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Time to act: The relationship of time perception, action and expertise

by

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ABSTRACT

Complex biological motion (e.g., dance) represents a unique, multifactorial domain that is rapidly gaining the interest of cognitive scientists and timing researchers in particular, given its spatiotemporal complexity and embodied nature. The study of timing through dance can provide valuable insight in remaining open questions and methodological discrepancies, via a more complex and ecologically valid perspective, extending the existing paradigms. This thesis is divided in to three chapters in an effort to further investigate the connection of complex biological motion (e.g., dance) and timing either by thoroughly reviewing the related literature of the past 15 years (Chapter 1) or by conducting original experiments combining these two elements (Chapters 2 & 3). Chapters 2 and 3 could potentially be included in our review's first aforementioned section, investigating the connection of dance and duration estimation in particular.

Chapter 1 is a narrative review that consolidates current literature on dance and a) duration estimation, b) synchronization/entrainment, c) temporal aspects of social interaction, and d) modality contribution in temporal perception. Thus, aiming to put together, for the first time, a complete picture of the knowledge gained to date on the interaction of dance and timing in regards not only to basic research findings but also potential clinical and technological applications. This overview hopefully, can also serve as a primer for questions that have yet remained unanswered both in timing and dance research.

Chapter 2 focuses on the different effect real vs. implied dance motion might have on duration perception, inspired by the notion of our timing estimates being often prone to distortions from non-temporal attributes. It has been argued that movement can be implied by static cues of images depicting an instance of a dynamic

event. Instances of implied motion have been investigated as a special type of stimulus with common processing mechanisms to those of real motion. Timing studies have reported a lengthening of the perceived time for moving as opposed to static stimuli and for stimuli of higher as compared to lower amounts of implied motion. However, the actual comparison of real-versus-implied motion on timing has never been investigated. In the present study, we compared directly the effect of two hypothetically analogous ballet steps with different amounts of movement and static instances of the dynamic peak of these events in a reproduction task. The analysis revealed an overestimation and lower response variability for real as compared to implied motion stimuli. These findings replicate and extend the apparent duration lengthening for moving as compared to static stimulation, even for static images containing implied motion, questioning whether or not the previously reported correspondence between real and implied motion transfers in the timing domain. This lack of correspondence was further supported by the finding that the amount of movement presented affected only displays of real motion.

In Chapter 3 we describe a series of experiments investigating the effect of motion direction on duration judgments. Motion direction has been considered as a modulating factor of timing as well. Relevant research shows an interval dilation when the movement is towards (i.e., looming) as compared to away from the viewer (i.e., receding). This perceptual asymmetry has been interpreted based on the contextual salience and prioritization of looming stimuli that allows for timely reactions to approaching objects. This asymmetry has mainly been studied through abstract stimulation with minimal social relevance. Focusing on the latter, we utilized naturalistic displays of biological motion and examined the aforementioned perceptual asymmetry in the temporal domain. In Experiment 1, we tested visual

looming and receding human movement at various intervals in a reproduction task and found no differences in the participants' timing estimates as a function of motion direction. Given the superiority of audition in timing, in Experiment 2, we combined the looming and receding visual stimulation with sound stimulation of congruent, incongruent, or no direction information. The analysis showed an overestimation of the looming as compared to the receding visual stimulation when the sound presented was of congruent or no direction, while no such difference was noted for the incongruent condition. Both looming and receding conditions (congruent and control) led to underestimations as compared to the physical durations tested. Thus, the asymmetry obtained could be attributed to the potential perceptual negligibility of the receding stimuli instead of the often-reported salience of looming motion. The results are also discussed in term of the optimality of sound in the temporal domain.

Key words: Reproduction task; Duration estimation; Biological motion

Ώρα για Δράση: Η σχέση της χρονικής αντίληψης με την κίνηση και την εξειδίκευση

ΠΕΡΙΛΗΨΗ

Η περίπλοκη βιολογική κίνηση (π.χ., χορός) αποτελεί ένα ξεχωριστό πολυπαραγοντικό πεδίο μελέτης, το οποίο χάρις την ενσώματη και χωροχρονική πτυχή του, έλκει με ταχύτατους ρυθμούς το επιστημονικό ενδιαφέρον στο τομέα της γνωσιακής επιστήμης, και πιο συγκεκριμένα, στη μελέτη της χρονικής αντίληψης. Η έρευνα της χρονικής αντίληψης μέσω του χορού, δύναται να απαντήσει σε διάφορα ανοιχτά ερωτήματα και μεθοδολογικές ασυμφωνίες, προσδίδοντας μια πιο σύνθετη και οικολογικής εγκυρότητας οπτική, επεκτείνοντας τα ήδη υπάρχοντα πειραματικά έργα. Η παρούσα διδακτορική διατριβή με στόχο μια περαιτέρω εξέταση ακριβώς αυτής της σχέσης της περίπλοκης βιολογικής κίνησης (π.χ., χορός) και της χρονικής αντίληψης, χωρίζεται σε τρία κεφάλαια: σε μια κριτική ανασκόπηση της σχετικής βιβλιογραφίας των τελευταίων 15 ετών (Κεφάλαιο 1) και στην πραγματοποίηση πρωτότυπων πειραμάτων που διερευνούν τη σύνδεση αυτών των δύο στοιχείων (Κεφάλαια 2 & 3). Τα πειράματα που περιγράφονται στα Κεφάλαια 2 & 3, μπορούν να συμπεριληφθούν στην πρώτη ενότητα της ανασκόπησης μας, μιας και εστιάζουν σε μια πιθανή διασύνδεση του χορού με την εκτίμηση της χρονικής διάρκειας.

Στο πρώτο κεφάλαιο παρατίθεται μια ανασκόπηση των υπαρχουσών ερευνών που στοχεύουν στην παγίωση της σχέσης του χορού με : α) την εκτίμηση της χρονικής διάρκειας, β) το συγχρονισμό, γ) τις χρονικές παραμέτρους της κοινωνικής αλληλεπίδρασης, και δ) την επίδραση της τροπικότητας στη χρονική αντίληψη. Ο σκοπός αυτής της ανασκόπησης, είναι να διαμορφωθεί για πρώτη φορά μια σαφής και ολοκληρωμένη εικόνα της εδραιωμένης γνώσης πάνω στην αλληλεπίδραση του

χορού και της χρονικής αντίληψης, η οποία δεν περιορίζεται σε αποτελέσματα βασικής έρευνας, αλλά ενέχει πιθανές κλινικές και τεχνολογικές εφαρμογές. Ευελπιστούμε αυτή η ανασκόπηση να λειτουργήσει ως εργαλείο στην περαιτέρω έρευνα των αναπάντητων ερωτημάτων στη χρονική αντίληψη αλλά και την εν γένει μελέτη του χορού.

Στο δεύτερο κεφάλαιο, εστιάζοντας ακριβώς στην προαναφερθείσα σχέση χορού και χρονικής αντίληψης περιγράφεται ένα πείραμα που εστίασε στη διαφορετική πιθανή επίδραση της αληθινής σε σύγκριση με την υπονοούμενη χορευτική κίνηση στην εκτίμηση της χρονικής διάρκειας. Έχει υποστηριχθεί ότι η κίνηση μπορεί να υπονοηθεί μέσω στατικών εικόνων, οι οποίες δύνανται να αποδώσουν ικανοποιητικά ένα δυναμικό γεγονός. Οι εικόνες υπονοούμενης κίνησης έχουν θεωρηθεί ένας ξεχωριστός τύπος ερεθίσματος, το οποίο μοιράζεται κοινούς μηχανισμούς επεξεργασίας με αληθινά κινούμενα ερεθίσματα. Σχετικές έρευνες έχουν δείξει μια υπερεκτίμηση της χρονικής διάρκειας των κινούμενων ερεθισμάτων σε σύγκριση με τα στατικά (χωρίς υπονοούμενη κίνηση) και των ερεθισμάτων που εμπεριέχουν περισσότερη σε σύγκριση με λιγότερη υπονοούμενη κίνηση. Ωστόσο, δεν έχει μελετηθεί ακόμα η άμεση σύγκριση αληθινής και αντίστοιχης υπονοούμενης κίνησης σε ένα χρονικό έργο εκτίμησης της διάρκειας. Στο συγκεκριμένο πείραμα, εξετάστηκε ακριβώς η επίδραση δυο υποθετικά ανάλογων ερεθισμάτων που εμπεριείχαν διαφορετική ποσότητα μπαλετικής κίνησης (ή υπονοούμενης μπαλετικής κίνησης) σε ένα έργο χρονικής αναπαραγωγής. Η ανάλυση έδειξε υπερεκτίμηση και μεγαλύτερη συνέπεια στις αποκρίσεις για τα ερεθίσματα που εμπεριείχαν αληθινή σε σύγκριση με υπονοούμενη κίνηση. Τα συγκεκριμένα ευρήματα επιβεβαιώνουν και επεκτείνουν παλιότερες μελέτες που υποστηρίζουν την υπερεκτίμηση κινούμενων ερεθισμάτων σε σύγκριση με στατικά, ακόμα και αν - όπως στην περίπτωση μας -

υπονοούν κινηση. Ταυτόχρονα, η προαναφερθείσα προτεινόμενη αναλογία ανάμεσα σε αληθινή και υπονοούμενη κίνηση αμφισβητείται στο τομέα της χρονικής αντίληψης. Η αμφισβήτηση αυτή ενισχύεται από τα αποτελέσματα μας όσον αφορά την ποσότητα της κίνησης που εμπεριείχαν τα ερεθίσματα, η οποία φάνηκε να επηρεάζει μόνο τις συνθήκες αληθινής κίνησης.

Στο τρίτο κεφάλαιο, παραμένοντας στην αναζήτηση της σχέσης χορού και χρόνου παρουσιάζονται δύο πειράματα εμπνευσμένα από την ιδέα ότι η εκτίμηση της χρονικής διάρκειας συχνά επηρεάζεται από μη-χρονικούς παράγοντες, όπως για παράδειγμα, τη κατεύθυνση της κίνησης. Έχει παρατηρηθεί ότι η κίνηση προς τα μπροστά (που πλησιάζει το συμμετέχοντα) υπερεκτιμάται σε σύγκριση με τη κίνηση προς τα πίσω (που απομακρύνεται από το συμμετέχοντα). Αυτή η αντιληπτική ασυμμετρία έχει ερμηνευτεί βάσει της εξελικτικής σκοπιάς, σύμφωνα με την οποία δίνεται προτεραιότητα στα ερεθίσματα που κινούνται προ τα μπροστά ως έχοντα εξέχουσα σημασία, έτσι ώστε να υπάρχει αρκετός χρόνος για τη κατάλληλη αντίδραση σε κάτι που μας πλησιάζει. Η μελέτη αυτή της ασυμμετρίας έχει γίνει κυρίως με αφηρημένα ερεθίσματα τα οποία στερούνται κοινωνικής συνάφειας. Με έμφαση ακριβώς στο κοινωνικό πλαίσιο, εμείς χρησιμοποιήσαμε νατουραλιστικά ερεθίσματα οικολογικής εγκυρότητας σε ένα χρονικό έργο αναπαραγωγής. Στο πρώτο πείραμα συγκρίναμε ερεθίσματα που παρουσίαζαν μια κοπέλα να κάνει ένα βήμα προς τα μπροστά (πλησιάζοντας τους συμμετέχοντες) ή προς τα πίσω (απομακρυνόμενη από τους συμμετέχοντες) σε διάφορα χρονικά διαστήματα και δε βρήκαμε καμιά επίδραση της κατεύθυνσης της κίνησης στην εκτίμηση της χρονικής διάρκειας. Βασιζόμενοι στην αναφερόμενη «ανωτερότητα» των ακουστικών ερεθισμάτων στα χρονικά έργα, στο δεύτερο μας πείραμα προσθέσαμε ήχο (λευκό θόρυβο) δημιουργώντας συνθήκες συμφωνίας (ήχος και οπτικό ερέθισμα

συμφωνούσαν ως προς την κατεύθυνση), ασυμφωνίας (ήχος και οπτικό ερέθισμα είχαν αντίθετες κατευθύνσεις) και ελέγχου (σταθερός/αμετάβλητος ήχος ανεξαρτήτως κατεύθυνσης του οπτικού ερεθίσματος). Η ανάλυση έδειξε υπερεκτίμηση της κίνησης προς τα μπροστά σε σύγκριση με την προς τα πίσω για τη σύμφωνη και τη συνθήκη ελέγχου, ενώ δεν παρατηρήθηκε κάποια επίδραση της κατεύθυνσης της κίνησης στην ασύμφωνη συνθήκη. Σε όλες τις συνθήκες τα διαστήματα που εξετάστηκαν υποεκτιμήθηκαν σε σχέση με την πραγματική τους αντικειμενική διάρκεια. Με βάση αυτή τη διαπίστωση, υποστηρίζουμε ότι η διαφορά που βρήκαμε μπορεί να αποδοθεί στη πιθανότητα να μη δίνεται τόση σημασία σε ήχους που απομακρύνονται σε αντίθεση με τη συνηθέστερη ερμηνεία που βασίζεται στην εξέχουσα σημασία των ερεθισμάτων που πλησιάζουν. Γίνεται επίσης εκτενής συζήτηση των αποτελεσμάτων μας σε σχέση με τη θεώρηση της ηχητικής τροπικότητας ως βέλτιστης σε χρονικά έργα.

Λέξεις κλειδιά: Έργο αναπαραγωγής; Έκτίμηση διάρκειας; Βιολογική κίνηση

1

Introduction

Dance upon a time: A review on the association of timing and dance

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Sgouramani, H., & Vatakis, A. (in preparation). Dance upon a time: A review on the association of timing and dance. *Timing & Time Perception Reviews.*

Introduction

You are dancing cheek to cheek with your loved one and time seems to stand still (i.e., distorted duration percept). You are both moving smoothly (i.e., interpersonal coordination in a social context) when he suddenly steps on your foot (i.e., synchronization/entrainment) as if he was listening to a different musical tune (i.e., multisensory interactions in timing) and the magical moment is unpleasantly interrupted. The association of dance and behavior has been of interest to cognitive science as evidenced by the number of reviews consolidating the current knowledge on the field (e.g., Bläsing et al., 2012, for a thorough review of studies related to dance and cognition; Brown & Parsons, 2008, for a short review on the neuroscience of dance; Karpati, Giacosa, Foste, Penhune, & Hyde, 2015a, for a review on the neural correlates of dance; Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011, for a review on biomechanical research and dance; Sevdalis & Keller, 2011, for a review on dance and social cognition). As yet, however, no such consolidation attempt has been made for the work conducted on dance and timing even though the two are inherently linked (i.e., dance is a universal form of art composed of movement through space and time; see Ravignani & Cook, 2016, on the evolutionary roots of dance as a co-timing behavior). This review aims, therefore, to survey the large body of the research conducted in the last 15 years on the association and the mechanisms governing dance and timing. We postulate that these studies form a new emerging field in the cognitive sciences that will play a crucial role in the future inquiry of timing and embodiment.

