

Master Thesis

**In search of lost time: Does dance experience enhance  
duration estimation performance?**

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## **Plagiarism Statement**

I declare that, apart from properly referenced quotations, this report is my own work and contains no plagiarism; it has not been submitted previously for any other assessed unit on this or other degree courses.

## Publications and Presentations

Sgouramani, E., & Vatakis, A. (in press). "Flash" Dance: How speed modulates perceived duration in dancers and non-dancers. *Acta Psychologica*.

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Sgouramani, E., & Vatakis, A. (2013). The influence of speed on duration estimation in dancers and non-dancers. Talk presented in the symposium "Time in perception: Binocular rivalry-temporal distortions", 14th Conference of the Hellenic psychological society, 15-19 May 2013, Alexandroupoli, Greece.

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## **Abstract**

Dance represents a unique, multifactorial domain that is rapidly gaining the interest of cognitive scientists and may be proved to be a rich source of information for timing research. The spatiotemporal complexity and embodied nature of dance make it a suitable tool to investigate various aspects of timing. This thesis, therefore, provides an overview of the recent but large body of work conducted to date on the interaction of dance and timing (see Chapter 1). The relevant literature has been divided into the subsections of dance and: a) duration estimation, b) synchronization and entrainment, c) social cognition, and d) multisensory integration. This overview of the current state of the art is enriched with open questions, methodological discrepancies, and extensions of current paradigms in order to further promote future research on the topic. This thesis aims to put together, for the first time, a complete picture of the knowledge gained to date on dance and timing in regards not only to basic research findings but also potential clinical applications.

This thesis also includes an experimental study on the interaction of speed and duration perception using dance stimuli and dancers' versus non-dancers as participants (see Chapter 2). Speed has been proposed as a modulating factor on duration estimation. However, the different measurement methodologies and experimental designs used have led to inconsistent results across studies, and, thus, the issue of how speed modulates time estimation remains unresolved. Additionally, no studies have looked into the role of expertise on spatiotemporal tasks (tasks requiring high temporal and spatial acuity; e.g., dancing) and susceptibility to modulations of speed in timing judgments. In the present study, therefore, using naturalistic, dynamic dance stimuli, we aimed at defining the role of speed and the

interaction of speed and experience on time estimation. We presented videos of a dancer performing identical ballet steps in fast and slow versions, while controlling for the number of changes present. Professional dancers and non-dancers performed duration judgments through a production and a reproduction task. Analysis revealed a significantly larger underestimation of fast videos as compared to slow ones during reproduction. The exact opposite result was true for the production task. Dancers were significantly less variable in their time estimations as compared to non-dancers. Speed and experience, therefore, affect participants' estimates of time. Results are discussed in association to the theoretical framework of current models by focusing on the role of attention.

# Chapter 1: Time to Dance

## 1. Introduction

You are dancing with the man of your dreams and time stands still (i.e., distorted duration percept). You listen to your favorite music piece and without realizing you are tapping your foot underneath your desk (i.e., entrainment). Your tango partner, being a beginner (role of experience), steps on your feet, as he did not coordinate his movement appropriately (interpersonal coordination/social cognition). The little girl on the ballet recital you just watched seemed terribly out of synch with the music (synchronization). It feels awkward watching a contemporary dance performance on TV on mute, while you listen to your favorite music program on the radio (multisensory integration). Movement and time are intertwined in all human activity, so the underlined brain mechanisms which lead to such a coexistence are of great interest.

Dance is a universal form of art, which serves as a medium of expression and is composed of movement through space and time. A growing number of researchers in the Cognitive Sciences have recently been turning into the study of dance and behavior (e.g., see Bläsing et al., 2012, for a thorough review; see Sevdalis & Keller, 2011, for a review focusing on dance and social cognition; see Brown & Parsons, 2008, for a shorter review). In this review, we are specifically interested in the link of dance and timing. We will, thus, provide an overview of all the studies conducted on the topic and we will go on to argue that these studies form a new emerging field in the Cognitive Sciences that will play a dominant role in the future study of timing and

embodiment. This argument will be supported by the recent (last decade) but large number of studies focusing on dance and: a) duration estimation, b) synchronization and entrainment, c) social cognition, and d) multisensory integration. The collection of these studies allows us to view dance as an art form (ranging from ballet and contemporary dance, to Charleston, tango, flamenco, street dancing, salsa, Irish and Greek traditional dances, tap-dance and Lindy-hop) but also as an experimental stimulus (ranging from static frames/pictures to dynamic video displays). Additionally, it allows us to explore the role of expertise (i.e., professional dancers' versus non-dancers), given that dance requires high temporal acuity (in terms of time-keeping mechanisms) and several years of extensive training to reach a professional level. Finally, the study of dance alone requires timing as a metric and, thus, timing has also been studied in relation to dance as a measurement variable of movement.

## **2. Duration estimation in dance**

An issue of major interest in timing is the way we estimate the passage of time, forming a sense of duration for a given event (see Grondin, 2010, for a review). Several aspects of this passage of time have been extensively examined allowing for the identification of factors that influence our judgments and lead to distorted temporal percepts. Recently, studies on time estimation have moved from the use of abstract, simple stimuli to more naturalistic, dynamic ones. This move has been supported by the hypothesis that animate moving stimuli may be processed differently than inanimate stimuli, in terms of duration, putting forward the implication for two separate “clock” mechanisms (Carozzo & Lacquaniti, 2012; Carozzo, Moscatelli, & Lacquaniti, 2010). Dance stimuli, either as images with implied motion, sequences of static frames in apparent motion, or dynamic videos, seem to modulate duration

judgments (Carozzo & Lacquaniti, 2012; Carozzo, Moscatelli, & Lacquaniti, 2010; Nather & Bueno, 2011, 2012a,b; Nather, Bueno, & Bigand, 2009; Nather et al., 2011; Orgs et al., 2011; Orgs & Haggard, 2011; Orgs, Hagura, & Haggard, 2013; Sgouramani & Vatakis, 2013). Additionally, the use of dance stimuli allows for the examination of expertise (professional dancers versus non-dancers) and the effect of spatiotemporal experience on duration estimates (Sgouramani & Vatakis, 2013).

The hypothesis of dissociated specialized time mechanisms for animate versus inanimate moving stimuli has been put forward by Carozzo, Moscatelli, and Lacquaniti (2010). In their study, they compared participants' performance in two different time estimation tasks (motor interception and discrimination), while presenting either a dancer (animate) or whirligig (inanimate), moving stimulus (matched in kinematic attributes). This comparison revealed shorter time estimations for the animate condition as opposed to the inanimate, providing support for separate processing systems. In a follow up study, using the same experimental set-up, the authors explored the effect of speed on time estimation. The results showed time distortions for a target moving stimulus (falling ball) as a function of the background, artificially-modified in speed, moving stimulus (either a dancer performing ballet steps or a moving whirligig; Carozzo & Lacquaniti, 2012). Specifically, task performance differed as a function of the background stimulus, with higher dancing speed resulting to an underestimation of the landing time of the ball (i.e., anticipatory button presses) and an overestimation for faster moving whirligig presentations. Such differences make the type of experimental stimuli used of critical importance and provide an argument for the preferred use of more naturalistic stimuli in experimentation (Sgouramani & Vatakis, 2013).

Naturalistic stimuli were also used by Orgs et al. (2011) in order to investigate the influence of perceived speed on time estimation. Specifically, they produced apparent motion using static images of a dancer displayed at a range of sub-second durations. Participants were asked to perform a bisection task (i.e., whether a square around the images was shown for a short or long period of time, with no anchor durations provided) and a speed discrimination task. Apparent moving stimuli that were perceived as faster led to a contraction of the subjective square presentation as compared to stimuli that participants reported as being slower (see also Orgs, Hagura, & Haggard, 2013). Using a similar experimental paradigm, Orgs and Haggard (2011) investigated the role of animacy on duration judgments when incorporating different interstimulus intervals (ISIs) on the perception of a feasible or impossible movement path. They presented images of dancers in a normal or degraded version and asked participants to estimate the elapsed interval (through a bisection task) and decide whether the display referred to possible or impossible movement. Results revealed a contraction in perceived time for the case of normal biological motion as opposed to the degraded display (in accordance to Carrozo et al.'s, 2010, results) and the tendency to judge the motion path as feasible for larger ISIs. The authors suggested the idea that top down mechanisms are involved in this temporal binding connected to apparent biological motion. Apparent biological motion through the use of static dance frames appears as a very promising stimulus presentation method in experimentation.

Furthermore, Nather et al. (2011) reported a time distortion as a function of the embodiment of body postures implying movement of different intensity. Movement intensity was manipulated using static pictures of Degas' ballerinas statues in a temporal bisection task with two ranges of standard durations (0.4/1.6 and 2/8 sec).

Bisection performance showed that postures implying greater movement intensity lead to longer timing judgments as compared to postures with lower movement intensity. The effect mentioned was present only for the short durations tested. The authors supported that a transient arousal caused by high intensity postures speeded up the rate of the pacer (based on the internal clock framework), while when longer durations were tested arousal gave place to higher cognitive processes (e.g., attention). In this case, dance pictures seem, once again, a perfectly suitable choice of stimuli due to their implied dynamics.

