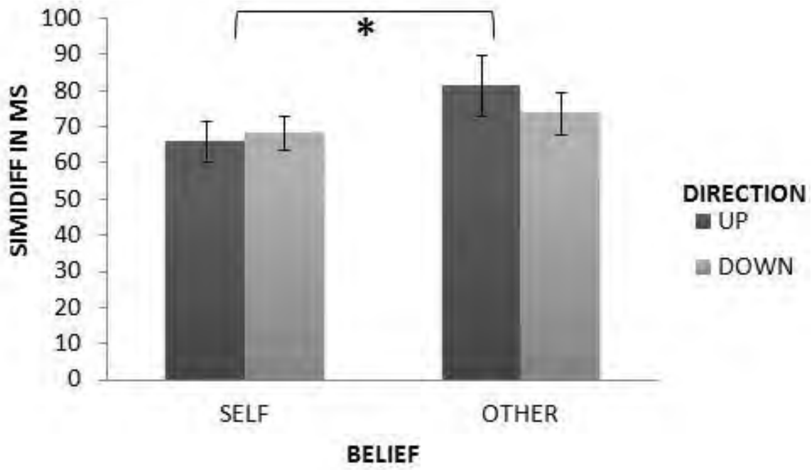


Figure A.5: ***Interaction between Belief and Direction on sdIMIdiff.*** * indicates significant difference for paired t-tests (Bonferroni corrected). Error bars represent the standard errors of the means.

Dependencies between Discrimination and Synchronisation Accuracy

The percentage of correct responses for each participant in the discrimination task was correlated against each participant's performance of all three DVs, across all trials of experiment 1 and 2 in which the stimuli Agent was either, their own or another agents' recording.

A significant negative correlation was found between the participants' ability to discriminate stimuli and their performance during Self Agent trials in IMIdiff (r (12) = -0.72, $p < 0.01$) and sdIMIdiff (r (12) = -0.66, $p < 0.05$) (Figure A.6).

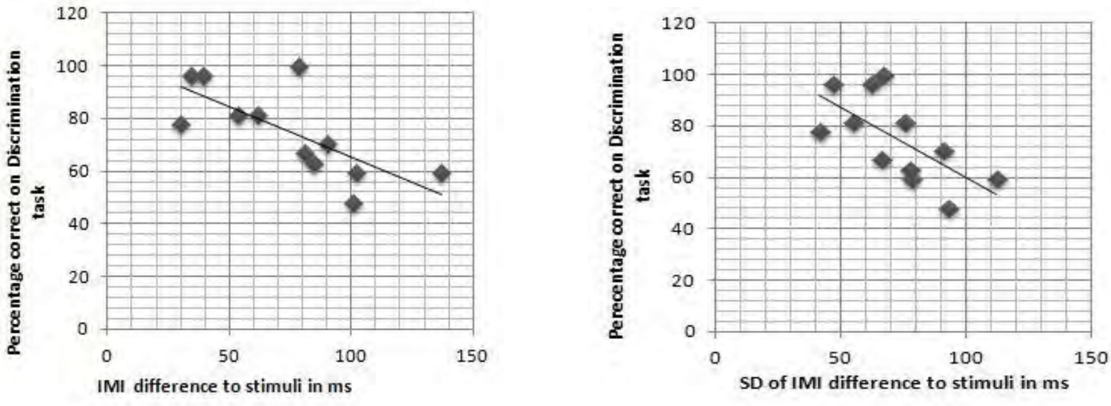


Figure A.6: ***Correlations between Discrimination Scores and IMIdiff and sdIMIdiff.*** Significant correlations were found for both. Top left represents the correlation of IMIdiff and the top right shows the correlation of sdIMIdiff.

Discussion

Firstly, similar to A and sdA no differences between the type of Agent were observed in experiment 1. Thus, no evidence for the role of action prediction in interpersonal synchronisation was found. In contrast to A of experiment 1, the absA measure showed that the average synchronisation error was not significantly different between Self-A and Other-A.

Secondly, with respect to experiment 2, a strong Belief effect was observed for both IMIdiff and sdIMIdiff. Less variable and closer IMI performances with those compared to the virtual performer were found for Self-B than with Other-B. Interestingly, the IMIdiff exposed an interaction between Belief and Agent as earlier hypothesised. Synchronisation of Self-A was not affected by Belief, however synchronisation of Other-A was affected by it. Here greater IMIdiff were found for Other-B than Self-B. Thus, it seems that Other-B decreased synchronisation performances with Other-A.

There may be several explanations for this, thus it should be noted that firstly this was the only interaction between Belief and Agent found out of five dependent measures used and secondly, that the measure of IMI for peak velocities should be considered with caution. The former is due to the movements used within the present study. Participants performed one movement followed by a pause. The IMI of the peak velocity includes these pauses, with that it may not be purely an inter-movement-interval. Instead this replicates a mixture of both, some active motion and static performance. Consequently, for future research continuous movements, without a pause would be more appropriate to calculate the IMI of peak velocities.

Despite of the criticism, one explanation would be in line with the internal forward model adopting an attention hypothesis. Participants IMIdiff for Self-A was not affected by the Belief, as due to internal predictions smaller discrepancies between the self-generated performance and those of the virtual performer were observed. In contrast, for Other-A, Belief affected participants synchronisation performances. For Self-B participants would expect better performance with their own recordings, yet perhaps at the beginning of each trial discrepancies between self-generated performance and the virtual performer were larger than expected. Thus, participants may have tried harder to decrease such discrepancies. In comparison, when participants believed to synchronise with another person they may have expected worse performances. Therefore, they may have noticed greater discrepancies between their own generated movements and those of the virtual performer at the beginning of each trial and decreased their attention towards the virtual performer and their own motor system.

Similarly, another explanation may be in line with the common coding theory. Here, participants IMIdiff for Self-A was not affected by the Belief, due to stronger resonance in the pre-motor system. Thus, participants were able to access simulations equally well for Self-B and Other-B conditions. Perhaps, greater resonance within the Mirror Neuron System is less prone to top-down modulation. In contrast, when synchronising with Other-A, smaller resonance within the pre-motor system may be expected. However, when participants believed to perform with their own recordings, they expected better performance. Therefore, participants may have either allocated more attention towards their performance or tried harder to access the simulations. In comparison, for Other-B in Other-A conditions, less effort may be made to improve their performances, as larger discrepancies were expected.

Nonetheless, these are just two example explanation one could make. As mentioned earlier, there may be too many uncertainties about this measure to conclude the involvement of internal predictions or simulations in interpersonal synchronisation. It may be more important to establish some role of predictions in synchronisation, excluding the belief factor (top down). Once a separate investigation into the role of internal predictions in interpersonal synchronisation is conducted, it would be of interest to further establish the reliability of top-down modulations. Lastly, a comparison between the synchronisation of continuous compared to intermittent dance movements could shed light into the ongoing debate whether dynamic timing is separate from discrete timing.

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