The text that follows has been organized based on studies focusing on dance and: a) duration estimation, b) synchronization/entrainment, c) temporal aspects of social interaction, and d) multisensory interactions in temporal perception. Under these general research areas, we will address dance not merely as an art form (ranging from ballet and contemporary dance, to Charleston, tango, flamenco, street dancing, salsa, Irish, ballroom, swing, Indian, club-like social dance, Greek traditional dances, African, tap-dance and lindy-hop), but also as an experimental stimulus (ranging from static images to dynamic video displays and live performances). We will also use this medium as a way to explore the role of expertise (i.e., dancers vs. non-dancers) on timing, given that dance requires high temporal acuity (in terms of time-keeping mechanisms) and several years of extensive training. The implications of the reviewed body of research are important for future applications that can provide us with low-cost physical activity programs for populations with certain deficits (e.g., Parkinson's Disease, autism) or valuable knowledge in terms of evolving technological issues (e.g., 3D animation, humanoid robotics). Together, these studies give us an insight into the contribution of rhythmical biological motion (i.e., dance) to the advancement of our current knowledge on different aspects of timing.

Duration estimation and dance: Defining the factors that lead to distorted temporal percepts

The estimation of a given interval is often influenced by non-temporal factors that lead to distorted temporal judgments (when compared to the actual physical duration of an interval). These altered temporal percepts have been accounted for by both cognitive (e.g., Attentional Gate Model, AGM; e.g., Allan, 1998; Zakay & Block, 1997) and neuronal approaches (e.g., coincidence-detection model, duration selective channels; e.g., Buhusi & Meck, 2005; Heron et al., 2012) in experiments that mainly utilized abstract stimulation (see Grondin, 2010; Matthews & Meck, 2016, for reviews). Timing studies aiming for more ecologically-valid set-ups have utilized dance as their experimental stimulation, which, in turn, lead to the evaluation of already known or new factors associated with distorted temporal percepts (i.e., speed, animacy, intensity of movement, and expertise). The research on these factors is presented in the text below.

Speed and animacy. Dance stimulation either as the main experimental target (e.g., Bachrach, Fontbonne, Joufflineau, & Ulloa, 2015; Deinzer, Clancy, & Wittmamm, 2017; Joufflineau, Vincent, & Bachrach, 2018; Sgouramani & Vatakis, 2014a) or as background stimulation (e.g., Carozzo & Lacquaniti, 2012; Orgs, Bestmann, Schuur, & Haggard, 2011) has been utilized in the study of time estimation as a function of speed. For example, Sgouramani and Vatakis (2014a) studied participants' duration judgments when presented with videos of a dancer performing identical ballet steps in fast or slow movement but of equal duration. They reported a significantly larger underestimation for fast as compared to slow videos during reproduction, while the exact opposite result was noted for production. These results were attributed to the attentional saliency of fast as compared to slow stimuli, with this attentional allocation leading to greater interval underestimation for the former stimuli (in accordance with the AGM; e.g., Allan, 1998; Zakay & Block, 1997; see also Minvielle-Moncla, Audiffren, Macar, & Vallet, 2010, on the role of attention via actual dance enactment). Time contraction, however, has also been reported for an extremely slow live dance piece (Bachrach et al., 2015; see also Joufflineau & Bachrach, 2016; Joufflineau et al., 2018), a result that was also attributed to attentional factors and, specifically, to the viewer's engagement to the body movements of the dancer (see Jola & Grosbras, 2013, reporting different corticospinal excitability for live as compared to recorded dance excerpts). Thus, the extremely slow dance tempo seemed to have slowed down spectators’ temporal estimation mechanisms, a modulation that endured even after the performance. However, no comparison with faster dance pieces were made, thus no firm conclusions can be drawn from this latter study.

Arousal accounts have also been adopted in interpreting the role of speed on time estimation For example, Deinzer and colleagues (2017) presented either a fast or a slow choreography of equal duration, but different content. Their analysis showed that even though participants reported (via questionnaires; but see Stevens et al., 2009, for portable, real-time audience responding instrument) a faster passage of time for the fast performance, they actually overestimated it during reproduction as compared to the slow performance piece. These results were interpreted in terms of higher arousal levels caused by the higher perceived speed, which, in turn, lead to event overestimations. However, arousal-based accounts have been associated with shorter intervals (e.g., Angrilli, Cherubini, Pavese, & Manfredini, 1997; Bar-Haim, Kerem, Lamy, & Zakay, 2010; Nather, Bueno, Bigand, & Droit-Volet, 2011; Sgouramani & Vatakis, 2014a) as those utilized in this study (i.e., 5 min). An alternative interpretation of these results could be based on the change model, where the fast dance piece inevitably contained a greater number of changes (i.e., movements) that lead to duration overestimation (e.g., Brown, 1995).

Overall, therefore, the issue of how speed of complex biological moving stimuli modulates time estimation remains unresolved with higher dance speed being linked to both over- and under-estimations (e.g., Bachrach et al., 2015; Deinzer et al., 2017; Jouffline au & Bachrach, 2016; Jouffline au et al., 2018; Sgouramani & Vatakis, 2014a). Interestingly, however, the same pattern of results is true for experiments using abstract stimulation, with some studies reporting time dilation for higher stimulus speeds (Fraisse, 1962; Kaneko & Murakami, 2009; Leisser, Stern, & Meyer, 1991; Makin et al., 2012; Mate, Pires, Campoy, & Estaún, 2009; Mathews, 2011; Tomassini, Gori, Burr, Sandini, & Morrone, 2011), while others reporting the exact opposite results (Bonnet, 1965, 1967; Matsuda, 1974). Therefore, one cannot readily argue that the social relevance derived by dance stimulation influences our percepts in a different manner.

Such an observation might be contradictory to the hypothesis that animate and inanimate moving stimuli are being processed differently in terms of duration (e.g., Carozzo & Lacquaniti, 2012; Carrozzo, Moscatelli, & Lacquaniti, 2010; Lacquaniti et al., 2014; Neri, Luu, & Levi, 2006; Orgs et al., 2011; Orgs & Haggard, 2011). A number of researchers have directly investigated the interaction of animacy with speed and time estimation by presenting dance as a background stimulus. Specifically, Carozzo and Lacquaniti (2012) had participants press a button in synchrony with a falling ball, while in the background a moving dancer or whirligig changed in terms of speed. Task performance differed as a function of the background stimulus, with higher dance speed resulting in an underestimation of the landing time of the ball and an overestimation for faster moving whirligig presentations. In a related study, Orgs and colleagues (2011) used apparent dance motion (or non-body and inverted body pictures as control conditions), while 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) and a speed discrimination task. Apparent dance stimuli that were perceived as faster led to interval underestimations as compared to stimuli that participants reported as being slower. Importantly, this effect was not present for the control conditions (Carozzo & Lacquaniti, 2012). Together, these studies show an interval underestimation that is specific to dance movement and linked to higher perceived speed. A finding that is attributed to segregated high-level mechanisms for dance as compared to non-dance stimulation, which are selectively modulated by perceived animacy interacting with speed. From an evolutionary point of view the human brain seems to be developed to primarily interact with movements of conspecifics and not abstract shapes (e.g., Nather, Anelli, Ennes, & Bueno, 2015). Overall, while studies that investigate dance speed as their target stimulus resulted in inconclusive findings, when the factor of animacy was introduced (as a background stimulus), results seem more concrete. Future temporal experiments should further investigate whether a distinction of dance and non-dance stimulation interacting with speed does exist.

Intensity of movement. The intensity of implied dance movement has also been revealed as a modulating factor on temporal judgments (see Bueno & Nather, 2012, for a review). In a series of experiments, Nather and colleagues utilized different images of body postures -static images of Degas' ballerinas statues- with implied movement of different intensity (see also Nather & Bueno, 2012b) and linked higher intensity movements to interval overestimations. For instance, Nather et al. (2011) through a bisection task (duration range: 0.4/1.6 and 2/8) reported longer time estimates for postures implying greater as compared to lower movement intensity, but only for the short durations tested. The short duration effects were attributed to a transient arousal caused by high intensity postures that led to a higher pacer rates, while, for longer durations, arousal gave place to higher cognitive processes (e.g., attention). However, another study with longer durations (i.e., 36 s) and a reproduction task (Nather & Bueno, 2011), also led to overestimations when more movement/displacement was implied and underestimation for images of more static postures, thus, contradicting previous interpretations. An alternative account with high intensity postures requiring an asymmetric schema with a great number of temporal markers (i.e., arms, legs, and head positions) was also proposed, which could be held responsible for the overestimations noted (see also Nather & Bueno, 2012a).

Conclusively, even though different explanations may apply, a link of high implied intensity to interval overestimations is corroborated. Even though images depicting instances of real dynamic events have been considered a special case of stimulation (see Freyd, 1987; Thornton & Hubbard, 2002, for reviews), one wonders whether or not actual moving dance stimuli of differential intensity would also result to interval overestimations. Sgouramani, Moutoussis, and Vatakis (2019) performed a direct comparison of how the intensity of real and implied dance motion modulates our duration judgments using a reproduction task (see also Sgouramani & Vatakis, 2014b). Interestingly, higher intensity movement was overestimated in comparison to lower intensity, but only for the case of real motion, contradicting the previously mentioned findings. The intensity of movement (implied and real) seems to influence participants' duration percepts, however, further clarification on the possible underlying mechanisms involved in order for such an influence to be appropriately explained are needed. The thorough investigation of the correspondent dynamics involved for both implied and real dance versions, apart from the timing domain could also promote the emerging fields of implicit dance learning (e.g., Opacic, Stevens, & Tillman, 2009) and neuroaesthetics (e.g., Orgs, Jagura, & Haggard, 2013).

Expertise. Dancers similarly to musicians (e.g., Cicchini, Arrighi, Cecchetti, Giusti, & Burr, 2012), can be considered experts in terms of time keeping mechanisms, as temporal accuracy is a prerequisite for their performance. Therefore, timing studies have compared dancers and non-dancers' performance with both dance (e.g., Henley, 2015; Nather, Bueno, & Bigand, 2009; Sgouramani & Vatakis, 2014a) and non-dance stimulation (e.g., Magnani, Oliveri, & Frassinetti, 2014), in order to examine a potential modulatory role of expertise on duration estimates. For instance, Nather et al. (2009) have reported a difference among dancers, art-trained, and naives. Dance stimuli of high implied intensity were further underestimated by dance-trained as compared to art-trained and naïve participants. This difference was attributed on the hypothesis that naives considered the high intensity stimuli as more complex/incomplete in terms of action continuation in comparison to dance-trained participants' judgments. For example, in one image the dancer appeared to be standing in one leg, thus, equilibrium might have been interpreted as a less stable stance as oppose to a two legs standing-relaxing position, which, in turn, led to overestimations as a function of expectancy for movement continuation. On the other hand, experts, given their familiarity with such 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. Differential results based on expertise were also obtained in the previously mentioned Sgouramani and Vatakis' (2014a) study, where dancers were significantly less variable in their time estimates as compared to non-dancers for dance videos of different speeds in a reproduction task. Similar results were also true in a study that non-dance stimulation was utilized (Magnani, Oliveri, & Frassinetti, 2014). Focusing on the temporal task, dancers and non-dancers had to encode and respond to temporal characteristics ignoring spatial features (i.e., during encoding phase a static line of three different lengths presented for three different durations; in testing phase a horizontally moving line towards either left or right). Underestimations by dancers as compared to overestimations of non-dancers were reported. Dancers' superiority in terms of anticipation and faster visual processing mechanisms due to their motor training were held accountable for the noted differences. Further investigation using different movement repertory should be employed, in order to disentangle whether differences between groups are due to production of the particular movement type displayed as stimulus or to a more generalized perceptual advantage (see also Henley, 2015).

Overall, the factors of speed and animacy, intensity of movement and expertise affect duration estimates. The aforementioned studies, however, have focused on vision, but we sense time and perceive dance through multiple modalities. This multisensory view, when investigated may add valuable knowledge on the association of dance and time estimates. For instance, a highly inspiring exploratory study focused on the time-keeping processes of a dancer during a choreography that was performed live on stage accompanied by music or in the absence of auditory information (Stevens, Schubert, Wang, Kroos, & Halovic, 2009). The actions of the dancer were recorded and analyzed in terms of scaling (acceleration/deceleration of certain movements) and lapsing (omission/insertion of certain steps) mechanisms. The total duration of the piece served as a dependent variable and these measurements were compared between on/off music conditions. The authors reported a 14 seconds difference, with the no-music condition leading to a shorter performance. These results possibly indicate that music serves as a time-keeping external mechanism that 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 contributor to this difference. Hence, the auditory stream along with the rest of our senses appears to be an interesting field for further exploration of the way we estimate duration.

Synchronization and entrainment while dancing

Having a great time in a club, while dancing up all night on the beat, is a real-life comprehensible example of what sensorimotor synchronization (SMS) is all about (i.e., the coordination of rhythmic movement with an external rhythm; Repp & Su, 2013). It involves temporal planning and precise movement control and it is important for a variety of rhythmic activities. SMS has been examined extensively mainly through the use of finger tapping tasks (see Repp, 2005; Repp & Su, 2013, for reviews). The continuous innovation in recording and analyzing body movements has allowed the extension from specific effectors (e.g., fingers) to the study of synchronized complex movement (e.g., dance) to external - usually auditory – pacers, thus, broadening the capabilities for the study of synchronization and entrainment (e.g., Brick & Bocker, 2011, describing new correlational methods for dance motion analysis; Naveda & Leman, 2010, proposing a topological gesture analysis, specific to spatiotemporal patterns; Oveneke, Enesku, & Sahli, 2012, for real time recognition of dance patterns; Volchenkov & Blasing, 2012, on the analysis of kinematics in classical ballet). This advancement is evident in the following subsections where specific motion patterns are linked to certain rhythmical attributes. Additionally, the role of expertise, recent applications and neuroscientific approaches related to SMS are being presented.