Nather and Bueno (2011) extended their above-mentioned findings by using a different temporal task (a reproduction task) and investigating longer durations. Participants were exposed for 36 seconds to images of Degas' ballerinas with different implied motion intensities and were asked to reproduce this interval right afterwards. The results were consistent with Nather et al.'s (2011) previous study, showing an underestimation for images of more static postures and an overestimation when more movement/displacement was implied in the display. These results were supported by previous findings obtained through reproduction and eye movement recordings (Nather, Bueno, & Bigand, 2009). Additionally, it was shown that stimuli of high intensity are further underestimated by dance-trained as compared to art-trained and naïve participants. This difference was explained via the storage-size and the expectancy model. That is, naïves considered the high intensity stimuli as more complex/incomplete (in terms of action continuation; e.g., in one image the dancer appeared to be standing in one leg, thus, equilibrium might have been interpreted as less stable stance as oppose to a two legs standing-relaxing position) and, thus, were led to overestimations. This was explained as expectancy for movement continuation induced by the displayed dance posture. On the other hand, dance-trained participants,

given their familiarity with dance stances (e.g., standing in one leg can often be the ending pose of previous movement) interpreted them as lower in complexity and more complete, thus leading to underestimations of the given interval as no expectations for continuation were created. In a similar study (Nather & Bueno, 2012a) but with participants reproducing an undefined exploration time (i.e., longer exploration times of the given stimulus), results showed no significant time distortion for the low-intensity pictures and an overestimation for high-intensity stimuli. A commentary on these selected stimuli in terms of the role time plays in Degas' paintings and sculptures emphasizes the strong connection between dance and time, via a more theoretical approach (Nather & Bueno, 2012b). These series of experiments highlight the important validity in investigating the modulation effects of implied motion on temporal estimation via different methodologies and for a large duration range, keeping the stimuli involved constant. Unaltered stimuli permit straightforward comparisons leading gradually to a general framework regarding all the possible duration distortions that can occur. Thus, the contribution from this particular lab, through their studies is of great importance on the field.

Attentional sharing during time estimation has also been recently explored in association to dance (Minvielle-Moncla, Audiffren, Macar, & Vallet, 2010). Specifically, professional dancers were asked to reproduce a given interval by actually walking a specific distance, while conducting a secondary task during the encoding phase. The secondary task was composed of conditions of variable difficulty where dancers had to either perform a cyclical arm movement, watch a partner moving his arm at a specific tempo, or improvise. Results showed a greater overestimation when dancers were improvising, which was considered as the most attentional demanding one, and, thus, validating the Attentional Gate Model's predictions (AGM; e.g.,

Pouthas & Perbal, 2004; Zakay & Block, 1997). According to the AGM, timing is associated with a timer and thus, a collection of pulses to an accumulator takes place. Therefore, when attentional resources are driven away from any timing task focusing on parallel events, overestimation of the intervals involved occur due to missed pulses. The role of attention in time estimation, therefore, should be further explored for it appears as a prominent factor in the definition of our temporal percept.

Moving from explicitly estimating durations to implicitly maintaining and reproducing movements of specific durations, a highly inspiring exploratory study focused on the time -keeping processes of a dancer during a choreography (performed live on stage) accompanied by music or in absence of auditory information (Stevens, Schubert, Wang, Kroos, & Halovic, 2009). Via a motion capture system, the actions of a dancer were recorded and analyzed in terms of scaling (acceleration/deceleration of certain movements) and lapsing (omission/insertion of certain steps) mechanisms, without them being counter exclusive. The total duration of the piece served as a dependent variable and these measurements were compared between on/off music conditions. Proposing a specific model for analysis via temporal windows of interest between conditions, Stevens et al. (2009) tried to interpret a 14 seconds difference noted, with the no-music condition leading to a shorter performance. These results possibly indicate that music serves as a time-keeping external mechanism which facilitates the accurate reproduction of movement in terms of duration, while during silence time distortions are more likely to occur. Lapsing seemed to be the main procedure responsible for this difference and the methodology reported could be proved a very valuable tool for future research inter-connecting time mechanisms and dance in such a direct way. Such experimental proposals lead the way to an ecologically valid approach and precisely highlight that duration estimation can be

addressed either explicitly or implicitly, in order to reach to valuable conclusions and form a general model.

### **3. Synchronization and entrainment while dancing**

Sensorimotor synchronization involves planning and precise movement control and is important for a variety of rhythmic activities. Synchronization has been extensively examined mainly through the use of finger tapping tasks (see Repp, 2005, for a review). Recently, however, new measurement methodologies and accurate motion capture systems have provided the opportunity to extend the study of synchronization to body parts and even whole-body movements. Consequently, the study of synchronized movement (e.g., dance) to external (usually auditory) stimuli is now possible.

One of the first studies to investigate synchronization in dance was that of Brown, Martinez, and Parsons (2006) that used positron emission tomography (PET) in order to determine the neural substrates of tango. Using tango to study complex coordinated action, the authors focused on three basic attributes: entrainment, meter, and patterned movement. Participants (amateur dancers) were asked to perform specific tango steps, with or without music, on an inclined platform in different experimental conditions. Via a subtractive design, they proceeded in several planned comparisons in order to isolate the brain regions involved in the above-mentioned temporal and spatial attributes. Activation comparison during tango while listening to music or without any rhythmic stimulation, led to the association of the anterior cerebellar vermis with entrainment. The right putamen was associated with meter given the higher activation noted during metric voluntary motion as compared to moving to a metric or irregular rhythm. Patterned movement was investigated by

having the participants either moving their legs in a cyclical motion with music or standing still but contracting their muscles following the meter. The medial superior parietal lobule, a brain area associated with proprioceptive and somatosensory processes, was shown to be involved in the processing of the spatial characteristics for reproducing a dance step. These findings are in accordance with previous studies on elementary sensorimotor activities and provide the first evidence on the neural basis of dance. Further neuroscientific investigations will allow for the formulation of a complete picture of dance and timing in the brain. Additionally, longitudinal exploration of the neuronal changes occurring during learning new dance routines of varying spatiotemporal complexity can provide insight on the role of timing in dance and the potential use of this knowledge dance in rehabilitation.

As already mentioned, sensorimotor synchronization has been mostly studied via finger tapping tasks. Based on such an experimental setup but extending it by adopting a more embodied point of view Sgouramani, Muller, van Noorden, Leman, and Vatakis (in preparation) investigated the role of the nature of the external pacer on synchronization abilities. Additionally the factor of expertise was also addressed by comparing the performance of professional dancers and non dancers. Their performance was recorded via a motion capture system, which allowed accuracy at a millisecond level. The task was to synchronize with an audiovisual metronome by actually performing a simple dance step. The metronome was either an audiovisual display of a dancer performing the step (normal condition), a blurred version of this display or an abstract square accompanied by noise. A facilitatory effect for the normal condition is expected in comparison to the other two, as it seems more informative for the task, including spatial attributes apart from temporal ones. Also,

dancers are awaited to be more accurate as oppose to non-dancers, due to their extensive training in terms of spatiotemporal accuracy.

Adapting an embodied point of view, Toiviainen, Luck, and Thompson (2010) conducted a study on body movement patterns induced by the metric structure of music. Participants in this study listened to a music piece at four different tempi and were encouraged to move freely while being recorded by a motion capture system. Measurement of participants' body movements revealed that mediolateral arm movements were often synchronized with the tactus level pulse, while rotation and lateral flexion of the upper torso were frequently found to entrain with periods of two and four beats, respectively. According to Toiviainen and colleagues, these regularities in entrainment reveal a connection between music-induced movement and the metric levels of music, which can imply an embodied encoding procedure of music structure through specific body parts. Future research on this domain, focusing on certain constrains in regards to the data retrieval and analysis, could shed light in the relationship of body movement and music. Thus, the utilization of dance, the art that combines precisely these two elements (i.e., entrainment and music) is ideal for these kinds of investigations. This attempt has already being made recently using motion capture system data for the creation of spatiotemporal frames via the noted regularities in Charleston and salsa dance (Leman & Naveda, 2010).

Synchronization of whole-body movements has also being investigated by Miura and colleagues through a dynamical systems approach (Miura, Kudo, Ohtsuki, & Kanehisa, 2011). According to the dynamic systems approach, the system tends to move from unstable periods to coordination modes that provide stability. This tendency supports the idea that certain movement patterns fit certain external rhythms for optimal synchronization. In such a framework, when an increase on movement

frequency occurs, a transition from less stable modes to more stable ones is noted. In order to better define the above and clarify which movement pattern may be optimal in sensorimotor synchronization, Miura and colleagues examined whole body movements of street dancers and non-dancers. These two groups were asked to perform two distinct movements with an upward (knee extension on the beat) or downward (knee flexion on the beat) direction in synchrony with an external auditory metronome of different frequencies. Analysis revealed that downward movement led to a more stable coordination in comparison to upward movement indicating the existence of distinguishable motion patterns in sensorimotor synchronization. The transient effect from a dynamic systems' standpoint was noted only when the movement requested was in an upward direction, during which, in higher frequencies, participants spontaneously altered to a downward movement even though the directions indicated differently. This implicit change in regards to the directionality of movement supports that downward motion facilitates synchronization and, therefore, for higher frequencies (i.e., higher task difficulty), participants inevitably turn to a downward direction in order to maintain the pacer's tempo. Results also showed that street dancers were more stable in their performance as opposed to non-dancers for both modes tested. Thus, acquired experience with activities such as dance, which require spatiotemporal acuity, seem to enhance sensorimotor synchronization abilities. Further investigation of the specific movement patterns that lead to optimal synchronization (using different dance types and visual or multimodal pacers) could lead to the formation of a general framework on sensorimotor synchronization.