Linking specific dance patterns to specific rhythmical characteristics. Research has suggested that optimal synchronization can be attained when certain movement patterns fit specific external rhythms (e.g., Grammer, Oberzaucher, Holzleitner, & Atmaca, 2011; Miura, Fujii, Yamamoto, & Kudo, 2015). These motion/dance affordances linked to specific musical/temporal characteristics and their identification, could lay the foundation in SMS studies. For example, Toiviainen, Luck, and Thompson (2010) conducted a study on body movement patterns induced by the metric structure of music. Participants listened to a music piece at four different tempi and were encouraged to move freely. Movement analysis revealed that mediolateral arm movements were often synchronized with the tactus level pulse, while rotation and lateral flexion of the upper torso with periods of two and four beats, respectively. Similarly, in Burger, Thompson, Luck, Saarikallio, and Toiviainen's (2013) study participants' free movement, while listening to 30 excerpts of different musical styles, indicated certain regularities, with clear pulses being linked to whole body motion, whereas spectral flux and percussiveness being mostly related to head and hand movement. Additionally, Burger, Thompson, Saarikallio, Luck, and Toiviainen (2010) reported a positive correlation between temporal regularity and flux-pulse clarity, implying that strong rhythmic components could encourage temporal regularity (see also Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2012, 2014). Also, Burger, London, Thompson, and Toiviainen (2017) found vertical movements (see also Solberg & Jensenius, 2017) of the hip and feet to be synchronized to the beat level for large amounts of low-frequency spectral flux and slower tempo musical excerpts, while the head and hands were mostly coupled to the weak flux stimuli at the bar level. Synchronization levels were higher for slower tempos, whereas an inverted u-shape effect was noted as tempos increased. Furthermore, Van Dyck et al.'s (2012) results showed more active movement of freely moving participants in the head and hips with a higher degree of tempo entrainment as the pressure level of the bass drum increased (a song with different sound pressure levels of the bass drum was presented).

The aggregate of this line of research points out that specific music characteristics are strongly connected or even induce effortlessly specific movement patterns (e.g., Fitch, 2016). Besides the aforementioned music characteristics, perceived emotions in music seem to also induce specific motion patterns (e.g., Burger, Saarikallio, Luck, Thompson, & Toiviainen, 2013) and felt emotions have been linked to distinct dance movements (e.g., Van Dyck, Maes, Hargreaves, Lesaffre, & Leman, 2013).

The role of expertise in SMS. Dancers due to their extensive training can be considered experts in SMS. For example, Miura, Kudo, Ohtsuki, and Kanehisa (2011) examined whole body movements of street dancers and non-dancers by having them perform an upward (knee extension on the beat) or downward (knee flexion on the beat) movement in synchrony with a metronome of different frequencies. Street dancers were more stable in their performance than non-dancers, especially during the upward movement condition (see also Miura, Kudo, & Nakazawa, 2013). This difference between dances and non-dances persisted in a subsequent finger tapping study (Miura, Fujii, Okano, Kudo, & Nakazawa, 2016), where dancers exhibited a more stable coordination pattern and a higher critical frequency of transition than non-dancers. It seems, therefore, that the superiority of dancers in SMS tasks is generalized and not effector specific or task dependent (but see Karpati et al., 2015b). Miura and colleagues (2016) supported that extensive motor-related training (e.g., dance practice) might overcome and modify stereotyped synchronization tendencies.

Complementing evidence on the effect of expertise is provided by Sofianidis, Hatzitaki, and McKinley (2012a). Dancers of Greek traditional dances and non-dancers had to mirror online a performer of either Irish or Greek traditional dances, whilst they were listening to simple verbal counting or to music. Kinematic analysis of the lower limbs revealed greater stability of limb oscillations and a higher degree of interlimb coupling for dancers compared to non-dancers. Different type of auditory guidance seemed to influence only the non-dancers (i.e., verbal counting compared to music was connected to more stable performance), whose performance deteriorated in a greater extent as compared to dancers when dancing novel Irish dance steps. Results indicate coordination superiority due to experience (see also Lee & Noppeney, 2011; Petrini, Rusell, & Pollick, 2009; Sgouramani et al., 2012). Hence, whether the superior temporal abilities of dancers reflect an existing generalized amelioration or are specific to temporal tasks related to dance training deserves further consideration (e.g., Karpati, et al., 2015b; but see also Cameron & Grahn, 2014, for a generalized superiority in terms of temporal abilities of percussionists in comparison to non-musicians). This would be important for forming dance related effective interventions in order to address targeted deficits in populations with Parkinson's disease or recovering from strokes (e.g., Hackney & Earhart, 2009, 2010). These populations have poor SMS abilities, thus, it is possible that specific dance routines could aid them overcome these disadvantages. 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 SMS (see also Sgouramani, Muller, van Noorden, Leman, & Vatakis, 2013).

SMS related applications. Our current knowledge on synchronization and entrainment has recently found several applications in robotics as well as in the field of education. Specifically, focusing on animation and humanoid robots Lee, Lee, and Park (2013) described an algorithm that generates new dance sequences based on musical similarity. Their system is strongly related to the link between specific motion patterns to certain musical pieces, which has been previously thoroughly addressed. As a first step they cluster dance movements, which are connected to musical attributes creating a music-motion database. Subsequently, an input of a new musical excerpt is compared to the formed database in order for the most similar music exemplar to be found and then the linked dance movement is being generated by the system as an output. Similarly, but concentrating on the creation of automatic choreographies, Ofli, Erzin, Yemez, and Tekalp (2012) also proposed a model of music-driven dance sequences under the same notion of music-motion mappings. In this vein, Leman (2007) introduced the term of embodied music cognition to describe the aforementioned connection of music and dance. Subsequently, based on the idea that Charleston and salsa dance are characterized by certain regularities in terms of motion patterns in combination to music, Leman and Naveda (2010) went on creating spatiotemporal frames via motion capture recordings. This was a substantial attempt to organize in a vocabulary-type manner repetitive dance movements. This newly introduced vocabulary led to the formalization of a representation model for humanoid dancers (see Oliveira et al., 2012).

Applications related to the dance/sports educational domain are recently driving the scientific interest as well (see Dania, Hatziharistos, Koutsouba, & Tyrovola, 2011, for a review of incorporating new technologies into dance classes; Huang, Cheng, & Chiang 2013; Yang, Leung, Yue, & Deng, 2012, for automatic dance lesson implementations). Maes, Amelynck, and Leman (2012) created an educational platform (Dance-the-Music) focusing on the domain of human-computer interaction. Spatiotemporal motion templates were used in order to model dance sequences which would stand for a teacher’s demonstration. Multimodal monitoring techniques allowed the real-time evaluation of students' performance and, thus, targeted feedback could be provided. Maes and colleagues (2012) corroborated in favor of the effectiveness of this platform, in terms of mastering several dance moves, providing a convenient tool in dance classes. Dance education benefits were also the starting point of a study focusing on differences in SMS performance when coordinating dance movements to a simple beat or a musical excerpt (Pollatou, Hatzitaki, & Karadimou, 2003). Pollatou and colleagues (2003), via video recordings of beginners performing specific dance steps in synchrony to either the rhythm derived from a tambourine (group 1) or music from a harmonium (group 2) measured the SMS accuracy. Better synchrony was detected for group 1 indicating that a rhythmical sequence of single beats could facilitate SMS in a beginners' dance class in comparison to a musical phrase of identical metrical structure (in accordance with Sofianidis et al., 2012a). Moreover, dance classes have been proposed as extremely important for preschool curricula, promoting healthy child development. Chatzihidiroglou, Chatzopoulos, Lykesas, and Doganis (2018) employed an eight week dance training program to investigate its effects on preschool children's development of rhythmic synchronization, balance, and movement reaction times (RTs; the ability to quickly respond to music stimuli). Pre- and post-tests were compared among the dance and the control group. Results showed a greater improvement in terms of synchronization and balance for the dance group compared to control participants, while no difference was found in RTs. To conclude, the aforementioned link of specific motion patterns to specific rhythmical attributes under the SMS context seems to have given valuable inspiration to applied practices.

Dance related SMS from a neuroscientific standpoint. Data deriving from neuroscientific investigations can allow the formation of a complete picture on dance and timing in the brain. One of the first studies to investigate synchronization in dance was by Brown, Martinez, and Parsons (2006) that used PET in order to determine the neural substrates of tango. The authors focused on three basic attributes: entrainment (spontaneous synchronization to an external pacer), meter (voluntary synchronization to regular metric rhythm), and patterned movement (spatial attributes of motion). Amateur dancers were asked to perform specific tango steps, with or without music, on an inclined platform. They were lying down and performed the steps by moving their legs, avoiding any other movement in different experimental conditions. The anterior cerebellar vermis was associated with entrainment, the right putamen with meter and the medial superior parietal lobule with the spatial characteristics of 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.

The neuronal substrate of dance and timing can also be investigated focusing on population with rare behavior in terms of synchronization via case studies. For example, Phillips-Silver and colleagues (2011) reported a person unable to synchronize his movement with the musical beat (data retrieved via motion capture recordings) or detect beat asynchronies of a model dancer bouncing on the beat (via a psychophysical task were judgments of “in time” and “out of time” were given while watching audiovisual displays). However, his performance in synchronizing with a metronome or maintaining bouncing regularity in silence were intact. This new form of congenital amusia suggests that time keeping mechanisms are of a distinct neurobiological origin from the ones responsible for beat detection in a musical context. This dissociation must be further examined and thus new data from this case are awaited in the near future, through neuroimaging methods as well.

A relatively new tool with a high temporal resolution has been also proposed, which allows participants to dance during the recording process, the fNIRS (monitoring tissue oxygen saturation, changes in hemoglobin volume and, indirectly, brain/muscle blood flow and muscle oxygen consumption; e.g., Ono et al., 2014). Ono and colleagues (2014) via a dance simulation video game asked participants to dance by stepping on indicated spots (spatiotemporal accuracy), while appropriately synchronizing their steps on the cues provided by a monitor. They demonstrated that the temporal accuracy of dance steps positively correlated with the persistent activation of the medial temporal gyrus, while it negatively correlated with the cumulative suppression of the frontopolar cortex. Authors concluded that responses obtained from fNIRS in these association cortical sites can serve as good predictors of the temporal accuracy of motor responses (see also Tachibanaa, Noah, Bronner, Ono, & Onozuka, 2011). Hence, even though one would assume that the neuroscientific approaches to investigate SMS with dance movements would be rather difficult (due to the complex movement involved and high temporal resolution required), inspiring means have already been utilized in order to address this complex issue.

All things considered, major advancements on the field of SMS investigation have been made. This progress is mainly rooted to the acknowledgment of a strong linkage between rhythm (e.g., music) and movement (e.g., dance). This connection has been defined as interdependence, thus, dance encompasses rhythmic attributes, while also rhythm induces specific dance patterns. Hence, the whole concept of rhythmic cognition has evolved rendering dance as a perfectly suitable mean to further expand the SMS scientific interest.

The social components of synchronized movement

The fundamental cooperative nature of dance apart from the synchronized movements to external stimulation (i.e., SMS), also involves interpersonal entrainment (i.e., synchronization with others). Synchronous interactions have also been associated with increased pro-social behavior and fostered social bonding (see Keller, Novembre, & Hove, 2014, a review on joint action; Trainor & Cirelli, 2015, on infant-adult synchrony), thus supporting that dance can be used to study the social components of shared action. Furthermore, timing and dance are interconnected with social interaction and inter-subjectivity and, thus, suitable means for the investigation of social-cognitive processes (e.g., empathy) and their links to coordination. Recent advancements in the toolkit of social entrainment research are important for the progression of this line of research (e.g., De Nies et al., 2012; Leman, Demey, Lesaffre, Noorden, & Moelants, 2009, on applied social games suitable to measure group synchrony). Focusing on the social context, we review below the work conducted in the underlying strategies of synchronized movement (i.e., dance) in couples and ensembles linked to enhanced social bonding, aesthetics appreciation, intensified feelings of togetherness/pleasure, and related applications.

Dyads and group synchronization as a function of expertise. From a social cognition point of view, dance can be proven bountiful in what it reveals on the actual ways a couple interacts (see van Alphen, 2014, for a theoretical justification of tango being in the scientific toolkit to investigate social interaction). For instance, Gentry and Feron (2004) investigated, using Lindy Hop (a swing-like type of dance), whether online leader-follower coordination is attained through shared physical action modes or context (i.e., music). Professional dancers danced while listening (through headphones) the same or different musical excerpts, which were balanced in terms of all their acoustic and temporal characteristics except for the traditional phrasal structure AABA that is strongly connected to particular movement patterns (e.g., one listened to AABA, while the partner listened to ABAA). Upon completion of their dance routines, participants were asked to judge whether or not they were listening to the same music piece or not. Results showed leaders to be at chance level (50%), whereas followers were quite accurate reaching an 82% detection of music piece alignment. The latter finding was attributed to the inappropriate movements posed by the leaders in relation to the music. Despite these deviations in movement, followers adjusted their movements to those of the leaders so as to maintain the dance flow. This novel experimental setup could be further extended through the use of more objective motion measurement methods for high temporal accuracy (see also Waterhouse, Watts, & Bläsing, 2014, in a case study of a duet with likewise no music or haptic stimulation, proposing a video annotation technique in order to investigate dyad entrainment, based on temporal cues and alignments) and the study of other structural levels of music focusing on temporal attributes (e.g., tempo differences) for the examination of continuous mutual temporal adaptation.

Dyadic interpersonal coordination was also examined through cross-wavelet transform analyses that provide the whole frequency range of movements as a function of time (Issartel, Marin, & Cadopi, 2006). Dancers and non-dancers were asked to freely perform arm movements either on their own or in coordination with their partners. Performance analysis revealed that dancers as compared to non-dancers were able to perform multi-frequency and in-phase anti-phase coordination simultaneously. In a subsequent study, Issartel, Gueugnon, and Marin (2017) provided complimentary findings when comparing novices, intermediate, and expert dancers in a wide range of movement frequencies. The complexity of performed motion, increased gradually from novices to experts with anticipation being critical for better motor control, which is acquired through extensive dance training. Expertise-related dance style differences were also true in Zaletel, Vučković, James, Rebula, and Zagorc’s (2010) study when comparing the ballroom performance of adult and young couples. Specifically, the former group showed longer and faster dance movements through space than the younger group (with the exception of Foxtrot) with the authors arguing that the extensive training of the adult couples allowed them to dance as a unit enacting with distinct softness complex fast steps. Hence, a preliminary conclusion could be that the actual way the enactment takes place by experts, might be a key factor for synchronized and smooth dancing in couples. Better interpersonal synchronization for dancers compared to non-dancers was also demonstrated by Washburn and colleagues (2014), where participants coordinated with a confederate while dancing three different choreographies (i.e., dance team routine, contemporary ballet, mixed style) that ranged in terms of difficulty. Results showed an expertise related coordination superiority, attributed to dancers’ physical experience that favored a better discrimination for the confederate’s dancing movements (see also Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010).

Apart from the investigation of duets, recent studies have also investigated the complex undertaking of ensemble synchronization that requires simultaneous precision and motion flexibility at different timescales (see Keller et al., 2014, proposing three skills as core factors of group synchronization: anticipation, attention, and adaptation). One such study was by Ellamil, Berson, Wong, Buckley, and Margulies (2016) who asked participants to dance freely to the music in a club-like environment. Analyses revealed an association of group synchrony of torso movement with pulsations that approximate walking rhythm (100–150 beats per minute), along with greater group synchrony during popular songs. Thus, group synchrony appeared to be linked to movement (walking) and music (song popularity) familiarity, which, in turn, allows movement-stimulus predictability that might be a crucial factor for ensemble synchronization. Another crucial factor is the role of the hierarchy of the group members, which was investigated by Maduell and Wing (2007) through the collection of cues (unimodal/multimodal, verbal/non-verbal) a flamenco ensemble utilizes when shifting roles during performance. Event video analyses revealed that while higher level members imposed changes and variations in performance, lower level members adapted to the role of a follower for maintenance of dance smoothness. Maduell and Wing proposed a connected network model framework, in which group members (separate nodes) are interconnected with different weights according to their role (leader vs. follower), thus leading to better coordination and smoother group performance (see also Honisch, Elliott, Jacoby, & Wing, 2016, proposing a novel paradigm to investigate the switch of timekeeping mechanisms between group members, depending on cue integration as a function of task or role in the group).

In line with this follower-leader role distinction during ensemble coordination, Himberg, Laroche, Bigé, Buchkowski, and Bachrach (2018) also examined the role of expertise. Dancers and non-dancers (see Noy, Levit-Binun, & Golland, 2015, on the original version of the mirror game, investigating interpersonal coordination) were asked to stand in a circle and mirror each other’s movements by engaging arm motion without assigned roles. Analysis revealed a correlation of subjective sense of individual and group connectedness and observed levels of in-group temporal synchronization. Dancers -as more experienced improvisers- reached a state of shared agency and togetherness by performing co-confident movements that emerged without an overt initiation, while non-dancers adopted a turn taking (follower-leader roles) strategy, which was linked to a reduced feeling of togetherness (see also Hart, Noy, Feniger-Schaal, Mayo, & Alon, 2014, on different motion signatures that differentiate the sense of individuality and togetherness during a mirror-game). Himberg and Thomson (2009) also demonstrated an expertise-related difference in ensemble performance in a study where experts and novices were asked to synchronize while performing a specific choreography on South-African traditional songs. Experts exhibited greater synchronization coherence as compared to the novices. This effect was attributed to the greater attentional focus of the experts on coordination given their high familiarity with the music and the movements. While, it was not the case for the novices, where it was necessary to simultaneously share attentional resources among new rhythms, dance movements, and ensemble synchronization (see also Himberg & Thomson, 2011). Overall, research show that experts, either in couples and as members of a larger group, seem to utilize different strategies in order to synchronize their movements as compared to naives. These strategies refer to either the adaptation of the leader role or the differential attention allocation.

Social and prosocial gains when dancing in synchrony. It has been argued that synchronous dance seems to promote social interaction (see von Zimmermann, Vicary, Sperling, Orgs, & Richardson, 2018, connecting group movement to affiliation). For instance, Woolhouse, Tidhar, and Cross (2016) examined the issue of establishing and reinforcing social bonding through dance by exposing groups of participants (blind grouping was used) with two musical excerpts of different tempi via headphones and different sashes with colors and symbols in an otherwise silent disco environment. Participants were asked to dance freely but to avoid bodily contact. Post experimental questionnaires revealed enhanced memory for sash color and symbol for the dancers that shared -unknown to them- the same musical stimulation. Given that social memory is an important component of social interaction, these results imply that synchronous dance facilitates social bonding and cohesion (see also Woolhouse & Tidhar, 2010) leading to visual attention modulations as measured by eye-tracking (Woolhouse & Lai, 2014). Additionally, Woolhouse and Lai (2014) reported increased visual inspection times for video displays of a dancer moving in synchrony to the music in comparison to asynchronous video displays. Hence, synchronous dance acts either as an embodied experience or as video instances seem to be linked to increased attentional allocation and enhanced memory encoding mechanisms (see also Reddish, Fischer, & Bulbulia, 2013, for a link of synchronous movement to a cooperation model).

Another interesting aspect of the social aspects of dance is how social interaction might influence the way we dance, instead of how synchronous movement affects social bonding. De Bruyn, Leman, Moelants, Demey, and Desmet (2008) investigated just that, by having adolescents to freely move to the beat of different songs in two different conditions: blindfolded (alone) and then without blindfolds (moving in a group set up) encouraging social interaction. Movement analysis showed that in the social condition participants exhibited better synchronization and greater motion intensity in comparison to the alone condition. The process of blindfolding, however, not the social context per se, might have modulated the reported results. Thus, in a subsequent study (De Bruyn, Leman, & Moelants, 2008) screens were used to create the alone condition in a group of children participants. Greater intensity but no better synchronization was true for the social condition. Hence, social interaction appears to be an influential factor for synchronized movement, which can be measured and quantified in an experimental set up such as the one described in the above studies.

Besides social interaction, a limited number of studies have also suggested that personality traits may also modulate our synchronized patterns. Specifically, Carlson, Burger, London, Thompson, and Toiviainen (2016) evaluated participants' in terms of personality traits and had them dance freely in synchronization to different musical excerpts, which were manipulated in terms of tempo. Analysis showed higher conscientiousness and lower extraversion correlating with greater responsiveness to tempo change. Thus, specific personality characteristics may be linked to differences in the embodied responsiveness/induced movement (i.e., dance) at tempo alternations (see also Luck, Saarikallio, Burger, Thompson, & Toiviainen, 2010), however, more research is necessary for such claims. Conclusively, interpersonal synchronization and social attributes seem to form a reciprocal linkage with synchronized group movement to enhance social bonding and, at the same time, social interaction to modulate the way an ensemble synchronizes their motion patterns.

The role of synchronous motion on aesthetic judgments and feelings. The essential role of synchrony in social cognition is evident when one observes the spectator-performer relationship and its immediate nature (see Konvalinka et al., 2011, on the synchronized arousal levels of performers and spectators during a fire-walking ritual). For instance, Vicary, Sperling, von Zimmermann, Richardson, and Orgs (2017) examined the way visual movement synchrony relates to the aesthetic judgment of a dance performance. During a live choreography manipulated in terms of synchrony, acceleration, synchrony, and visual change served as variables to predict audience's enjoyment and togetherness responses, along with heart rate changes. Analysis revealed predictive relationships between synchrony, enjoyment ratings, and spectator arousal levels, when spectators would collectively form a consistent positive or negative aesthetic evaluation. The resulted were interpreted in terms of the social signal transmission that leads to social cohesion, moving on from the social bonding theory to a coalition signaling theory (see Hagen & Bryant, 2003). Thus, implying a linkage between aesthetic judgments of synchrony and the extent to which an audience identifies with the performing group (see also Calvo-Merino, Jola, Glaser, & Haggard, 2008; Cross, Kirsch, Ticini, & SchuÈtz-Bosbach, 2011; Orgs, Hagura, & Haggard, 2013; Torrents, Castaner, Jofre, Morey, & Reverter, 2013, on dance aesthetics; Manfre, Augello, Pilato, Vella, & Infantino, 2016, on humanoid dancing in an aesthetically pleasant way). Himberg and colleagues (2018) extended the findings on aesthetic appreciation by describing them as a phenomenon of the pleasure derived by collective agency linked to dancing together. In their study, two groups performed a rhythm battle task. In phase 1, groups were separated, and each group had to generate an improvised rhythm via body movements, while in phase 2, an external auditory pacer was provided based on each rhythm and the separating door between the groups would open. In the final phase, the pacer was ceased, and groups were asked to move towards the opposite side of the room, thus requiring spatial proximity between groups. The winning team was the one with higher synchronization rates and resistance to entrainment when the second group was present. Results indicated a correlation between tempo similarity (among the team) and increased feelings of enjoyment and closeness. The authors claimed that the embodied feeling of togetherness might play a role, more generally, in the aesthetic experience of performing arts.

The association of pleasurable engagement with synchronous dance has also been demonstrated in Solberg and Jensenius's (2016) study. In a club-like environment, participants danced to a dj set resulting in notable changes in the group's motion quantity during the "break routine" (i.e., breakdown, build-up, and drop). Self-reports of intense pleasure and motivation were associated to these peak moments in the track, while this intersubjectively embodied experience of a club dance seemed to be reinforced by the presence of others. The authors linked their findings with the central role of dopamine release, which appears to connect pleasure with the urge to dance (see also Witek, Clarke, Wallentin, Kringelbach, & Vuust, 2014). Tarr, Launay, Cohen, and Dunbar (2015) investigated the Endogenous Opioid System (EOS) with a link to dance, seen as an effective group bonding activity. Tarr et al. (2015) manipulated both synchrony and exertion separately by employing four different conditions: high exertion-synchrony (i.e., participants listened to the same music and performed the same full-body dance movements), high exertion-partial synchrony (i.e., same music - different full-body dance movements), low exertion-synchrony (i.e., same music - same small hand gestures while seated), and low exertion-partial synchrony (i.e., same music - different small hand gestures). Analysis demonstrated positive independent effects on self-reported social bonding and pain threshold for both synchronization and exertion (see also Tarr, Launay, & Dunbar, 2016). Tarr and colleagues argued that elevated levels of opioids seem to be connected with social attachments, besides pain thresholds.

Altogether, these cognitive, psychophysical, and physiological functions (i.e., enhanced aesthetic enjoyment for synchronous dance, feeling of togetherness, increased liking among partners, elevated levels of endorphin and dopamine) form the foundations of social interaction. Thus, the deep-rooted social aspect of synchronous movement (i.e., dance) and its fundamental timing properties can be proven a beneficial choice as a tool in the expanding research of social cognition.

Applications related to the social benefits of synchronous movement. The above-mentioned link between synchronized movement and social bonding has found several applications in clinical populations with social deficits. For instance, Koehne, Behrends, Fairhurst, and Dziobek (2016) examined directly how temporal aspects of social interaction in dance can benefit people with empathy dysfunction (i.e., Autism Spectrum Disorders). They divided their participants in a dance/movement intervention group that practiced dance patterns fixating on interpersonal movement imitation and synchronization, and a control group that focused on individual motor coordination (see Behrends, Móller, & Dziobek, 2012, for an extended theoretical outline of the dance exercises utilized). Pre- and post-intervention questionnaires revealed a larger improvement on emotion inference, but not empathic feelings for the experimental group in comparison to the control one. Hence, a low-cost dance therapy program seemed to ameliorate to an extent specific social aspects of a population known for aberrant social interaction modes (see also Samaritter & Payne, 2013). Interpersonal communication and joint-action activities have been associated to fostered empathy, thus, further investigation of the exact movements and dance styles employed could explain the null effect of empathy reported (see also Schmidt & Dziobek, 2016, on higher kinesthetic empathy scores for Capoeira and Tango in comparison to Salsa and Break dance dancers). The development of rehabilitation programs based on the notion that synchronous movement enhances social interaction abilities seems a very promising line of inquiry (see also Lakens & Stel, 2011, associating synchronous movement to increased entitativity; Ribeiro & Fonseca, 2011, for a review focusing on the association of dance improvisation and empathy).

Overall, the social aspects of synchronous movement in different dance styles have been well documented. Dance, seen as rhythmic joint action in couples or groups points out an implied hierarchy that modulates members' way of moving. Furthermore, dancing in synchrony fosters social bonding, while at the same time, enhanced social interaction leads to better synchronization. Synchronous dance seems to be associated to greater aesthetic appreciation and positive feelings and these observations on the temporal facets of social cognition have found several applications with multiple gains in clinical populations.

Modality contribution connecting dance and timing

The majority of the studies that have been already discussed refer mainly to the visual modality, however, we sense timing through different sensory inputs. The multisensory nature of our perception is governed by a set of rules that allow us to integrate incoming information into one synchronous and unified experience (e.g., Vatakis & Spence, 2010) and understand the crossmodal associations of multiple modalities. Thus, temporal integration of dance movement and audiovisual cue interaction in time during complex rhythmical acts will be subsequently addressed in detail. Finally, the contribution of haptic cues in sensorimotor and interpersonal coordination as well as modality interference in the sense of agency is also thoroughly described. Hence, an effort for several different aspects of multisensory processing to be covered is made.

Audiovisual integration in dance. To date, a few only studies that have attempted the investigation of multisensory temporal integration in naturalistic movement and, in particular, dance (see Jola et al., 2013). Dance in the multisensory literature, first made its appearance as point light displays (PLD) for the study of audiovisual integration in biological motion. Arrighi, Marini, and Burr (2009) selected tap dancing as their stimulus given the equivalence of information for both audition and vision (i.e., the sound of the feet is as important as the leg movements). Two experiments were conducted investigating facilitation (i.e., the extend by which irrelevant sensory information enhances participants' performance) and summation (i.e., the enhancement of participants' performance due to audiovisual rather than unimodal stimulation). In experiment 1, a visual search paradigm was utilized with visual-only and audiovisual presentations (synchronous vs. asynchronous tapping sounds added). Participants were better at discriminating tap-dance sequences in audiovisual synchronous as compared to asynchronous condition. Authors argued that attentional capture and known principles of multimodal neurons could probably explain this facilitatory effect. In experiment 2, a detection paradigm was employed (auditory-only, visual-only and synchronous/asynchronous audiovisual stimulation). Analogously, enhanced detection for audiovisual synchronous as compared to the other conditions was reported. Taken together findings from both experiments show an enhanced performance for audiovisual conditions as compared to asynchronous and unisensory conditions, promoting our knowledge on multisensory processing (see also Sgouramani et al., 2012, comparing dancers and non-dancers during a Simultaneity Judgment task, SJ, with dance audiovisual displays; Su, 2014c, reporting influenced point of subjective simultaneity by the visual cue of peak velocity via a SJ task). This processing seems to be developed quite early and change over the course of infancy (Hannon, Schachner, & Nave-Blodgett, 2017). Hannon and colleagues (2017) performed two experiments (8-12 and 5-8 months infants were tested in experiment 1 and 2 respectively) employing an infant-controlled habituation paradigm. During habituation phase infants watched audiovisual clips of a dancer moving in synchrony to music. In the test phase, infants were either exposed in synchronous or asynchronous videos or in mere visual displays. Results derived from infants' visual fixations indicated a preference for asynchronous relative to synchronous videos, but only for the older group. These findings provide the first evidence on the origins and development of audiovisual integration for complex stimuli.