#### **4. Social Cognition: I dance, you dance, we dance**

The shaping of one's self that differentiates the individual from others, but still allows interaction, communication, and collaboration for a common goal is as yet a not well-understood process. Timing and dance are two domains closely connected with social interaction and inter-subjectivity and, thus, suitable tools for the investigation of our sense of self.

Sevdalis and Keller (2009) recently examined how the type of action executed and the modality presented affects recognition of one's self. Participants in this study were recorded via a motion capture system, while clapping, walking, or dancing in synchrony with music. Point-light display excerpts were derived from these recordings for each participant and then displayed (own versus other's movement) with or without synchronous auditory stimulation. Participants had to indicate whether each clip was displaying himself/herself or someone else. Using  $d'$  as an index of self-detectability, analysis revealed that for dance accuracy was significantly higher as opposed to clapping and walking, while the modality of presentation (visual or audiovisual) did not influence the results. Personal execution motifs aid, therefore, the recognition of self-action and given that dance is a highly personalized movement pattern its' use for the investigation of self-recognition was ideal. In regards to modality, further research is necessary with the inclusion of auditory feedback (e.g., the sound of the steps of the individual) other than music, as a more informative and personalized cue.

Social cognition, apart from an evident focus on the sense of agency, also extends on couple/group interactions. An example of this can be evidenced in the performance smoothness of a dance couple that is based on real-time coordination and cue recognition. Gentry and Feron (2004) investigated online couple coordination through the use of Lindy Hop, a swing-like type of dance. The authors' particular

interest was whether the coordination between the “leader” and the “follower” is attained through the shared physical action modes or the context (i.e., music). In order to address this, professional dancers were asked to dance to the music, while they were either listening (through headphones) the same or different musical excerpts. The music stimuli were aligned in terms to all their acoustic characteristics besides “semantic” structure. Certain musical styles used were expected to induce different movement patterns, thus, if dancers were susceptible to the influence of auditory context this would be noted. On the other hand, if the physical interaction between the couple is robust, the auditory context was expected to have no influence on performance. Participants were also asked upon dance completion to judge whether or not they were listening to the same music piece or not. In this latter task, results showed the “leaders” to be at chance level (50%), whereas “followers” were quite accurate in their discriminations (82%). The accuracy noted in “followers” was, as the authors conclude, due to the inappropriate movements posed by the “leaders” in relation to the music. Despite this they managed to cope with the “leader’s” proposals by adjusting their own movements in order to maintain the dance flow. This novel experimental setup could be further extended in the future through the study of other structural levels of music apart from “semantic” (e.g., temporal attributes). Additionally, a more objective measurement methodology such as motion or video capture along with motion energy analysis can be implemented for the further study of couple coordination in dance.

Coordination of groups of performers has also been recently studied through a connected network model framework. Connected network models define group members as interconnected but separate nodes. The node connections take up different “weights” according to their role (leader vs. follower), thus leading to better

coordination and smoother group performance (Maduella & Wing, 2007). This framework was implemented in a study using Flamenco for the investigation of how dancers communicate and, thus, coordinate through the use of cues (unimodal or multimodal). The relationship of “leader” and “follower” was also examined using force transducers in order to clarify the development and sharing of a common tempo. The results of this study were restricted in cross correlation indexes (data obtained from video analysis) and, even though preliminary for a complete picture on ensemble coordination, provide us with a first look on group coordination.

Interpersonal coordination in dyads has also been examined with a focus on dance expertise (Issartel, Marin, & Cadopi, 2006). Specifically, in Issartel, Marin, and Cadopi’s study, professional contemporary dancers and non-dancers were asked to freely perform arm movements either on their own or in coordination with their partners. Cross-wavelet transform analysis revealed that dancers were able to perform pluri-frequency and in-phase anti-phase coordination simultaneously in comparison to non-dancers. Thus, researchers claimed that expertise enhances our coordination capabilities; however further investigation involving whole-body actions is needed.

Synchronization is not limited to coordinated couple/group interaction for achieving smooth dance performance, but also to spontaneous interpersonal synchrony. Spontaneous synchrony has been of great interest in the last couple of years, given that entrainment occurs unintentionally between two (or more) members in interaction. In an attempt to investigate how spontaneous interpersonal synchrony is affected by somatosensory feedback, Sofianidis and colleagues (2012) conducted a study comparing professional dancers (specialized on Greek traditional dancing) and non-dancers during a rhythmical sway task. The participants, in this study, were divided into expert dancers, non-dancers, and mixed couples and they were asked to

either adopt a spontaneous sway of their own or follow an external metronome. The task was performed with both participants moving their legs (at the joint level of the ankle) with their eyes closed, one next to the other, on force platforms. Participants were either in constant contact through a light fingertip-touch or there was no communication between them. The center of pressure (CoP) of their feet on the force platforms was analyzed and used as an index of entrainment. Results showed an improvement of interpersonal synchrony (greater coherence) for all couples when sensory information was provided but only for the condition with no auditory cues. When auditory cues were available, only dancers seemed to benefit from the sensory feedback, while non-dancer and mixed couples did not show any enhanced interpersonal synchrony in the contact as oppose to the no-contact condition. The authors concluded that dancers could better integrate and utilize the multimodal information provided due to their training.

Social interaction in timing and dance has also recently been investigated in clinical populations. After a thorough review on empathy and the elements that constitute it, Behrends and colleagues (Behrends, Möller, & Dziobek, 2012) focused on the importance of kinesthetic attributes for people with empathy dysfunction. The authors evaluated a series of tasks in order to develop a rehabilitation program for populations with empathic and pro-social deficits (e.g., autism spectrum disorder). This program included tasks on motoric cooperation and imitation (exercises during which two or more people move simultaneously, sharing spatial and temporal dimensions or situations where people are dancing in a homolateral or mirror-converted context or even just a group dance motif that includes certain rhythmic repetitions), acknowledging synchronous movement as for the enhancement empathic abilities. The authors support the structure of their program based on the idea that

kinesthetic empathy can be fostered through dance therapy involving interpersonal communication and joint-action activities. Thus, they hypothesize that if people with empathy deficits follow such a program their abilities to interpret/adopt other people's emotions, thoughts, movements, point of view will be improved and, as a result, their interpersonal communication will be ameliorated. Currently, the idea and benefits of this program is theoretical and as yet no data/experimentation exist that support the proposed method. However, such frameworks, contribute importantly on the emerging field of dance therapy and inter-disciplinary scientific approaches that could lead us to a better knowledge of the formation of our sense of self and others.

### **5. Multisensory integration of complex biological motion**

Multisensory processing is a topic that has attracted much attention in Cognitive Sciences, but as yet several issues regarding timing remain unresolved. Processing time differences driven by modality and stimulus-type and traveling speed differences of each signal modality, raise the major question of how we combine incoming information into one synchronous and unified experience (Vatakis & Spence, 2010). To date there are very few studies that have attempted to investigate multisensory temporal integration in motion, mostly as part of the move from simple to more naturalistic stimuli (Vatakis & Spence, 2010).

Arrighi, Marini, and Burr (2009) investigated audiovisual integration in biological motion using point-light displays of tap dancing videos. Tap dancing was used given that this type of stimulus includes visual and auditory attributes that are equally contributing to a proper tap-dance excerpt (i.e., the sound of the feet is as important as the leg movements). Two separate experiments were conducted investigating facilitation (whether sensory information irrelevant to a certain task

enhances participants' performance to a target modality) and summation (whether audiovisual information enhances participants' performance as opposed to unimodal stimulation). Initially, a visual search paradigm was utilized with presentations of visual information and visual information along with in and out of synchrony auditory information. Participants were better at discriminating tap-dance sequences when auditory information were used in synchrony with the visual displays, results that led the authors to argue that the temporal coincidence of the two different streams of information provides an advantage at visual detectability, even if the auditory information is uninformative for a given task. Thus, attentional capture and known principles of multimodal neurons could probably explain this facilitatory effect. In their second experiment, Arrighi et al. investigated summation using a detection paradigm of auditory- and visual-only stimulation as well as audiovisual in and out of synchrony. Results revealed enhanced detection when both modalities were presented in synchrony, promoting the role of timing in theories of audiovisual integration. Extension and replication of these findings through typical multisensory integration tasks such as simultaneity and temporal order judgments (SJ and TOJ, respectively) could allow for better understanding multisensory integration in dynamic events. Previous research with complex stimuli and the factor of expertise (i.e., musicians/dancers; e.g., Lee & Noppeney, 2011; Petrini, Russell, & Pollick, 2009; Vatakis & Spence, 2006, 2010) could be the base for such setups using various dance stimuli (e.g., Sgouramani et al., 2012). In particular, Sgouramani and colleagues using a SJ task, aimed at defining the temporal integration window for experienced (i.e., professional dancers) and naive (non-dancers) participants utilizing a series of simple ballet steps as dynamic, audiovisual stimuli. Preliminary results showed that dancers had a smaller integration window as compared to non-dancers. Those steps, which

had been rated as higher in terms of complexity, required larger auditory leads to be perceived as synchronous, as opposed to the simpler ones, a result that was true for both groups of participants. Thus, experience and level of complexity seemed to be modulating factors in audiovisual integration.