The investigation of audiovisual integration processes for complex dynamic events was the target for Su's (2014b) study as well. She set out to address a possible interaction between bottom-up mechanisms (integration promoted by temporal synchronicity) and top-down processes (content congruency of auditory and visual information). Participants performed a detection task of an auditory temporal deviant. The visual (PLD of a bouncing human-like figure) and auditory (i.e., beat) information varied in terms of content congruency (downward motion to the beat-congruent vs. upward motion-incongruent) and temporal synchrony (audiovisual stimulus synchronous vs. asynchronous) resulting into four combinations. Results showed that participants were better at detecting the auditory deviant in incongruent and asynchronous conditions implying stronger integration for congruent and synchronous displays. Hence, both content congruency and temporal synchrony seem to be linked to enhanced audiovisual integration of rhythmical biological motion. Utilizing the same stimulation, Su (2014d) investigated the effect of a visual beat during a rhythm change-detection task (experiment 1) and a synchronization task (experiment 2). In both experiments auditory and audiovisual (see also Su, 2014a) conditions were tested across increasing levels of auditory interference (increasing the auditory polyrhythmic complexity) and resulted into converging findings. Audiovisual conditions led to overall higher sensitivity to a change in the auditory rhythm and increased synchronization levels to a regular auditory beat, in comparison to auditory conditions. This benefit induced by the visual beat was more prominent during the highest interference levels. Su (2014d) interpreted their findings based on the principles of inverse effectiveness. Thereby, the magnitude of visual enhancement increased while auditory performance was gradually impaired (due to augmented auditory interference), thus, dynamic rich visual information can modulate auditory temporal perception, when auditory signal is weakened. In accordance to this suggestion, London, Burger, Thompson, and Toiviainen (2016) tested participants in a tempo-rating task in three different conditions (audio only-rhythm and blues, R&B songs, visual only-PLD dancing and audiovisual-visual vigorous vs. relaxed dance sequences). Focusing on the third condition, results showed faster tempo rates for the audiovisual clips including vigorous motion in comparison to the audio only condition. Notably the relaxed motion had no effect. Hence, a cross-modal interference occurred, indicating multimodal processing of tempo but in specific conditions.

Synchronization with visual rhythmical cues. Even though instinctively we might link the concept of rhythm to audition, it seems that visual modality can provide similar temporal cues under certain contexts. For instance, precisely the extraction of meter and rhythmical structures from the periodical swing-dance like motifs was recently examined in a SMS study (Su, 2016b). Su (2016b), based on the action-perception coupling concentrated on the temporal patterns derived from a visual dance excerpt. She requested participants to tap in synchrony to PLD performing Charleston and Balboa movements. Results suggested that the leg movements marked the beat while the trunk movements were perceived as the subdivisions between successive beats (see also Su, 2016a, on this subdivision argument). Further verifications on the temporally structured multimodal nature of rhythm representations in a dance sequence were provided by Su and Salazar-López (2016). In experiment 1 flamenco video excerpts were used in a duration reproduction task. A potential visual beat cue was embedded or not in the displays of arms/legs movements (or more complex dance patterns in experiment 2) and compared to auditory stimulation. Better temporal estimation when visual beat was included was true for a all conditions tested. Subsequently, in experiment 3 congruent/incongruent sound was added but no interference occurred, suggesting that the difference reported should not be attributed to internal representation of the impact sounds. In accordance with Su (2016a,b), these consistent findings were interpreted as evidence of observers extracting visual beats from rhythmical motion (i.e., dance) similarly to strategies applied during auditory stimulation, probing music-dance coupling (see also Panagiotakis, Holzapfel, Michel, & Argyros, 2013, on the production of a 3D dance animation derived by the combination of auditory and visual temporal characteristics).

In a recent study Lee, Barrett, Kim, Lim, and Lee (2015) also addressed this cross-modal correspondence between audition and vision in terms of shared temporal/rhythmical characteristics (Experiment 1) and examined the factor of actual enactment as an extension, introducing sensorimotor contribution to rhythm cognition (experiment 2). Lee and colleagues in their first experiment tested how the viewing of dance motions shapes auditory meter perception. Deviant sounds at four metrical positions with different metrical levels (elicited by a visual dance, a sequence of abstract visual stimuli, or no visual stimulation) were manipulated, serving as targets. Participants had to respond to targets as quickly as possible by pressing a button. Analysis showed slower reaction times only for the dance condition. Lee and colleagues attributed this finding to decreased efficiency of auditory processing due to simultaneous attentionally capturing visual information. Experiment 2 was identical as a procedure but a very popular dance ("Gangam Style") was used as stimulus and participants were divided into two groups (participants who had actually performed this dance vs. those with mere visual familiarity). Results showed greater reaction times differences between high and low metrical positions for the group with physical experience. Lee et al. (2015) suggested that embodied internalized rhythmical motion might lead to finer ability to discriminate metrical positions. Hence, both visual and sensorimotor information seem to modulate our temporal perception of auditory rhythms. Besides these rhythmical attributes derived by multimodal channels, the effect of visual stimulation in duet dancing was recently addressed (Brown & Meulenbroek, 2016). In this particular study, two pre-professional dancers stood back to back in two conditions (i.e., 1: one dancer had mirror access seeing him/her/self and partly his/her partner, 2: no mirror access) while performing specific dance sequences with their arms in three different tempi. Tempo was provided via a metronome before the movement and was ceased the moment the dancers started moving. Analysis revealed a positive effect of mirror use on interpersonal coordination but not on couple's synchronization. Brown and Meulenbroek argued that internalized beat combined with visual feedback seems beneficial but not in a systematic manner. Further exploration on the issue can provide informative knowledge on the way a dance class is structured (i.e., typically mirrors are used).

This acquired knowledge that highlights common sensorimotor mechanisms for visual rhythms in dance and auditory rhythms can be utilized in other applications besides dance education as well. For example, precisely these redundancies in tempo and rhythm information shared in audio and visual streams could aid in the formation of rehabilitation strategies for Cochlear Implant (CI) users. CIs though effective for speech, face certain constraints for music cognition. In a relevant study Vongpaisal and Monaghan (2014) focused on the possible ways multimodal cues could optimize CI users' music appreciation. In two experiments CI users and normal-hearing participants' performance was compared in a 2AFC task utilizing Cha Cha, Jive, Slow swing, and Tango. In experiment 1 a music excerpt (i.e., auditory) as reference had to be matched with one out of two dance video displays (i.e., visual), whereas in experiment 2 the opposite comparison was to be made. CI users performed well above chance in both experiments, however similar to normal-hearing group they were more accurate in experiment 2. Thus, both groups were better at differentiating auditory temporal cues in music than visual temporal cues in dance.

Conclusively, the shared temporal properties of visual and auditory modalities, their interactions, along with the multimodal nature of rhythm patterns, provide evidence on the complexity of an everyday event such as rhythmical dance. In addition this visual auditory correspondence in terms of rhythmical properties could be proven optimal for populations with auditory deficits.

The way we dance shapes what we hear. Dance is a multimodal activity, we move to the music (i.e., audition), we adjust to the cues of our dance partners (i.e., vision), and we constantly receive proprioceptive and sensorimotor information during movement. Focusing on these inter-modal relations and dance, the possible effect of how we move on what we hear has also been addressed by Phillips-Silver and Trainor's (2007) study. Participants during a training phase listened to an auditory excerpt of ambiguous metrical structure while bouncing their knees similarly to the experimenter either every two (Duple group; i.e., march) or three beats (Triple group; i.e., vals). Thus, in the absence of physical auditory accents, "felt" accents were induced. During the test phase a 2AFC task was completed with participants choosing (march/vals rhythms) which excerpt was similar to that of the training phase. Analysis revealed that participants tended to choose the rhythm they had actually previously enacted. Thus, participants' metrical interpretation of an ambiguous auditory stimulus was modulated by vestibular stimulation arising from metrical body movements. This strong multisensory connection of body movement and auditory rhythm processing was also true in a similar experiment with infants (Phillips-Silver & Trainor, 2005; see also Maes & Leman, 2013, for another study connecting action and perception, with an emphasis on semantic attributes - i.e., happy, sad choreographies and musical pieces - instead of temporal characteristics, e.g., rhythm).

Such findings are of critical importance, as if movement alternates our auditory perception, one can wonder whether it can enhance it as well, focusing on future applications for population with certain auditory deficits. For instance, a recent short training program proposed by Vongpaisal, Caruso, and Yuan (2016) included two training phase conditions in order CI young users to learn new songs (only auditory learning vs. auditory-motor learning). In the auditory-motor learning condition, participants danced in synchrony to what they were listening to. Results derived from a subsequent identification task showed greater memory for songs which were actively learned via dance. This enhanced performance was attributed to multimodal processes, indicating that the formation of a more robust representation (in terms of temporal musical cues) involves active rhythmical engagement (i.e., dance). Therefore, the development of methods and protocols which apply this reported multimodal benefit for CI users can have substantial results in the amelioration of the way they perceive music.

This described linkage between auditory and sensorimotor mechanisms, seems to be a two-way scheme. Hence, besides dance patterns shaping what we hear, this interaction could exist the other way around as well. For example, Grosshauser, Blasing, Spieth, and Hermann (2011) focused on an original wearable device that allows the real-time sonification of impact sounds derived from movements, through a closed feedback loop. Such devise allows an active agent to attend to the sounds he/she produces while moving and proceed to adjustments/corrections when necessary. During pilot experiments involving simple ballet jumps it was tested whether real time auditory feedback could enhance 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. This 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. A similar wearable device was used in Pitale and Bolte’s (2018) pilot study examining children with cerebral palsy (CP). Typically developing children and CP children wore the prototype, which provided them with a heel-strike auditory real-time feedback. The high device accuracy of identified heel strikes seems extremely promising for future experimentation.

Both these new tools could also be used in learning environments (e.g., sport academies) leading to faster results due to multisensory integration. Additionally, applications in clinical settings (e.g., blind individuals) focused on facilitating their everyday activities appear extremely promising (e.g., by providing auditory feedback while walking enhanced stability and better coordination could be achieved). Thus, our current knowledge on the inter-modal procedures while dancing seems to promote both basic and applied scientific research.

Haptic information in dance synchronization. Interpersonal coordination while dancing shapes a social context under which, haptic information among the dancers is being often exchanged. Thus, apart from audiovisual and sensorimotor correspondence the contribution of haptic input on dancing activities has also driven the scientific interest. For instance, Sofianidis, Hatzitaki, Grouios, Johannsen, and Wing (2012b) investigated the ways spontaneous interpersonal synchrony is affected by somatosensory feedback. Dancers, non-dancers, and mixed couples performed a rhythmical sway task, either by adopting a spontaneous sway of their own or following an external metronome. Partners were standing one next to the other on force platforms, moving their legs (eyes closed) and were either in constant contact through a light fingertip touch or no communication between them existed. Analysis showed an improvement of interpersonal synchrony (greater coherence) for all couples when haptic information was provided but only for the condition where no external pacer was available. In the presence of the external pacer, only dancers seemed to benefit from the sensory feedback, while non-dancers and mixed couples did not show any enhanced interpersonal synchrony. Sofianidis and colleagues (2012b) argued that dancers seem to have an improved multisensory integration capacity, which allows them to more easily entrain to their partner while audio and tactile stimulation are simultaneously provided. In a follow up study Sofianidis, Elliott, Wing, and Hatzitaki (2014) now provided two different frequencies (slow/fast) via headphones to the couples and included three touch conditions (touch/touch and at the half of the procedure do not touch/do not touch and at the half of the procedure touch). Participants were asked to voluntary entrain to the metronome. In this case tactile and auditory stimulation were not coherent as before. Results showed that only dancers' couples were able to prioritize the signals and actually synchronize according to the metronome while ignoring the haptic information. This enhanced ability to segregate stimuli was attributed to their prior experience. Interestingly, in the mixed couples non-dancers were found to be attracted to the dancer's frequency resulting in a leader-follower relationship. Sofianidis et al. (2014) supported the idea that non-dancers are susceptible to sensory feedback whereas dancers can more easily maintain their motor plan.

The combination of findings deriving from these studies provide new insights on a crucial role a professional dancer/practitioner could play during physical rehabilitation and fall prevention interventions. The information transferred via touch could be proven extremely helpful for populations which struggle in motor coordination procedures, thus, the quite rare experimentation – at least so far - looking into haptic-auditory association with synchronization is valuable (see also Gentry & Murray-Smith, 2003, on an implementation of a human-follower interacting with an haptic device-leader in a swing like dance session with music providing timing alignments).

Modality contribution in the sense of agency. Our sense of self is an extremely complex procedure that combines inputs from all our senses. Hence, it is interesting to examine which multimodal cues aid us to distinguish ourselves from the others. For instance, Sevdalis and Keller (2009) captured PLD of the motion of participants while they clapped, walked, or danced in synchrony with music. Subsequently, own versus other's movement was displayed with or without synchronous auditory stimulation and participants had to detect self versus other. Analysis revealed that detection of one's self while dancing was higher as compared to clapping and walking, while the modality of presentation (visual or audiovisual) did not have an effect. 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 (see also Loula, Prasad, Harber, & Shiffrar, 2005 reporting action-dependent self recognition with higher accuracy for dance actions). However, the presentation of the actual step sounds of the given individual would compose a more informative and personalized cue, thus, resembling the visual signal contribution for the audiovisual event presented and therefore is more likely to be integrated given its semantic congruency (i.e., unity effect; Vatakis & Spence, 2007, 2010). Under a similar notion in a follow up study (Sevdalis & Keller, 2010) based on the hypothesis that synchronous auditory information might improve self-recognition when the visual displays are impoverished, they introduced new conditions on a similar set up. The visual information was clapping displays in different degradation levels (15, 8, 6, and 2 markers available) and the auditory information contained three levels: none, music only, and music + clapping sounds/generated by the agents' action itself. Results showed decreased accuracy for decreased visual stimulation. Interestingly, agent recognition was not influenced by the presence of auditory information irrespectively of its form. Sevdalis and Keller (2010) argued on the high informativeness of kinematic cues and the specialty of biological motion which encompasses dynamic properties without the need of additional support from auditory stimulation. Hence, implications of an hierarchy of cues for self-other discrimination procedures were proposed. Synchronicity manipulations on the audiovisual signals provided might provide different results, thus, further investigation is still needed.

In summary, focusing on the temporal aspects of multisensory integration, dance proved to be a well-situated stimulus for such studies, as it involves informative biological motion. Relevant knowledge can contribute to the development of applications on audiovisual displays in media, amelioration on internet social connection networks and communications (e.g., ameliorating the misaligned audiovisual streams during video calls), as well as sensory substitution. Furthermore, the implementation of a human-like robot capable of interacting in an aesthetic valuable way with human dancers, by incorporating multimodal signals has been recently described (Augello et al., 2016). 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.