The role of auditory information on dance performance has been investigated recently for novel versus familiar dance routines (Sofianidis, Hatzitaki, & McKinley, 2012). Steps derived from traditional Irish and Greek dances were demonstrated by a professional dancer, while experienced (professional dancers of Greek traditional dances) and naïve participants were asked to perform online the steps by mirroring them, whilst they were listening either to simple verbal counting or to music. Kinematic analysis of the lower limbs revealed degraded coordination for naïve participants (i.e., Greeks) when dancing novel Irish dance steps and when music was present as opposed to counting. This deterioration was not noted for the professional dancers, indicating coordination superiority due to experience/familiarity. Even though this study opens new avenues for research on multisensory integration (i.e., auditory, visual, and sensorimotor interactions), the use of precisely dance styles that are totally different from traditional Greek dance seems necessary. In order to separately address if the enhancement noted in professional dancers is due to either expertise (extensive training with generalized superiority in sensorimotor tasks) or familiarity with the stimuli involved. Therefore, it seems Greek and Irish dance are far too similar in terms of kinematics and maybe not the best choice for such a clarification, thus, a comparison of Greek dances with a totally different dance style (e.g., flamenco or ballet) could be proven more convenient in follow up studies.

Sensory integration and its' effect on action performance has recently been examined through an original wearable device allowing the real-time sonification of

impact sounds derived from movements, through a closed feedback loop (Grosshauser, Blasing, Spieth, & Hermann, 2011). Such device allows an active agent to attend to the sounds he/she produces while moving and proceed to adjustments/corrections when necessary. Grosshauser and colleagues tested this device in pilot experiments involving simple ballet jumps and examined if a real time auditory feedback could ameliorate dancers' performance. Indeed, dancers could appreciate online - through the sound provided - the suitable corrections that must be undertaken in order to attain a better execution of the given step. Such a device could be proved extremely useful for manipulations in terms of delayed/altered feedback, thus, a useful tool for further investigation on strategies followed to correct movement based on the modality stimulated.

## **6. Discussion**

In the present review, we provided an overview of a large number of studies that were conducted during the past decade, which investigated the interaction of timing and dance. The relevant literature was divided into the subsections of dance as it relates to: a) duration estimation, b) synchronization and entrainment, c) social cognition, and d) multisensory integration. In the first subsection the recent work on duration judgments was described, emphasizing the need to clearly define the modulating factors defining our distorted time percepts, such as biological motion as opposed to inanimate movements, or speed and intensity. Most of these studies have focused on vision, therefore the need for a modification of the described experimental setups in order to include other modalities as well, emerges. An investigation of possible interactions between modulating factors in one modality (e.g., speed of a visual stimulus) and the duration judgments in another modality (e.g., auditory

events), appears to be a fruitful extension of our current knowledge on this topic (i.e. intermodal interference). It is an interesting field, that besides its' philosophical extensions as to how we share a sense of time, a complete model on the formation of time estimation can be applied (especially for short intervals) in domains such as artificial limbs prosthetics, 3D animation, and cinema. Therefore, the combination of timing in this sense with dance seems importantly appropriate as dance is a complex human action.

In the second subsection of synchronization and entrainment in dance, the trend of using ecologically valid set-ups in order to investigate sensorimotor abilities has been highlighted. Besides a great interest in the sense of basic research, findings on this domain can be applied in sports education, dance therapy, and learning (e.g., musicians) that are based on sensorimotor abilities. The third subsection on social cognition described the recent works on the formation of our own self and the way we smoothly coordinate with a partner or a group. Progress on this topic is closely related to implementation of human-machine interaction, robotics, dance therapy as well as rehabilitation (e.g., autism spectrum disorders). At the final subsection, which focused on the temporal aspects of multisensory integration, dance proved to be a well situated stimulus for such studies, as it involves complex biological motion. Relevant knowledge can contribute to the development of applications on audiovisual displays in media, amelioration on internet social connection networks and communications, as well as sensory substitution. Thus, the modeling of the temporal aspects of complex movement patterns such as dance will potentially advance the current state of the art in both basic research and applied domains.

This review aimed at providing a glimpse on recent studies investigating the cognitive mechanisms involved in these everyday activities through the link of dance

and timing. Through this review, we would like to encourage researchers from the time perception domain, to consider dance as a fruitful tool in order to approach the possible modulating effects of dynamic, complex, naturalistic, and embodied biological motion as well as extensive spatiotemporal training on our time percept. Besides these possible time-alternations, the study of the origin and the metrical attributes of dance per se, is also a promising field, which renders an adaptation/extension of the above-mentioned dance-paradigms pertinent in the near future.

## Chapter 2: “Flash” Dance

### 1. Introduction

Summer vacations in a remote Greek island felt like a week, the same feeling you are currently experiencing during the first hour of your first day back to work! The passing of time is often misperceived and several hypotheses have been put forward in order to better understand the underlying mechanisms of this altered percept. Given that time estimation is ever present in all our daily activities, the clarification of the way people actually judge a specific duration is of great interest for timing researchers.

In order to construct a general framework for time perception, several models have been proposed from both a behavioral (e.g., the Scalar-timing model and its extension the Attentional Gate Model, AGM; e.g., Allan, 1998; Zakay & Block, 1997) and a neuronal approach (e.g., coincidence-detection model, duration selective channels; e.g., Buhusi & Meck, 2005; Heron et al., 2012). To-date, the AGM has been one of the most often cited models of timing (e.g., Pouthas & Perbal, 2004; Zakay & Block, 1997). The AGM associates timing with a timer and it is based on a three-stage process. The clock stage consists of an accumulator, where emitted pulses at a constant rate are collected. Collection of pulses is dependent on attention, where increased pulse accumulation is noted when more attention is devoted to the elapsed time. The memory stage refers to a working memory system that maintains the

specific time interval presented and a long-term memory system, which holds information regarding past pulse accumulations. The last stage of the AGM is that of the decision making stage, where a comparison is made between the ongoing pulses to the reference memory in order to produce a temporal judgment for a given interval.

Apart from the many investigations of timing differences promoted by task, interval (e.g., Buonomano & Karmarkar, 2002; Harrington et al., 2011; Lewis & Miall, 2003; Matell & Meck, 2000), and modality (e.g., Droit-Volet et al., 2007; Hass et al., 2012; Ono & Kitazawa, 2011; Penney, 2003; Tomassini et al., 2011), the notion of how speed of motion affects duration judgments has also been of great interest since the 60's. Using mostly simple visual stimuli (i.e., moving dots, geometrical shapes), some studies have found time dilation for higher stimulus speeds (Fraisse, 1962; Kaneko & Murakami, 2009; Leisser et al., 1991; Makin et al., 2012; Mate et al., 2009; Mathews, 2011; Tomassini et al., 2011), while other studies have reported the exact opposite results (Bonnet, 1965, 1967; Matsuda, 1974). According to the internal clock framework, the assumed relationship between speed and pulse rate has usually been used as a possible explanation of the above mentioned findings. This speed-pulse rate relationship supports that presentation of a fast moving stimulus speeds up the firing rate of the pacemaker leading to higher pulse accumulation and, thus, overestimation of the elapsed time (e.g., Kaneko & Murakami, 2009; Makin et al., 2012; Mathews, 2011). Alternate accounts provide support for a change model, whereby time estimation takes place through counting different indices. Thus, faster moving stimuli are assumed to contain more changes providing temporal cues that lead to a greater number of accumulated pulses (e.g., Brown, 1995). Notably, most of these studies have focused on the sub-second level or relatively short durations (<3

secs) and they have, usually, neglected the possible attentional effects that may be involved in timing distortions promoted by speed.

Today, therefore, speed has been assumed to be either the “accelerator” of pulse generation or the source of temporal cues given the increased number of changes present in a fast stimulus. It is, however, not clear whether stimulus speed per se is what actually influences duration estimates or rather temporal frequency, the timings utilized, and/or the number of stimulus changes. For example, Kanai et al. (2006) manipulated speed and temporal frequency independently in a set of dynamic, abstract stimuli (concentric grating) at the sub-second level. Participants’ reproduction estimates in this study showed dilation of time when temporal frequency was increased, while no such effect was obtained for increased stimulus speeds. Similarly, Brown (1995) in an attempt to dissociate motion, speed, and number of stimuli in time estimation, he measured time estimation for intervals of 6-18 secs. He reported a greater degree of overestimation for faster moving stimuli as compared to slow ones and attributed this finding to the number of events/changes of the stimuli presented. The insufficient data of how speed per se affects time estimation and the use of different methodologies and timings render direct data comparisons inappropriate. Therefore, the question of how speed might alter our percept of time remains unanswered.

In addition to the difficulty of defining the modulating effects of speed alone on duration estimation, the nature of the moving stimuli used in various studies could also be the source of the inconsistent previous results. Recent studies, for example, have reported differences in time estimation in the presence of animate as compared to inanimate movement, suggesting independent processing mechanisms for different types of motion (Carrozzo et al., 2010; Orgs & Haggard, 2011; Wang & Jiang, in

press). Consistent with this hypothesis, Carrozzo and Lacquaniti (2012) reported time distortions for a target moving stimulus (falling ball) as a function of the artificially-modified speed of a background moving stimulus (either a dancer performing ballet steps or a moving whirligig). Task performance differed as a function of the background stimulus, with higher dancing speed resulting to an underestimation of the landing time of the ball (i.e., anticipatory button presses) and overestimations for faster moving whirligig presentations. Such differences make the type of experimental stimuli used of critical importance and provide an argument for the preferred use of more naturalistic stimuli in experimentation.

Investigations using more naturalistic settings have only recently being attempted. For instance, Grivel et al. (2011) investigated time estimation as a function of speed alternations on a series of videos showing crowd moving in an accelerated, normal, or decelerated manner (speed was artificially-modified). Participants were asked to watch these videos and, subsequently, to produce a 20 sec interval. Production performance resulted in a shortening of duration estimation when an accelerated video was presented as compared to the normal and decelerated presentations. Naturalistic stimuli were also used by Orgs et al. (2011) in order to investigate the influence of perceived speed on time estimation. Specifically, they produced apparent motion using static images of a dancer displayed at a range of sub-second durations. Participants were asked to perform a bisection task (i.e., whether a square around the images was shown for a short or long period of time, with no anchor durations provided) and a speed discrimination task. Apparent moving stimuli that were perceived as faster led to a contraction of the subjective square presentation as compared to stimuli that participants reported as being slower.

Furthermore, Nather et al. (2011) reported a time distortion as a function of the embodiment of body postures implying movement of different intensity. Movement intensity was manipulated using static pictures of Degas' ballerinas statues in a temporal bisection task with two ranges of standard durations (0.4/1.6 and 2/8 sec). Intensity can be associated to speed given that implied movement intensity involves speed changes, whereas static postures do not. Bisection performance showed that postures implying greater movement intensity lead to longer timing judgments as compared to postures with lower movement intensity. The effect mentioned was present only for the short durations tested. The authors supported that a transient arousal caused by postures with more movement intensity speeded up the rate of the pacer, while when longer durations were tested arousal gave place to higher cognitive processes (e.g., attention).

The use of more naturalistic stimuli in time estimation, although exciting, is coupled with some problems. For example, in the study of Carozzo and Lacquaniti (2012), the main focus was the possible differences obtained in time estimation when animate or inanimate motion (in different speeds) was utilized. An interaction of speed and animacy on duration judgments was also noted but these results did not allow for a precise clarification of the effect of speed on time estimation. Similarly, Nather et al. (2011) focused on the intensity of the implied movement and not on speed per se. Additionally, Orgs et al. (2011) through the use of apparent motion managed to control for the number of changes presented in each condition, however speed differences were only implied (apparent velocity was altered) and could be confounded with the size of the movement's path. Finally, all the above-mentioned studies used either static images (Nather et al., 2011; Orgs et al., 2011) or artificially

modified videos (Carrozzo & Lacquaniti, 2012; Grivel et al., 2011), thus limiting their ecological validity.

Given the above-mentioned issues and the inconsistency of the previous findings, it remains unclear how and why stimulus speed might affect one's timing estimates. In the present study, therefore, we examined how speed affects time estimation, while controlling for stimulus changes. From a prospective point of view (i.e., participants were aware of the timing nature of the task), two independent tasks were performed -a production and a reproduction task- in order to estimate the timing of video clips of simple ballet steps. The steps were performed at a fast or slow velocity (without artificial speed manipulation; see Methods), while keeping all other parameters constant (i.e., spatial attributes, number of changes). The intervals used were of 3, 6, and 9 secs, thus, allowing us to measure performance for both shorter and longer intervals. According to the previous literature, the control for stimulus changes, and video presentation during the encoding phase (for the reproduction task), we hypothesized that if speed proves to be an “accelerator”, a greater overestimation of fast videos (as compared to slow ones) was expected during the reproduction task and the reverse pattern was expected for the production task.

Apart from further elucidating the effects of speed on time estimation, we were also interested on the susceptibility of expertise and stimulus familiarity on estimations driven by speed. We, therefore, experimented with professional dancers, a group with extensive training on spatial and temporal response accuracy (e.g., Calvo-Merino et al., 2010) and previous long-term enactment of the stimuli presented. Given the expertise and experience of this group and the above-mentioned hypotheses, we expected that dancers' performance would be superior (i.e., higher accuracy and lower variability) to that of non-dancers.

## **2. Methods**

### ***2.1 Participants***

Fourteen professional dancers ( $M = 29.3$  years of age, 12 females) and 14 non-dancers ( $M = 31.4$  years of age, 12 females) took part in the experiment. The professional dancers possessed a diploma from the Greek Ministry of Culture, which corresponds to more than 15 years of extensive dance training. Non-dancers had no ballet or dance experience. All participants reported normal or corrected-to-normal visual acuity.

### ***2.2 Stimuli and apparatus***

Two simple ballet steps (Step 1: pas de bourre; Step 2: pas de cheval; see Fig. 1) were performed in a fast and slow speed by a professional dancer. Step 1 involved movement through space, while Step 2 had no spatial displacement, thus allowing for the exploration of how movement in space may affect participants' duration estimates. Ballet was chosen as a dance form due to the very specific movement repertory that does not resemble any other every day activity, thus allowing us to control for movement familiarity for the non-dancers. The stimuli were recorded in a dance studio using a Sony PMW-EX1 high definition camera. Both the fast and slow steps were designed so that the exact same movement, in terms of spatial attributes and number of changes, was performed. The two different Step-types (Step 1 and Step 2) were performed at two different speeds (fast vs. slow) and three different intervals were used (3, 6, and 9 secs), thus, resulting in a total of 12 videos. In order to ensure that the fast and slow performance of the different Steps used was actually perceived as such, an online survey was conducted (using Survey Gizmo; <http://www.surveygizmo.com>). Survey participants viewed all the video clips and had to rate each clip in terms of speed. A Likert scale was provided (with 1 being very

slow and 7 being very fast). Twenty-one dancers and 69 non-dancers, who did not participate in the main experiment, completed the survey. Survey analysis showed that the fast versions of both Steps presented were rated as faster in all durations as compared to the slow versions [ $F(2,176) = 4.06, p = 0.02$ ].



**Figure 1.** Static frames extracted from the original ballet videos displaying A) Step 1 [pas de bourre] containing a spatial displacement and B) Step 2 [pas de cheval] with no spatial displacement.

Performance of the different steps (i.e., fast vs. slow) resulted in different video durations, thus in order to make the fast and slow video versions equal in duration, 15 static frames were added at the beginning and the end of each fast clip. The static frames were extracted from the original videos (first and last frame) using Adobe Premiere Pro CS5.5. Thus, both slow and fast presentations were composed of a

single dance step of equal duration (i.e., 3 secs). The 6- and 9-sec videos were created using loops of this initially created 3-sec video. As a result, the 3-sec condition was composed of a single dance step presentation, whereas the 6- and 9-sec conditions were composed of two- and three-step repetitions with one and two transitions connecting these repetitions, respectively. The step transitions were smoothed by the “wipe” transition effect, which was added between the last and the first frame of each repetition, thus leaving the dynamic movement intact. The number of transitions was equal for the respective fast and slow video versions, thus, no confounds in regards to number of changes/indices/events existed between these conditions. Stimulus creation in the way described allowed us to maintain a naturalistic presentation (i.e., no artificial speed modification) and at the same time control for changes. The sound was removed from all videos. The stimuli were presented on an Acer, ASPIRE 7750G laptop. The experiment was conducted using Presentation programming software (Version 15.0; Neurobehavioral Systems Inc.). Eight repetitions of each condition were divided into two blocks with breaks in between. The order of stimulus presentation was randomized.

### ***2.3 Experimental procedure***

Participants performed a reproduction task followed by a production task. They were seated approximately 60 cm from the screen in a dimly lighted room. A short practice block preceded both tasks in order to familiarize the participants with the experimental procedures (no feedback was given and the durations utilized differed from those used in the main tasks). Experimentation did not exceed the 30 minutes for the reproduction task and the 20 minutes for the production task. Participants were instructed not to use any counting strategies.

During the reproduction task, participants watched a video of a certain duration followed by a static image of a dancer (static image extracted from the first frame of a different dance video, which was not used in the experiment, to ensure that the transition from the video to the static image would be easily noticeable). The aim was to reproduce the duration of the video presented by leaving the static image on the screen for an equal amount of time. When participants thought the elapsed time was equal to the video duration, they pressed ENTER and the next trial was initiated. In the production task, the instruction “Produce an interval that equals X seconds” appeared on the screen and, subsequently, a video was presented. Participants were asked to leave the video on the screen for the duration that had been indicated in the instructions. Next, they pressed ENTER when they thought the duration in question was reached.

### **3. Results**

#### ***3.1 Analysis***

Two psychometric measures were derived from the raw participant data, the accuracy (i.e., estimated time divided by the original duration in each condition) and the coefficient of variation (CV; i.e., the standard deviation divided by the mean duration judgment). Accuracy indicates whether participants had underestimated ( $<1$ ) or overestimated ( $>1$ ) the physical duration of a given interval. CV is a measure of the participants' response variability, with higher CV indicating greater response variability. Analysis was performed using a repeated measures analysis of variance (ANOVA) with Group (dancers vs. non-dancers) as the between-subjects factor and Speed (fast vs. slow), Step-type (Step 1 vs. Step 2), and Duration (3, 6, and 9 secs) as the within-subjects factors for both the reproduction and production tasks. For all of

the analyses reported here, Sidak corrected t-tests (with point of statistical significance set to  $p < 0.05$ ) were used for all post-hoc comparisons.