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2

Move still: The effects of implied and real motion on the duration estimates of dance steps

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Introduction

Imagine you are a hero in a comic book and you are running away from the bad guys, what kind of image would convey this dynamic event? This is a tangible example of an image implying motion. The use of a single image to suggest movement has been of great interest for both artists (e.g., Dobrez, 2013; Nather & Bueno, 2012c; Reason, 2004) and scientists (e.g., Cutting, 2002; Nather & Bueno, 2008). The seminal memory tests of Freyd and colleagues (1983; Freyd & Finke, 1984) have illustrated the dynamic nature of mentally extrapolating (i.e., "representational momentum") an action that is implied in frozen-action photographs (see Freyd, 1987; Thornton & Hubbard, 2002, for reviews). More recently, Acik, Bartel, and Konig (2014) using eye-tracking demonstrated similar fixation selectivity when comparing real versus implied motion stimuli, concluding that static cues can be sufficient in revealing movement in a scene. Similarly, Elseways et al.'s (2014) visual working memory study using dance stimuli also supported that recognition of movement based only on posture is possible, even though somewhat poorer than that of real moving stimuli. The link between real and implied motion has also been supported through data showing common neuronal substrates (i.e., medial temporal/medial superior temporal cortex) in both humans (e.g., Cattaneo, Schiavi, Silvanto, & Nadal, 2017; Concerto et al., 2016; Kim & Blake, 2007; Kourtzi & Kanwisher, 2000; Lorteije et al., 2006; Lu, Li, & Meng, 2016; Mineo et al., 2018; Osaka, Matsuyoshi, Ikeda, & Osaka, 2010; Proverbio, Riva, & Zani, 2009; Senior et al., 2000; Urgesi, Moro, Candidi, & Aglioti, 2006; see also David & Senior, 2000; Kourtzi, 2004, for reviews) and monkeys (e.g., Jellema & Perrett, 2003; Krekelberg, Dannenberg, Hoffmann, Bremmer, & Ross, 2003). Moreover, common direction-selective circuits for both real and implied motion have been suggested by motion and positional after-effect experimentation in both adults and infants (e.g., Lorteije et al., 2007; Pavan, Cuturi, Maniglia, Casco, & Campana, 2011; Shirai & Imura, 2014, 2016; Winawer, Huk, & Boroditsky, 2008).

The role of implied motion in perception has recently drawn the attention of researchers in the timing domain given the tight link of motion and timing. Specifically, Nather and colleagues (see Bueno & Nather, 2012, for a short review) have investigated extensively the effect of implied motion on duration estimates utilizing dance stimuli (i.e., images of Degas' ballerinas-statues with various body postures implying different amounts of movement/induced intensity). For instance, Nather, Bueno, Bigand, and Droit-Volet (2011), via a bisection task (where short and long standard durations are learned by the participants and, subsequently, a series of test intervals are discriminated as more similar to the short or long standards), reported a greater overestimation for statues depicting movement of higher as compared to lower intensity for short durations (i.e., 0.4 to 1 sec), while no such effect was noted for longer intervals (i.e., 2 to 8 sec). These differences were attributed to the transient effect of arousal induced by high intensity images that deteriorated for longer intervals. However, when a reproduction task was utilized, an overestimation of higher as compared to lower intensity images was found for an interval of 36 secs (Nather & Bueno, 2011; see also Nather & Bueno, 2012a; but see Nather, Bueno, De Abreu, & Gomes, 2010, for a null effect). This finding cannot be accounted for by an arousal modulation and was, thus, interpreted based on the "change model" (e.g., Poynter, 1989), where body positions implying motion of higher as compared to lower intensity were considered as stimuli that involved more changes/events resulting in an interval overestimation. Further efforts to clarify such inconsistencies showed that the intervals presented (e.g., Nather & Bueno, 2012b, examined intervals of 9, 18, 27, 45 sec and found an overestimation for stimuli of higher intensity in implied motion only for the 27 secs), the task implemented (e.g., eye-tracking along with force-platform in a reproduction task; Nather, Bueno, & Bigand, 2009, 2013; Nather et al., 2010), and the type of stimuli utilized (e.g., cubist-abstract paintings, optical art, animals vs. human figures; Nather, Anelli, Ennes, & Bueno, 2015; Nather, Fernandes, & Bueno, 2012, 2014; Nather, Mecca, & Bueno, 2013) could modulate time estimation of implied motion. Overall, this line of research does not allow for any integrative conclusions on the role of implied motion on timing, as results are often contradictory.

Similarly, timing studies utilizing naturalistic images -other than dance- with or without implied movement have also resulted in inconsistencies. For instance, Moscatelli and colleagues (2011) utilized images of athletes with or without implied movement in a time discrimination task (for intervals in the range of 0.5-1.1 sec) and even though participants were more accurate for images depicting implied motion (i.e., lower just noticeable difference scores), no significant difference in implied vs. static images was noted (i.e., similar point of subjective equivalence). Yamamoto and Miura (2012), however, when comparing images of human and animal characters in an either running or standing position (for intervals ranging 0.4-1 sec) reported overestimations for the former as compared to the latter stimuli. The exact opposite result was reported in Chen, Pizzolato, and Cesari’s (2014) reproduction experiment, where images of a pole-vaulter (highly dynamic posture), fencer (less dynamic posture), and scrambled images (static) were compared in both sub- (0.3-1 sec) and supra-second (1.1-1.8 sec) intervals. That is, while no effect was found for longer durations, in the sub-second range, images depicting highly dynamic actions were underestimated in comparison to less dynamic or static ones. These findings were interpreted as the result of differential attentional allocation, with highly dynamic pictures being more attentional capturing and, thus, leading to interval underestimations (e.g., Chen et al., 2014).

Although time estimation with implied motion stimulation has lead to conflicting results, the same is not true for experiments comparing real motion versus static (without implied motion) presentations, where a time dilation for the former as compared to the latter has been repeatedly illustrated (e.g., Brown, 1995; Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Kaneko & Murakami, 2009; Lhamon & Goldstone, 1975; Mitrani & Stoyanova, 1982; Roelofs & Zeeman, 1951). This dilation effect has been attributed to the number of changes (i.e., speed, motion coherence, and spatial and temporal frequency; i.e., “change model”; e.g., Poynter, 1989) present in a moving as compared to a static stimulus. Under this theoretical framework and the previously reported correspondence of real and implied motion (e.g., David & Senior, 2000; Freyd, 1987; Kourtzi, 2004; Thornton & Hubbard, 2002), one wonders how a direct comparison of real and implied motion would affect time estimations given that both types of stimulation contain actual or implied changes, respectively (cf. Moscatelli et al., 2011).

In the present study, therefore, we sought to address this gap in the literature by comparing - through a reproduction task - displays of a dancer performing ballet steps with varying degrees of movement and static snapshots of these steps that imply the analogous ballet movements. Inspired by the Nather et al. studies (e.g., Bueno & Nather, 2012), we utilized ballet movements given their highly dynamic nature. According to the real-implied motion correspondence (e.g., David & Senior, 2000; Kourtzi, 2004) and the “change model” (e.g., Poynter, 1989), we hypothesized that both real and implied motion presentations will have a similar effect on duration estimates, given that both types of stimuli (i.e., real and implied) were derived from the same ballet step and, thus, should involve the same number of real or implied changes. Furthermore, we expected stimuli with higher amounts of motion, hence containing greater number of changes (both for real and implied conditions) to be overestimated[1] as compared to those with lower amounts of movement (see Bueno & Nather, 2012, for a review; Nather & Bueno, 2011, 2012a, 2012b; Nather et al., 2011; Yamamoto & Miura, 2012). This hypothesis is also in accordance with the theory of magnitude (e.g., Walsh, 2003), which proposes a tight link between space and time due to the experienced statistical contingencies of the physical world (e.g., Bueti & Walsh, 2009). Under this notion, time, space, and quantity share a positive relationship, hence overestimations are expected for stimuli with higher as compared to lower amounts of movement (i.e., more movement or greater displacement to lead to lengthened time estimates; e.g., Rammsayer & Verner, 2014, 2015; Sgouramani & Vatakis, 2014, 2015b; Xuan, Zhang, He, & Chen, 2007; but see Yates, Loetscher, & Nicholls, 2012, for opposite task-driven results).

2. Methods

2.1. Participants

Twenty-one participants (M = 27.7 years of age, age range: 23-35; 13 females) without any dance experience took part in the experiment. All participants reported

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[1] We utilized the term “overestimation” to refer to changes in participants’ timing percept when conditions are being compared and not in terms of the physical duration of the stimuli presented. Thus, it is used in a relative manner for the cases where participants estimate a stimulus presentation as lasting longer/shorter than the corresponding stimulus with which is being compared.

normal or corrected-to-normal visual acuity. The experiment was performed in accordance with the ethical standards laid down in the 2013 Declaration of Helsinki and informed consent was obtained from all participants. The study was approved by the Ethics Committee of the Department of History and Philosophy of Science of the National and Kapodistrian University of Athens.

Stimuli and apparatus

In order to directly compare real and implied motion, we created stimuli that were derived from the same source stimulus for both conditions (i.e., no background or any other visual feature differences; cf. Yamamoto & Miura, 2012). Additionally, we carefully controlled for the body posture of the dancer and, in particular, we focused on the position of arms and legs based on Nather et al.'s (2013) eye-tracking findings on the most attentional capturing elements of the ballerina's statues. Thus, in the real motion conditions, the video displays of the two ballet steps presented (i.e., battement tendu derriere and first arabesque) differed on the height of the extended leg from the floor (i.e., the leg extended backwards either remained on the floor or was lifted up to 90^0) and the height of the arms (i.e., the arms were placed either below or above shoulder level). For the implied motion conditions, static images were derived from the last frame of the video displays of the respective real motion conditions. These instances depicted the final pose, thus, the image of the dancer with the leg extended on the floor or lifted and with the arms below or above shoulder level, respectively (i.e., lower vs. higher amounts of movement, respectively; Vatakis & Sgouramani, 2015; see Figure 1).

Figure 1 about here

The stimuli were recorded in a dance studio using a Sony PMW-EX1 high definition camera. The original video clips of real motion lasted 840 ms. Six different intervals were used (840, 1040, 1280, 1520, 1760, and 2000 ms) for both the real and implied motion conditions, resulting in a total of 12 stimulus presentations. In order to avoid the interference of factors such as speed, stimulus change, and spatial-related cues in the timing task, the above-mentioned intervals were created by adding static frames at the beginning and end of each video clip (see Sgouramani & Vatakis, 2014). These static frames were extracted from the first and last frames of the original video clip using Adobe Premiere Pro CS5.5. No sound stimulation was presented.

In order to ensure there was indeed a difference in the perceived movement for the images presented, an online survey was conducted (using Survey Gizmo; http://www.surveygizmo.com). Forty-three non-dancers, who did not participate in the main experiment, completed the survey. The participants viewed and rated the stimuli in terms of the amount of implied motion they contained using a Likert scale from 1 to 7 (with 1 being no motion/static and 7 being extremely high amounts of motion). The analysis showed that the images of the battement tendu step were rated as implying significantly less motion ($M = 2.28$) than those depicting an arabesque step ($M = 4.42$) [$t(42) = -8.47$ $p < 0.001$], as expected.

Stimuli were presented on an Acer, ASPIRE 7750G laptop. The experiment was conducted using Presentation programming software (Version 15.0; Neurobehavioral Systems Inc.). Ten repetitions of each condition were divided into two blocks with a short break in between. The order of stimulus presentation was randomized using shuffling without replacement.

Experimental procedure

Participants were seated approximately 60 cm from the computer screen in a dimly light room and performed a reproduction task. They were asked to watch a video clip of a particular duration, which was then followed by the presentation of a blue square, hence the transition from the encoding to the reproducing phase was easily noticeable. Their task was to reproduce the duration of the video clip presented by allowing the blue square to remain on the screen for an equal amount of time. When the participants thought the elapsed time was equal to the video clip duration, they pressed the “Enter” key and the next trial was initiated. The participants were instructed not to use any counting strategies. Experimentation did not exceed the 20 minutes with a break included.

Results

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's indicating greater response variability. Analysis was performed using a 3-way repeated measures analysis of variance (ANOVA) with the factors of Motion (real vs. implied motion), Amount of Motion (more vs. less motion), and Duration (840, 1040, 1280, 1520, 1760, and 2000 ms). For all the analyses reported here, Bonferroni corrected t-tests (with point of statistical significance set to $p < 0.05$) were used in all post-hoc comparisons.

The accuracy analysis revealed a significant main effect of Motion [$F(1,20) = 10.14$, $p = 0.005$, $\eta^2 = 0.33$], with stimuli containing real motion being judged as lasting longer ($M = 1.15$) than those containing implied motion ($M = 1.04$). A significant main effect of Amount of Motion was also obtained [F(1,20) = 18.35, $p < 0.001$, $\eta^2 = 0.47$], with displays containing higher amounts of movement (M = 1.12) being judged as lasting longer than those that contained lower amounts of movement (M = 1.07). Additionally, a significant main effect of Duration was obtained [F(5,100) = 79.58, $p < 0.001$, $\eta^2 = 0.79$], with shorter durations being overestimated as compared to longer intervals (M = 1.49, 1.25, 1.09, 0.99, 0.91, and 0.84 for 840, 1040, 1280, 1520, 1760, and 2000 ms, respectively), a finding consistent with Vierordt's law (1868; i.e., as interval duration increases the associated temporal estimation decreases). Moreover, the interaction of Duration by Motion was significant [F(5,100) = 28.49, $p < 0.001$, $\eta^2 = 0.58$], where for the first four intervals tested (i.e., 840, 1040, 1280, and 1520), stimuli containing real motion (M = 1.63, 1.31, 1.15, and 1.03, respectively) were estimated as lasting longer than those containing implied motion (M = 1.34, 1.19, 1.03, and 0.95, respectively), while for the two longest durations tested (i.e., 1760 and 2000 ms) this difference failed to reach significance (M = 0.93, 0.83, and 0.90, 0.85 for real and implied motion, respectively; see Figure 2A). Finally, the interaction of Motion and Amount of Motion was also significant [F(1,20) = 18.39, $p < 0.001$, $\eta^2 = 0.47$], with stimuli containing higher amounts of movement being judged as lasting longer than those containing lower amounts of movement (M = 1.19 and 1.10, respectively), but only for the real motion conditions. No such differences were noted for the implied motion stimuli presented (M = 1.05 and 1.03 for higher and lower amounts of movement, respectively; see Figure 2B). All other interactions did not reach significance (Duration by Amount of Motion [F(5,100) = 1.12, $p > 0.05$, $\eta^2 = 0.05$], Duration by Amount of Motion by Motion [F(5,100) = 0.97, $p > 0.05$, $\eta^2 = 0.04$]).