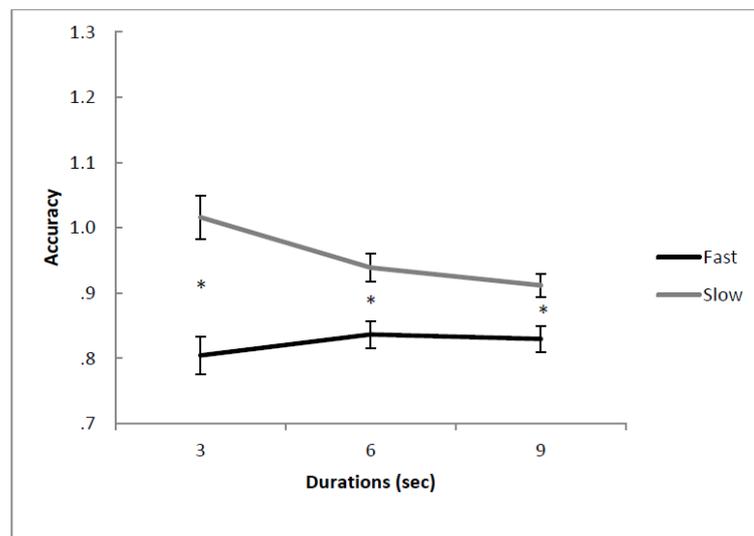
### ***3.2 Reproduction Task***

#### ***3.2.1 Accuracy***

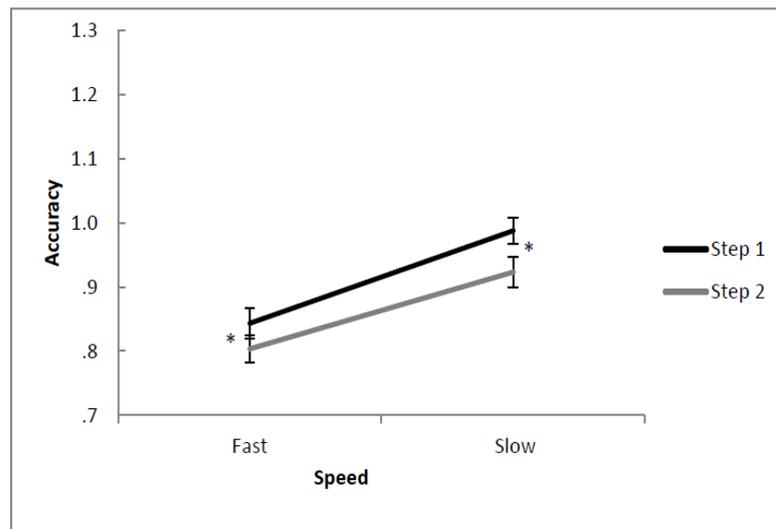
In regards to accuracy, main effects for Speed, Step-type, and Duration were significant, while no effect of Group was obtained. Specifically, a main effect of Speed was obtained [ $F(1,26) = 105.61, p < 0.001, \eta^2 = 0.80$ ], with the fast stimulus versions being further underestimated ( $M = 0.82$ ) than the slow ones ( $M = 0.96$ ). Thus, speed appears to modulate participants' duration judgments. A main effect of Step-type was also noted [ $F(1,26) = 49.33, p < 0.001, \eta^2 = 0.65$ ], with participant's being more accurate in their duration judgments for Step 1 as compared to Step 2 ( $M = 0.92$  and  $0.86$  for Step 1 and 2, respectively). As already mentioned, Step 1 contained a spatial displacement, while Step 2 was performed at a constant spatial position, thus, the differential performance accuracy could be associated with this spatial displacement difference (see Fig. 2B). A main effect for Duration was also obtained [ $F(2,52) = 4.09, p = 0.02, \eta^2 = 0.14$ ], with participants performing significantly better in the 3- as compared to the 9-sec condition, while no differences were obtained for the 6-sec condition ( $M = 0.91, 0.89,$  and  $0.87$  for 3, 6, and 9 sec, respectively).

Analysis of the reproduction data also resulted in a Speed by Duration interaction [ $F(2,52) = 27.16, p < 0.001, \eta^2 = 0.51$ ]. For each duration presented, the difference between the fast and slow stimulus versions was significant, with the fast versions being underestimated more than the slow versions (Fast:  $M = 0.80, 0.84,$  and  $0.83$ ; Slow:  $M = 1.02, 0.94,$  and  $0.91$  for 3, 6, and 9 sec, respectively; see Fig. 2A). The interaction of Step-type by Group was also significant [ $F(1,26) = 4.49, p = 0.04, \eta^2 = 0.15$ ], with both groups being more accurate for Step 1 as compared to Step 2

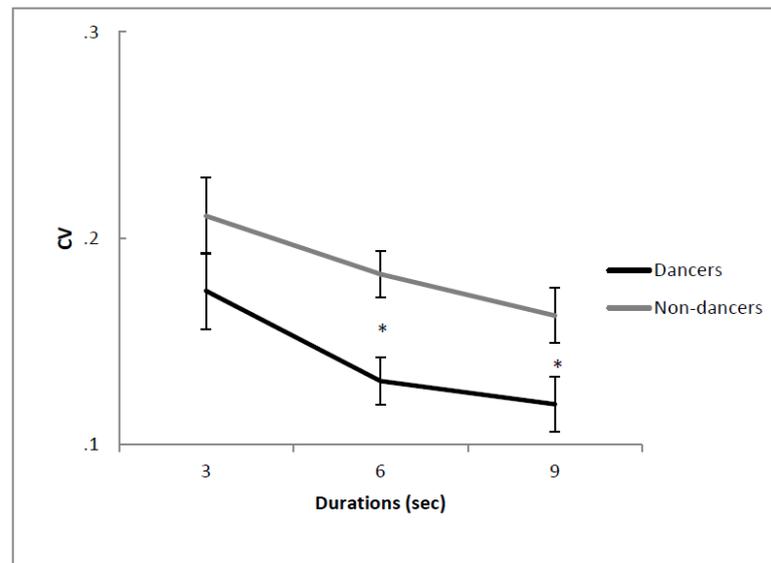
(Dancers:  $M = 0.94$  and  $0.90$ ; Non-dancers:  $M = 0.89$  and  $0.83$  for Step 1 and 2, respectively). Significance was also obtained for the interaction of Speed by Step-type by Duration [ $F(2,52) = 4.55$ ,  $p = 0.01$ ,  $\eta^2 = 0.15$ ]. For all durations utilized, both steps differed in accuracy, with the fast stimulus versions leading to greater underestimation compared to the slow ones (Step 1-Fast:  $M = 0.83$ ,  $0.85$ , and  $0.85$ ; Slow:  $M = 1.03$ ,  $0.99$ , and  $0.95$ ; Step 2-Fast:  $M = 0.78$ ,  $0.82$ , and  $0.81$ ; Slow:  $M = 1.00$ ,  $0.89$ , and  $0.88$  for 3, 6, and 9 sec respectively). Additionally, even though dancers were more accurate ( $M = 0.92$ ) than non-dancers ( $M = 0.86$ ), the between-subjects factor failed to reach significance [ $F(1,26) = 1.87$ ,  $p > 0.05$ ]. All other interactions were not significant.

**A**

B



C



**Figure 2.** Mean accuracy of speed (fast and slow conditions) (A) and of speed and step type (B) and mean CV of group (i.e., dancers and non-dancers; C) are plotted as a function of duration (3, 6, and 9 secs) in the reproduction task. The error bars represent the standard errors of the means (within subjects for A and B and between subjects for C). Significant differences ( $p < 0.05$ ) are highlighted by an asterisk.

### 3.2.2. Coefficient of variation (CV)

In regards to CV, a main effect of Duration and Group was obtained, with the effects of Step-type and Speed not reaching significance. In detail, a main effect of

Duration was noted [ $F(2,52) = 11.19, p < 0.001, \eta^2 = 0.45$ ], with participants being significantly less consistent in their responses for 3 ( $M = 0.19$ ) than for 6 ( $M = 0.16$ ) and 9 secs ( $M = 0.14$ ), while comparison between the 6- and 9-sec condition did not reach significance. A significant main effect for Group was obtained [ $F(1,26) = 7.22, p = 0.01, \eta^2 = 0.22$ ] (see Fig. 2C), with dancers being less variable in their judgments ( $M = 0.14$ ) as compared to non-dancers ( $M = 0.18$ ). All other main effects and interactions did not reach significance.

Overall, the analysis of the reproduction data showed a general underestimation of the durations presented. The fast versions of the dance stimuli were underestimated more than the slow versions. Dancers were significantly more consistent in their responses as compared to non-dancers in all conditions presented.

### ***3.3 Production task***

#### ***3.3.1 Accuracy***

Focusing on accuracy and consistent with the results obtained from the reproduction task, the main effects of Speed, Step-type, and Duration were significant, while the factor of Group once more failed to reach significance. Specifically, a main effect of Speed was noted [ $F(1,26) = 5.45, p = 0.03, \eta^2 = 0.17$ ] (see Fig. 3A) with fast video versions being overestimated ( $M = 1.13$ ) more than the slow ones ( $M = 1.08$ ). Thus, again, speed appears to alter the participants' time perception. However, during the production task a greater overestimation for the fast videos as compared to the slow ones was obtained, whereas the opposite result was true in the reproduction task (an expected finding given the inverse relationship of these two tasks; Brown, 1995). Additionally, a main effect of Step-type was obtained [ $F(1,26) = 6.96, p = 0.01, \eta^2 = 0.21$ ], with performance in Step 1 being better ( $M = 1.09$ ) than that for Step 2 ( $M = 1.12$ ). This is in agreement with the findings of the

reproduction task. A main effect of Duration also reached significance [ $F(2,52) = 16.25, p < 0.001, \eta^2 = 0.38$ ]. Once more, longer durations were associated with shorter duration judgments, thus, a significantly greater overestimation occurred in the 3-sec condition ( $M = 1.16$ ) in comparison to the longer durations ( $M = 1.11$  and  $1.04$  for 6 and 9 sec, respectively; no difference between 6 and 9 sec was obtained).

An interaction of Duration by Group was also obtained [ $F(2,52) = 16.91, p < 0.001, \eta^2 = 0.39$ ], dancers did not differ in their performance across durations ( $M = 1.08, 1.12, \text{ and } 1.08$  for 3, 6, and 9 sec, respectively), whereas non-dancers were less accurate in the 3- ( $M = 1.24$ ) as compared to the 6- ( $M = 1.10$ ) and 9-sec conditions ( $M = 1.01$ ). Step-type by Group was also significant [ $F(1,26) = 6.78, p = 0.01, \eta^2 = 0.21$ ]. Dancers were equally accurate for Step 1 ( $M = 1.09$ ) and Step 2 ( $M = 1.09$ ), while non-dancers were more accurate for Step 1 ( $M = 1.09$ ) than for Step 2 ( $M = 1.15$ ). Moreover, the interaction of Step-type by Speed also reached significance [ $F(2,52) = 6.72, p = 0.01, \eta^2 = 0.20$ ], with Step 1 being further overestimated ( $M = 1.12$ ) for fast as compared to slow stimulus presentations ( $M = 1.05$ ), while this difference was not obtained for Step 2 ( $M = 1.13$  and  $1.11$  for fast and slow, respectively; see Fig. 3B). Even though, the dancers once more appeared to be more accurate in their duration judgments ( $M = 1.09$ ) than non-dancers ( $M = 1.12$ ), the difference was not significant [ $F(1,26) = 0.04, p > 0.05$ ]. All other interactions failed to reach significance.

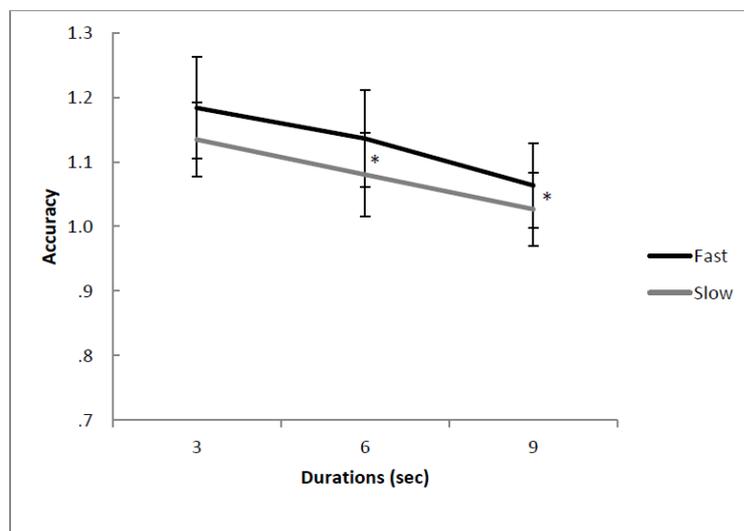
### ***3.3.2 Coefficient of variation (CV)***

In regards to CV, a main effect of Duration and Group was found (see Fig. 3C). In agreement with the results of the reproduction task, no main effects of Speed and Step-type were obtained. The main effect of Duration [ $F(2,52) = 10.97, p < 0.001, \eta^2 = 0.30$ ] revealed the highest variability for the shortest interval (i.e., higher CV;  $M$

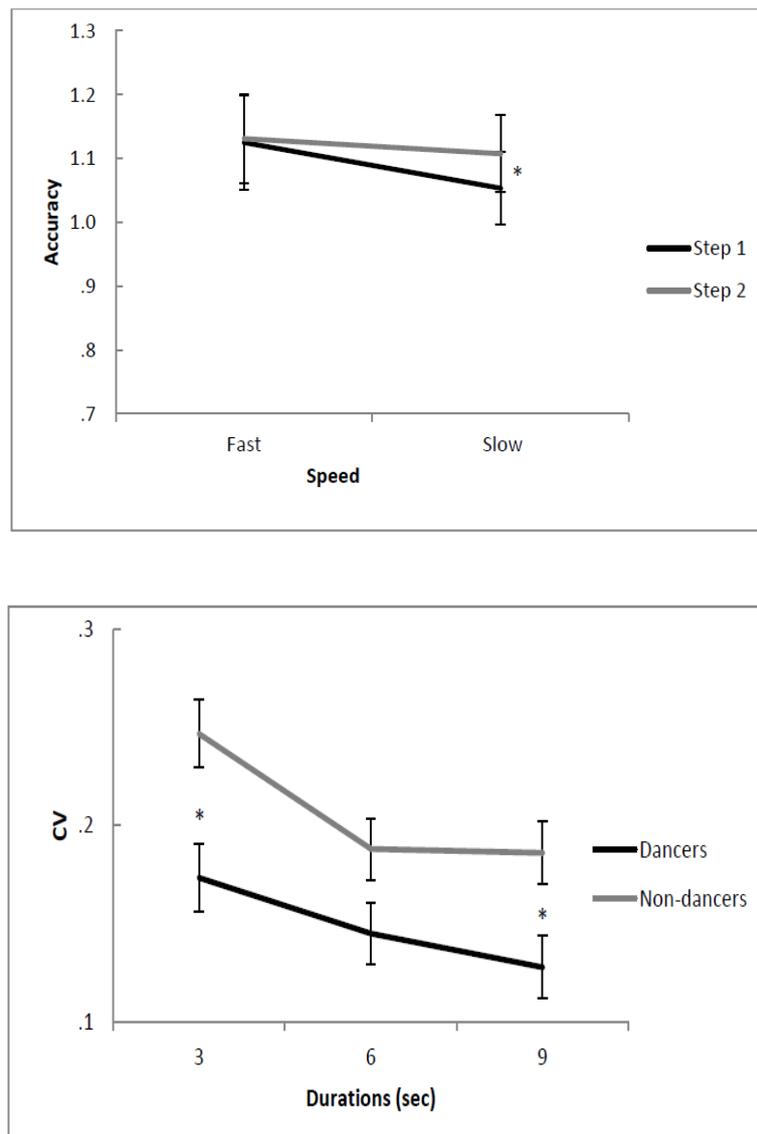
= 0.21, 0.17, and 0.157 for 3, 6, and 9 secs, respectively; no difference was found for 6 vs. 9 secs). Dancers ( $M = 0.15$ ) were significantly more consistent in their response in comparison to non-dancers ( $M = 0.20$ ) [ $F(1,26) = 9.93$ ,  $p = 0.004$ ,  $\eta^2 = 0.28$ ]. All other main effects and interactions failed to reach significance.

Overall, the analysis of participant's performance in the reproduction task revealed an effect of speed on time estimation. However, the direction of the speed modulation is different to that obtained for the reproduction task (with fast videos being further overestimated than slow ones). Dancers were significantly more consistent in their responses than non-dancers in all conditions presented (a finding also noted for the reproduction performance).

A



B



**Figure 3.** Mean accuracy of speed (A) and of speed and step type (B) and mean CV of group (C) are plotted as a function of duration (3, 6, and 9 secs) in the production task. The error bars represent the standard errors of the means (within subjects for A and B and between subjects for C). Significant differences ( $p < 0.05$ ) are highlighted by an asterisk.

## Chapter 3: Discussion

The primary aim of this study was to investigate the role of speed on time estimation, while controlling for the number of events/changes of the stimuli presented. We found a greater underestimation for the fast stimulus versions when compared to the slow ones in the reproduction task, while the exact opposite result (i.e., a greater overestimation) was found for the production task. In production tasks, an overproduction indicates that the criterion value is attained later, thus, an underestimation of the elapsed time occurs. Therefore, the opposite results in comparison to those obtained in reproduction were expected and justified (Pouthas & Perbal, 2004; Zakay, 1993). We also investigated whether or not high level of expertise with spatiotemporal tasks can influence the interaction of speed and time estimation using professional dancers and non-dancers as participants. In both the production and reproduction tasks, dancers were significantly less variable in their estimations as compared to non-dancers. Thus, speed and acquired experience appear to modulate our judgments of event duration.

Our findings bring into question the assumptions often made by the internal clock models regarding the relationship between speed and the pacemakers' rate (e.g., Kaneko & Murakami, 2009; Makin et al., 2012; Mathews, 2011). If speed played the role of an 'accelerator', then an overestimation for the fast versions of the stimuli would be expected in the reproduction task, as more pulses would be emitted

compared to the slow stimulus presentations. However, in our case the opposite effect was found. Taking into consideration that the number of changes was controlled (see Section 2.2), the factor of attention – which has previously been neglected – becomes a plausible explanation of our findings and of the effects of speed on time estimation.

Attentional aspects have mostly been addressed in dual-task paradigms (e.g., Block et al., 2010; Moncla et al., 2010; Taatgen et al., 2007; Tse et al., 2004), where reproduction of a target stimulus and a secondary (usually demanding) task resulted in target underestimation. Similarly, in single task experimental designs, it has been suggested that in the cases where a target stimulus is “interesting” or attentional demanding in terms of processing, the attentional resources devoted to the elapsed time regress (e.g., Angrilli et al., 1997). Thus, an underestimation of a given target interval is expected. In our case, therefore, if one considers the fast dance steps as more attentional capturing compared to the slow ones, the results obtained here fit well with the predictions of the AGM. That is, in the reproduction task, given the differential attentional allocation to the stimuli, a loss of pulses during encoding (memory storage) occurred, leading to a greater underestimation for the target durations for the fast stimulus versions as compared to the slow ones. On the other hand, during the production task, a greater loss of pulses due to further attentional capture of fast moving stimuli as compared to slow ones, required a larger number of accumulated pulses (in conventional time units) in order for the target interval to be reached, leading to overproductions.