The CV analysis showed a significant main effect of Motion [F(1,20) = 8.66, $p = 0.008$, $\eta^2 = 0.30$], with participants having higher response consistency when viewing the real (M = 0.21) as compared to the implied (M = 0.24) motion stimuli (see Figure 2C). All other main effects and interactions failed to reach significance (Duration [F(5,100) = 1.83, $p > 0.05$, $\eta^2 = 0.08$], Amount of Motion [F(1,20) = 1.71, $p > 0.05$, $\eta^2 = 0.07$], Duration by Motion [F(5,100) = 1.66, $p > 0.05$, $\eta^2 = 0.07$], Amount of Motion by Motion [F(1,20) = 0.12, $p > 0.05$, $\eta^2 = 0.72$], Duration by Amount of Motion [F(5,100) = 1.23, $p > 0.05$, $\eta^2 = 0.05$], and Duration by Amount of Motion by Motion [F(5,100 = 1.02, $p > 0.05$, $\eta^2 = 0.04$]).

Figure 2 about here

Discussion

In the present study, we investigated - for the first time - time estimates for ballet steps of real as compared to implied motion and with different amounts of movement using a reproduction task. Real motion stimuli were overestimated and had a higher response consistency (i.e., lower CV) when compared to stimuli of implied motion. Additionally, when ballet steps containing real motion were presented, participants overestimated the stimuli that contained higher as compared to lower amounts of movement, while no such differences were noted for ballet steps containing implied motion. These results raise the potential non-correspondence between real and implied motion stimulation in the timing domain as demonstrated in other perceptual domains (see David & Senior, 2000; Freyd, 1987; Kourtzi, 2004; Thornton & Hubbard, 2002).

The overestimation noted in our data for real as compared to implied moving ballet steps contradicts our original hypothesis of similar modulating patterns for both real and implied motion on duration estimates, but is in line with previous findings of an apparent lengthening of the duration of real motion stimuli as compared to static - without implied motion- ones (e.g., Brown, 1995; Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Kaneko & Murakami, 2009; Lhamon & Goldstone, 1975; Mitrani & Stoyanova, 1982; Roelofs & Zeeman, 1951). This latter comparison has been reported many times for abstract stimuli and the present work replicates and extends these findings for more complex stimuli such as those of ballet steps utilized in this study. Notably, even though we utilized images depicting the analogous motion to that of the real moving stimuli, this implied motion effect did not influence participants' timing estimates (see also Vicary et al., 2014, for analogous differences in visual working memory tests of dynamic events being more accurately encoded and retrieved in real as compared to implied motion conditions). This result can be accounted for by the predictions made by the "change model" (e.g., Poynter, 1989), according to which real movement can be considered more informative given the (actual and not implied) spatiotemporal changes, which presumably lead to interval overestimations. Additionally, our results are compatible with the contextual change hypothesis according to which the remembered stimulus' duration is mediated by the amount of contextual change embedded in the stimulus (e.g., Block, 1978; Block & Reed, 1978). In our case, one can argue that real motion presentations encompass a greater amount of contextual changes in comparison to implied motion and were, thus, judged as lasting longer.

The CV results we obtained yield additional support to this real versus implied motion distinction (i.e., real motion stimuli being more informative might have led to better prediction strategies adopted by the participants), at least in terms of time estimation, with greater response consistency for real as compared to implied motion presentations. Hence, a direct comparison of real and implied motion, at least in the timing domain, tentatively argues for distinct processing mechanisms or differential involvement of the same brain areas for real or implied motion (see Zeki, 1999b, in the context of opt art, arguing that while real movement is registered in both V1 and V5, illusionary movement mainly involves V5 and to a smaller degree V1).

Our data analysis also showed -as originally hypothesized- that real motion stimuli that contain higher amounts of movement - as rated (see Methods) - were judged as lasting longer than stimuli containing lower amounts of movement. This finding is compatible with the theory of magnitude (e.g., Walsh, 2003) and previous studies that corroborated that size, space, and quantity of stimulation are linked to time estimates via a positive relationship (e.g., Rammsayer & Verner, 2014, 2015; Sgouramani & Vatakis, 2015b, 2014; Xuan et al., 2007). According to this framework, the estimation of time, size, spatial displacement, and quantity is based on shared accumulation strategies connected to a single mental magnitude system (Walsh, 2003). A common neuronal substrate (e.g., inferior parietal cortex) for these procedures has been advocated by Walsh supporting further this connection. Our results can also be accounted for by the “change model” framework (e.g., Poynter, 1989), as stimuli with higher as compared to lower amounts of movement inherently contain a greater number of spatiotemporal changes (e.g., leg/arms height) and, thus, interval overestimations occur.

Interestingly, while for the real motion conditions, different modulations of participants’ timing estimates are being reported as a function of the amount of movement involved, a null effect was obtained for implied motion presentations.

These findings are in conflict with our expectations and previous literature (e.g., Chen et al., 2014; Nather et al., 2011; Yamamoto & Miura, 2012; but see Moscatelli et al., 2011). We speculate that three key points may shed some light on the source of these inconsistencies. Firstly, some evidence support that the order of stimulus presentation may modulate participants' timing performance (e.g., Nather & Bueno, 2011; Nather et al., 2015). Thus, contradicting results could be due to presentation order effects, which in our case were controlled for by proper stimulus randomization. Secondly, the utilization of static images implying motion showing either the starting or end point of the corresponding dynamic event has been previously debated (e.g., Acik, Bartel, & Koning, 2014; Jellema & Perrett, 2003; Urgesi, Moro, Candidi, & Aglioti, 2006), with no firm conclusions. In our study, given the nature of the movement selected (i.e., dance step), it was thought to be depicted better at the peak of the action, which happens to be the end posture (see also Dobrez, 2013, on the role of asymmetry in still images depicting movement). Our choice is in accordance with other studies that have also utilized the end posture and have reported an effect on timing estimates (e.g., Bueno & Nather, 2012; Nather & Bueno, 2011, 2012a; Nather et al., 2011). Thirdly, the naturalistic form of our displays, presenting real biological motion as compared to images of ballerinas-statues or computer-generated images (e.g., Nather et al., 2011; Yamamoto & Miura, 2012; see also Watanabe, 2008, for different timing effects when comparing biological, scrambled biological, and object motion) could have led to the obtained null effect. That is, the latter type of stimuli, even though complex and indicative of biological motion, lack the naturalistic context that the former stimuli contain (see also Moscatelli et al., 2011). In addition, the utilization of actual biological motion is critical, as it has been considered as a special kind of stimulus with social relevance (e.g., Benton, Thirkettle, & Scott-Samuel, 2016). Furthermore, in terms of the notion of independent temporal processing mechanisms for animate as compared to inanimate movement (e.g., Carrozzo, Moscatelli, & Lacquaniti, 2010; Orgs & Haggard, 2011; Wang & Jiang, 2012), one could argue that implied motion pictures of a dancer (i.e., animate) - the stimuli used in the present study- in comparison to ballerinas-statues (i.e., inanimate) - the stimuli used in past studies - could modulate our timing percepts, thus explaining our contradictory to previous studies (e.g., Bueno & Nather, 2012; Nather & Bueno, 2011, 2012a; Nather et al., 2011) findings.

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FIGURE CAPTIONS

Figure 1. Static frames extracted from the original videos displaying versions of A) lower and B) higher (as rated) amounts of movement for both the real and implied (highlighted with red) conditions.

Figure 2. Mean accuracy of the interaction of Motion (real vs. implied) by A) Duration (840, 1040, 1280, 1520, 1760, and 2000 ms) and B) Amount of Motion (higher vs. lower), as well as C) the mean coefficient of variation (CV) of the Motion (real vs. implied) conditions. The error bars represent the standard errors of the means. Significant differences ($p < 0.05$) are highlighted by an asterisk.

Figure 1

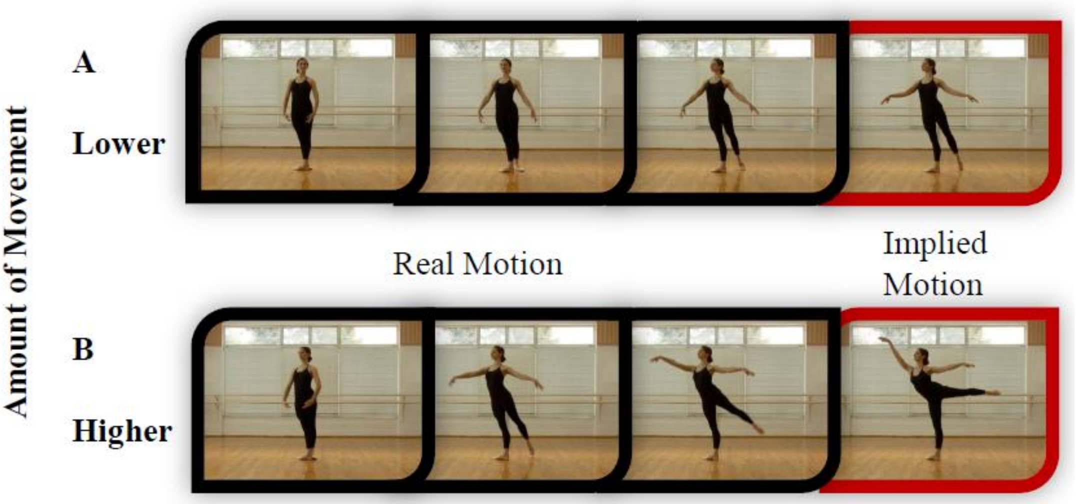
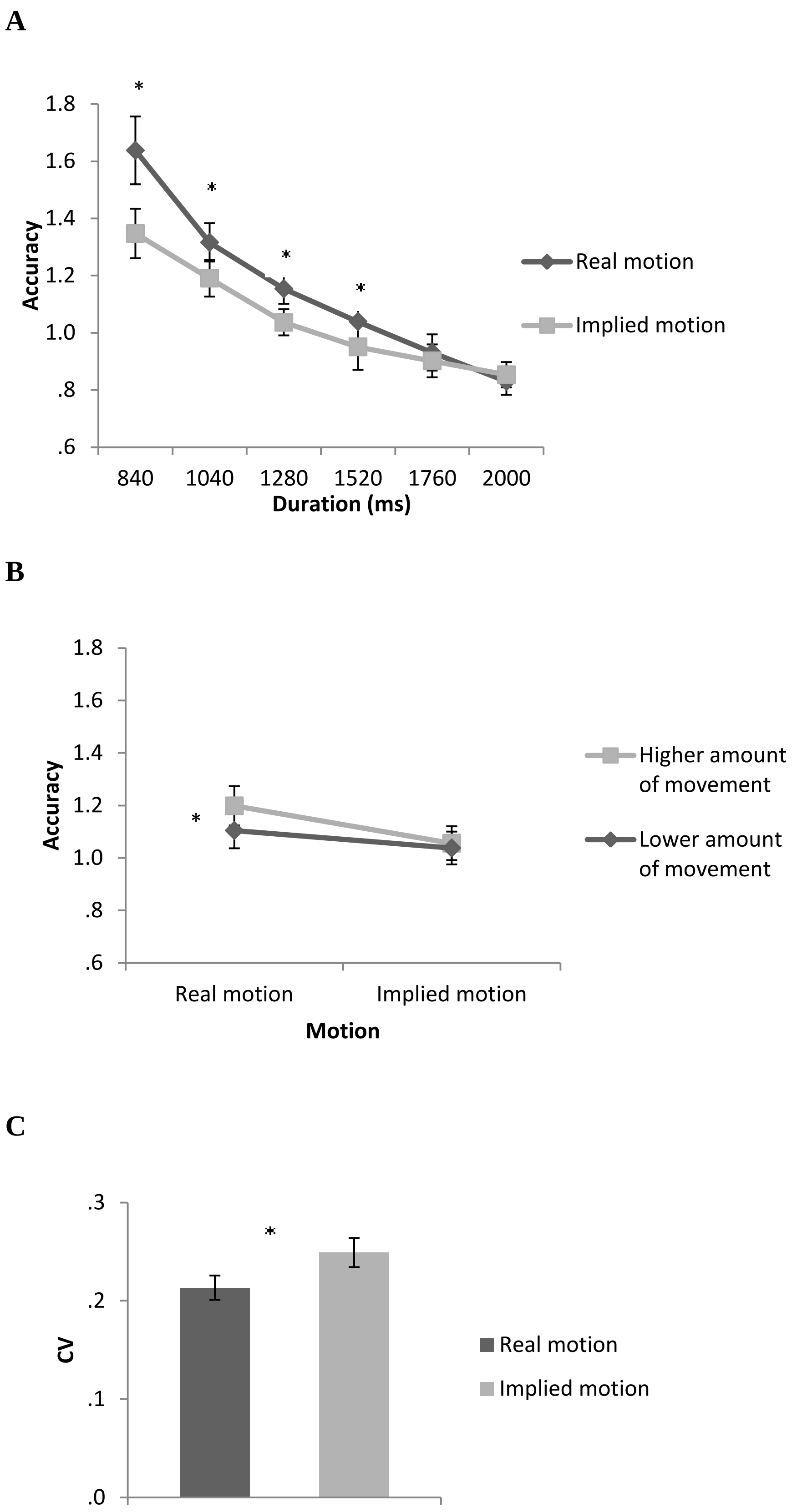

Amount of Movement
A
Lower
Real Motion
Implied Motion
B
Higher

Figure 2


A
*
*
*
*
1.8
1.6
1.4
1.2
1.0
.8
.6
Accuracy
840
1040
1280
1520
1760
2000
Duration (ms)
Real motion
Implied motion
B
1.8
1.6
1.4
1.2
1.0
.8
.6
Accuracy
*
Real motion
Implied motion
Motion
Higher amount of movement
Lower amount of movement
C
.3
.2
.1
.0
CV
*
Real motion
Implied motion

3

Modulating subjective timing through looming and receding biological motion

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Introduction

Timing is essential and ever present in our everyday lives. Its' subjective percept, however, is rarely objectively veridical, but rather susceptible to various factors such as stimulus characteristics. One such characteristic is the directionality of motion (a non-temporal attribute), which when presented in the form of looming (i.e., movement towards the viewer) and receding (i.e., movement away from the viewer) movement it has been shown to affect duration judgments in visual (e.g., Kline & Reed, 2013; New & Scholl, 2009; Ono & Kitazawa, 2010; Wittmann, van Wassenhove, Craig, & Paulus, 2010), auditory (e.g., DiGiovanni & Schlauch, 2007; Grassi, 2010; Grassi & Darwin, 2006; Schlauch, Ries, & DiGiovanni, 2001), and audiovisual conditions (e.g., Grassi & Pavan, 2012; van Wassenhove, Buonomano, Shimojo, & Shams, 2008). The comparison of looming versus receding motion is based on the notion of a perceptual asymmetry, where the former type of movement is considered more salient than the latter, thus providing the advantage to appropriately react (i.e., fight or flight) to an approaching (potentially harmful) stimulus (e.g., Hall & Moore, 2003; Neuhoff, 1998, 2001). This adaptive bias leads to the prioritization of looming as compared to receding signals and has been observed in rhesus monkeys (e.g., Maier, Neuhoff, Logothetis, & Ghazanfar, 2004; Schiff, Caviness, & Gibson, 1962) and human infants (e.g., Schmuckler, Collimore, & Dannemiller, 2007; Walker-Andrews & Lennon, 1985).