Evidence that higher stimulus speed is more attentional capturing than stimuli of lower speed mainly comes from the reported asymmetry in classical visual search paradigms (Fencsik et al., 2005; Ivry & Cohen, 1992). That is, smaller reaction times have been noted when a fast-moving target is traced among slow-moving distractors,

whereas larger reaction times were found for slower targets moving among fast-moving distractors. Hence, fast-moving stimuli seem to ‘pop-out’ in a greater degree than slow-moving stimuli, supporting the idea that higher speeds capture attention more than lower stimulus speeds. Support for greater attentional capture for fast-moving stimuli has also been supported from a biological standpoint (Grivel et al., 2011). Specifically, the human capacity to attend to something that moves fast can provide us with an advantage for potentially faster reaction to a given stimulus.

Given the above evidence of fast-moving stimuli leading to greater attentional capture, direct consequences on the functioning of the internal clock are expected. Specifically, under the AGM framework, attention taps into the switch gate and not the pacemaker module. This gate-pacemaker dissociation has been proposed by Burle and Casini (2001). In their study, they examined how arousal and attention act on different levels of time processing using a production task (i.e., presentation of different intensities of click trains and/or a secondary speeded reaction task). The authors reported no interaction between the intensity modulation and the secondary task, thus, the independent modulations that were noted had additive effects. Overestimations were noted for low intensities and dual-task conditions in comparison to high intensities and single-task performance, where an underproduction of duration was obtained. Given the opposite effects of the manipulations performed in regards to the arousal level and attention and the absence of an interaction between these two factors, a dissociation was advocated by the authors. That is, arousal influences the pacer’s rate, while attention the switch gate of passing pulses. In the present study, there was no acceleration of the pacer’s rate due to higher stimulus speed and, thus, it can be assumed that speed did not affect the participants’ arousal levels. Given our reported results, one can argue that the capture of attention seems to

be the explanatory factor. Hence, higher speed is more attentional capturing than lower speed and, thus, a greater underestimation of intervals is noted for fast dance videos in comparison to slow ones.

The involvement of differential attentional allocation in our study is also supported by the range of durations tested. It has been suggested that different processing mechanisms are in place for durations above and under 3 secs. Short intervals have been associated with arousal mechanisms that modulate the internal clocks' pace rate, while for longer durations attentional factors that influence the switch gate have been proposed (e.g., Angrilli et al., 1997; Bar-Haim et al., 2010; Nather et al., 2011). For example, Angrilli et al. (1997) in a study investigating the association of arousal levels with time estimation, utilized IAPS pictures displayed for 2, 4, and 6 secs in a reproduction task (among other methods). An overestimation provoked by the high arousal stimuli in the 2 secs progressively shifted to underestimation when longer durations were presented. Respectively, low arousal stimuli were progressively underestimated as the durations presented were longer. The authors suggested the involvement of separate/different mechanisms controlling time estimations for longer durations. Similar position was supported by Bar-Haim et al. (2010), in a study comparing anxious and non-anxious participants in a 2, 4, and 8 secs reproduction task for threatening or neutral pictures. Anxious participants overestimated threatening stimuli relative to the non-anxious participants. However, this difference seemed to disappear for longer durations. Our duration range (i.e., 3, 6, and 9 sec) did not tap on alternations in arousal levels, but on allocation of attention. That is, faster dance videos were more attentional capturing than slow ones and, thus, an underestimation of the intervals presented was obtained.

Participants' performance in our study led to a greater underestimation as we moved to longer durations, a finding that is in accordance with Vierordt's law (where as we move towards larger intervals a greater underestimation is expected due to negative bias; e.g., Brown, 1995). Eagleman and Pariyadath (2009) proposed an influence of repetition on coding efficiency in time estimation, in correspondence with neural response (firing rates). According to this proposal, repetition suppression at a neuronal level (i.e., lower neuronal response when stimuli are being repeated in comparison to novel displays) relates to the fact that repeated stimuli are judged as lasting for a shorter period as compared to novel stimuli of equal physical duration. Thus, the magnitude of the neuronal response is directly related to the estimated duration of a given interval. In the present study, the stimuli with longer duration (e.g., 6 or 9 secs) were composed of loops of the same step (i.e., repetitions), thus their underestimation may be associated with the idea proposed by Eagleman and Pariyadath. However, this idea was proposed for a restricted time scale of less than a second, thus further investigation is needed to examine whether or not this repetition effect can also apply for longer stimulus durations.

As the underestimation was increasing for longer durations, the participant's CVs were decreasing at those longer intervals, a pattern that seems to violate the scalar property. However, several other studies have reported similar findings and interpreted this as an increased precision of timing for longer durations as opposed to shorter ones (Chang et al., 2011; Lewis & Miall, 2009; Wearden & Lejeune, 2008). The fact that all these studies have utilized different duration ranges does not yet permit solid conclusions on whether different clock mechanisms are in play or the difficulty of the task could be driving the violations reported with the differences noted in CVs. Even though, it has been recently suggested that variable CVs may

indicate possible counting strategies (Rattat & Droit-Volet, 2012), the fact that we explicitly advised participants otherwise and the timing used in our experiment exclude counting as a possible strategy in our study.

Apart from the AGM framework, the differential allocation of attention and its effects on time estimation have also been proposed in other models of timing. For example, Buhusi and Meck (2009) have also examined the consequences of attentional sharing. Adopting a more neuronal view, they proposed that brain areas involved in time perception are connected to circuits of attention and working memory. Thus, if something captures one's attention during the time-keeping processes, a resource reallocation might happen and this could also account for our reported differences for faster-attentional grabbing stimuli on duration estimation. Buhusi and Meck (2005) have also proposed that time perception might emerge from synchronicity of cortical oscillations (coincidence-detection model), but indicated that "the coincidence-detection model and the pacemaker-accumulator model may be two sides- neural and behavioral- of the same coin" (p. 764). Hence, there is a probability for neuronal approaches not to be counter exclusive with behavioral ones. Further research on both aspects will probably lead to the formation of a general, robust, and predictive model on time perception.

As already mentioned, we were also interested in how long-term experience with spatiotemporal events could affect the interaction of speed and time estimation. Our results showed professional dancers to be significantly more consistent in their duration judgments as compared to non-dancers. The only relevant recent study, which however did not address the influence of speed on time estimation, is that of Cicchini et al. (2012). They compared the performance of expert percussionists, string musicians, and naïve participants in a duration reproduction task using light flashes.

An optimal encoding of interval (in a sub-second level) was reported in expert percussionists as compared to naïves and string musicians, indicating a modulating role of extensive training in music. The veridical response of drummers in comparison to the central tendency to the mean noted in the other two groups was explained through a Bayesian approach. Specifically, the advantage in performance for drummers was interpreted through incompatibility with central tendency, as accuracy and precision is required by their profession. This difference occurred only when flashes were presented as stimuli, while it was diminished when the flashes were replaced with auditory tones. This modality aspect could explain in our case the fact that even though dancers were generally more accurate than non-dancers, this difference did not reach significance. Given the fact that dance is a multisensory experience, dancers due to their extensive training, are accustomed to audiovisual events. That is, maybe the presentation of stimuli only in the visual modality was not the appropriate type of presentation for optimal performance. Follow-up studies, using auditory and audiovisual stimulus presentations, can clarify whether expertise superiority becomes more evident within and/or across modalities. Alternatively, inadequate complexity of the chosen steps could be the reason accuracy did not reach significance, thus making pertinent the need for future testing of more complex dance steps.

Apart from the future study of higher in complexity dance stimuli, the differential performance we found for the two different Step types also calls for future work on how spatial attributes affect duration judgments. Specifically, our results showed higher performance accuracy for Step 1 (with spatial displacement) as compared to Step 2 (no spatial displacement; see Fig. 2B and 3B). Time and space may be governed by common processing and metric mechanisms (e.g., Buetti and

Walsh, 2009; Glasauer et al., 2007). Hence, in our case, the advantage obtained for Step 1 as compared to Step 2, could be interpreted in terms of spatiotemporal mapping. That is, in order to construct an interval, additional information from the spatial domain in terms of - for example, the distance that can be travelled within a certain duration - could enhance our accuracy on time estimation (Christian et al., 2012). Taking into consideration, that in our everyday lives space and time are tightly connected, integrative information derived from these two dimensions could potentially provide us with the capacity to estimate the abstract sense of time, through the more tangible spatial attributes. This idea is being additionally supported by recent studies on the relationship of language and time (e.g., Boroditsky, 2001, 2002; Casasanto & Boroditsky, 2008). These studies have been focusing on linguistic metaphors and cultural differences emerging from differences in linguistic constructions and their possible effects on timing. Even though, there is an emerging interest on the possible connection between space and time, the interaction of these two dimensions with a modulating factor on time perception, such as speed, has not yet been addressed. Given our results, the use of naturalistic stimuli with an even greater emphasis in spatial differences, in a similar experimental set up, could lead us to new findings on the interaction of time and space in duration estimation.

Overall, our results showed that both stimulus speed and familiarity/expertise with spatiotemporal events can modulate one's timing percept. Specifically, in reproduction, faster event presentations led to a greater underestimation as compared to slower events, whereas the opposite was true for production. Additionally, dancers were significantly less variable in their estimations as compared to non-dancers. Our study, given the stimulus control in terms of number of changes, provides us with clear evidence on the modulating role of speed alone on time estimation. Additionally,

the issue of acquired experience and speed on duration judgments was addressed for the first time, thus opening the possibilities for further experimentation on the topic.

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