Timing research on the described perceptual asymmetry has revealed an analogous temporal asymmetry with a time dilation being reported for looming as compared to receding audiovisual (e.g., Grassi & Pavan, 2012; van Wassenhove et al., 2008), auditory (e.g., DiGiovanni & Schlauch, 2007; Grassi, 2010; Grassi & Darwin, 2006; Schlauch et al., 2001), and visual stimuli (e.g., New & Scholl, 2009; van

Wassenhove et al., 2008; Wittmann et al., 2010; but see Grassi & Pavan, 2012; Kline & Reed, 2013; Ono & Kitazawa, 2010). For instance, van Wassenhove and colleagues used an oddball paradigm (i.e., five consecutive stimuli with the odd - in terms of duration and/or features - stimulus on the 4th position of the sequence) in a series of experiments contrasting expanding (i.e., looming) with contracting (i.e., receding) discs and/or upward versus downward frequency-modulated sweeps in unimodal and audiovisual congruent and incongruent conditions. The authors reported a time dilation for a looming disc and/or sound sweep (with congruent directionality for the audiovisual cases) embedded in a series of steady discs-sweeps, whereas a time compression was noted when a steady disc-sweep pair was embedded in a series of looming discs. These findings were interpreted based on the contextual salience of the looming target in comparison to the receding conditions. Similarly, in a visual-only oddball task, Wittmann and colleagues also reported a time dilation for looming as compared to receding stimuli (see also New & Scholl, 2009, Experiment 4).

Not all studies, however, are in agreement with the above-mentioned findings with some visual-only studies reporting a null effect (e.g., Grassi & Pavan, 2012; Kline & Reed, 2013) or a time contraction (e.g., Ono & Kitazawa, 2010) for looming as compared to receding stimuli. Specifically, in a series of experiments, Ono and Kitazawa utilized apparent motion in depth to create looming and receding stimulation (i.e., two markers - a small and a large one - were presented sequentially to create the looming conditions, while the reverse order was used for the receding conditions) in an empty interval estimation task (i.e., participants were asked to estimate the length of the interval between the offset of the first and the onset of the second marker). The analysis revealed an underestimation of the empty intervals of looming as compared to receding conditions. It could, however, be argued that the way stimulus presentation took place could have led to the reported time contraction. The apparent motion in depth was created by two frames, with the target interval actually preceding the presentation of the second marker that indeed evoked the apparent looming-receding percept. Whereas, it is usually the case that the actual looming/receding stimulus is being timed and not the preceding empty interval. Thus, this apparent motion manipulation has certain shortcomings when compared to the previously conducted studies on the topic. Grassi and Pavan utilized an adjustment task, where participants had to match in terms of duration a looming or receding target (i.e., a disc and a sound that increased or decreased in size and intensity, respectively) with a duration-adjustable stationary stimulus in visual, auditory, and audiovisual presentations. In contrast to previous studies (e.g., New & Scholl, 2009; van Wassenhove et al., 2008; Wittmann et al., 2010), a null effect was obtained for visual-only presentations, while the looming-receding temporal asymmetry for the auditory and audiovisual conditions was due to a greater underestimation of the receding stimuli rather than to an overestimation of the looming stimulation. These results were interpreted based on the potential perceptual negligibility of receding sounds instead of the often-supported salience linked to looming stimulation (see also Brady & Oliva, 2012, reporting a receding perceptual hysteresis effect). Kline and Reed also refer to the possibility of an impaired percept when it comes to 2D receding stimulation via an oddball paradigm, reporting a looming-receding temporal asymmetry for 2D but not for 3D stimulus presentations (i.e., depth-rendered balls). They suggested that during 2D presentations, the receding movement could have led to the false percept of a stationary stimulus, and, hence, led the participants to underestimate the receding as compared to the looming stimulation. In 3D conditions, however, this asymmetry disappeared as both looming and receding presentations were perceived as moving in depth. In sum, current research does not allow one to strongly support the extension of the looming-receding asymmetry on the temporal domain, especially when one focuses on visual-only stimulation.

The evolutionary standpoint of the looming-receding asymmetry encompasses inherently a social interplay in terms of appropriately interacting with or reacting to other animate targets. The above-described research, however, has mainly utilized abstract stimulation (e.g., expanding versus contracting discs; see Grassi & Pavan, 2012; Kline & Reed, 2013; New & Scholl, 2009; Ono & Kitazawa, 2010; van Wassenhove et al., 2008; Wittmann et al., 2010) and not biological motion or other such ecologically-valid stimulation (for studies supporting the use of naturalistic stimulation see e.g., Alais & Melcher, 2007; Baker & Graf, 2009; Conrad, Kleiner, Bartels, Hartcher, O'Brien, & Bulthoff, 2013; Harrison, 2012; Sgouramani, Moutoussis, & Vatakis, 2019; Sgouramani & Vatakis, 2014a,b; Watson, Pearson, & Clifford, 2004; Wittmann et al., 2010), thus not allowing a thorough investigation of the potential social aspects of the looming-receding asymmetry. The social aspects of this asymmetry could be viewed in terms of the research on person recognition, which supports that the movement of an approaching walker (i.e., a form of looming motion) is utilized as a common real-life context for recognition during social interaction (e.g., Hahn & O'Toole, 2016; Pilz, Vuong, Bulthoff, & Thornton, 2011), with the head, body, and gaze of the walker providing social cues, which are preferentially processed when compared to non social stimulation (i.e., landscapes or objects; e.g., End & Gamer, 2017). These social cues are being perceptually prioritized by the human visual system so as to pick up socially relevant information and, thus, to interact effectively by inferring an approaching walker's intentions (e.g., Blake & Shiffrar, 2007, for a review). Furthermore, biological motion has been identified as a unique type of socially-relevant stimulus with research showing separate neuronal populations responsible for encoding forward and backward walking, promoting the idea of a dual channel model (e.g., Benton, Thirkettle, & Scott-Samuel, 2016). Given these findings, one wonders whether extending the looming-receding asymmetry in a biological motion set-up will influence -in an even more pronounced way as compared to the previous studies- our timing percepts.

The present study, therefore, is an attempt to add social relevance and resolve the aforementioned inconsistencies of a temporal looming-receding asymmetry in the visual modality (e.g., Grassi & Pavan, 2012; Kline & Reed, 2013; New & Scholl, 2009; Ono & Kitazawa, 2010; van Wassenhove et al., 2008; Wittmann et al., 2010). We, thus, examined the possible effects of an approaching as compared to a receding walker on time estimation utilizing a reproduction task. Previous studies reporting an overestimation for looming as compared to receding presentations (e.g., van Wassenhove et al., 2008; Wittmann et al., 2010) supported that the contextual salience of the looming as compared to the receding targets could be accounted for by the predictions of the Attentional Gate Model (AGM; e.g., Allan, 1998; Zakay & Block, 1997). The AGM is in fact an extension of the initially proposed information processing models, where timing is associated with an internal clock (Treisman, 1963; Gibbon, Church, & Meck, 1984) based on a three-stage process: an accumulator that collects pulses emitted at a constant rate (i.e., pacemaker), a working memory component that encodes the specific time interval presented, and a decision making component, where the ongoing pulses are compared to the reference memory for response selection. Thus, according to the AGM, an arousing stimulus, such as a looming disc, can lead to a higher pulse generation by the pacemaker, which, in turn, will lead to a greater pulse accumulation and, therefore, to a temporal dilation of a given interval as compared to the respective receding disc. This overestimation[2] of an approaching stimulus results in the earlier-in-time percept of a contact with a behaviorally urgent event (Franconeri & Simons, 2003). This subjective duration judgment could potentially allow the viewer with an adequate amount of time to appropriately react to this event. Thus, this overestimation could be viewed as a type of warning signal or cue for proper interaction (i.e., fight or flight; see Kline & Reed, 2013; New & Scholl, 2009; Wittmann et al., 2010). We assume that if this reported temporal asymmetry is indeed explained from this evolutionary standpoint, the stimuli chosen for this study, given their aforementioned high social semantic value (e.g., Benton et al., 2016), will further augment it (see also Wittmann et al., 2010, referring to similar expectations for ecological valid stimulation).

Experiment 1

Methods

Participants

Twenty-four participants (17 females; M= 25.5 years of age, age range: 18-38) reporting normal or corrected-to-normal visual acuity, took part in the experiment as volunteers (with no compensation). The experiment was performed in accordance with the ethical standards laid down in the 2013 Declaration of Helsinki and informed consent was obtained from all participants.

Stimuli and apparatus

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[2] We use the term "overestimation" to refer to changes in participants' temporal percepts when different conditions are being compared and not when comparing physical with subjective duration of the stimuli presented. It is, thus, used in a relative manner for the cases where participants estimate a stimulus presentation as lasting longer or shorter than the corresponding stimulus with which it is being compared.

A single simple step performed by a female was used for the creation of our experimental stimuli. The stimuli were composed of the female making a step towards (i.e., looming stimulus, visible neutral face) or away (i.e., receding stimulus, visible back of the head) from the viewer, with the female starting from the same location and travelling the same distance (i.e., one step; 85 cm) for both looming and receding movements (see Figure 1; see Vatakis & Sgouramani, 2015; http://dx.doi.org/10.6084/m9.figshare.1453169, for stimulus download). The visibility of the neutral face in the looming presentations, along with the absence of the face in the receding conditions was adopted as one would normally expect in real life situations, thus avoiding potential unpredictability (i.e., often linked with overestimation effects; e.g., Pariyadath & Eagleman, 2007; Tse, Intriligator, Rivest, & Cavanagh, 2004; see also Karsşılar, Kısa, & Balcı, 2018, on the ways backward biological motion gains plausibility) interfering with the experimental set-up.

Figure 1 about here

The stimuli were recorded in a dance studio using a Sony PMW-EX1 high definition camera. The original video clips of both looming and receding movement had a duration of 960 ms (25 fps; 720x576, presented on a black screen background). Three different intervals were used (960, 1200, and 1440 ms) for the creation of the looming and receding stimuli, resulting in a total of 6 video clips. In order to avoid the interference of factors such as speed, stimulus change, and spatial-related cues in the timing task, the above-mentioned intervals were created by adding an equal number of static frames at the beginning and end of each video clip (i.e., 3 and 6 frames were added at the beginning and end of the video clips for 1200 and 1440 ms, respectively;

see Sgouramani et al., 2019; Sgouramani & Vatakis, 2014a). These static frames were extracted from the first and last static frame of the original video clip using Adobe Premiere Pro CS5.5. Finally, all sound stimulation was removed for all video clips.

Stimuli were presented on an Acer, ASPIRE 7750G laptop. The experiment was conducted using Presentation programming software (Version 15.0; Neurobehavioral Systems Inc.). Ten repetitions of each condition were divided into two blocks with a short break in between. The order of stimulus presentation was randomized.

Experimental procedure

Each participant was seated approximately 60 cm from the computer screen (free viewing conditions) in a dimly lighted room and performed a reproduction task. They were asked to watch a video clip of a particular duration, which was then followed by a static image of a female (i.e., image extracted from a different video clip -not used in this experiment- of the same person to ensure that the transition from the video to the static image would be easily noticeable). Their task was to reproduce the duration of the video clip presented by allowing the static image to remain on the screen for an equal amount of time. When the participants thought the elapsed time was equal to the video clip's duration, they pressed the "Enter" key and the next trial was initiated. The participants were instructed not to use any counting strategies and were explicitly advised that they should estimate the interval precisely from the moment a stimulus would appear on the screen irrespective of stimulus movement. A short practice session took place in the beginning, with a random selection of four video clips and different durations presented once. These data were excluded from the final analysis. No feedback was provided during the practice or main sessions. Experimentation did not exceed the 25 minutes with a break included.

Results

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's indicating greater response variability. Analysis was performed using a repeated measures ANOVA with the factors of Directionality (looming, receding) and Duration (960, 1200, and 1440 ms). For all the analyses reported here, Bonferroni corrected t-tests (with point of statistical significance set to $p < 0.05$) were used in all post-hoc comparisons.

The accuracy analysis failed to show a significant main effect of Directionality, even though participants estimated the looming stimuli as lasting longer than the receding ones, this difference was not significant ([$F(1,23) = 0.72$, $p = 0.40$, $\eta^2 = 0.03$]; M= 955 and 937 ms for looming and receding stimuli respectively; see Fig. 2A). (Note that the reported means throughout the Results section do not refer to actual durations but to the ratio of the reproduced to the given interval.) A main effect of Duration was obtained [$F(2,46) = 159.452$, $p < 0.001$, $\eta^2 = 0.87$], with shorter durations being overestimated as compared to longer ones (M = 1.15, 0.92, and 0.76 for 960, 1200, and 1440 ms, respectively), in line with Vierordt's law (1868), which states that shorter durations tend to be overestimated, whilst longer durations are underestimated (e.g., Brown, 1995; Magnani, Oliveri, & Frassinetti, 2014; Sgouramani & Vatakis, 2014a; Tse et al., 2004). No Directionality by Duration interaction was obtained [$F(2,46) = 0.08$, $p = 0.92$, $\eta^2 = 0.004$]. The CV analyses showed no main effects of Duration [$F(2,46) = 0.65$, $p = 0.56$, $\eta^2 = 0.02$] and

Directionality [$F(1,23) = 0.39$, $p = 0.53$, $\eta^2 = 0.01$], and no interaction [$F(2,46) = 0.07$, $p = 0.93$, $\eta^2 = 0.003$; see Fig. 2B].

Discussion

In accordance with the literature supporting no temporal looming-receding asymmetry for visual stimuli (e.g., Grassi & Pavan, 2012; Kline & Reed, 2013, for 3D stimulation; but see Kline & Reed, 2013, for 2D stimulation; New & Scholl, 2009; van Wassenhove et al., 2008; Wittmann et al., 2010) and against our hypotheses, there was no effect of direction of motion on duration judgments. Taking into consideration the special nature of face processing in vision (e.g., Susilo, Yovel, Barton, & Duchaine, 2013), we conducted a control experiment examining face visibility as a function of looming vs. receding movement so as to explicitly investigate a potential role of the face (visible or not) in our reported null effects. We, thus, experimented with 24 new participants (22 females; M = 30.65 years of age, age range: 26-36), who performed similar to Exp. 1 a reproduction task, while viewing four different displays: a face visible-looming, a head visible-looming, a face visible-receding, and a head visible-receding stimulus. Analysis of these data showed -similar to Exp. 1- no main effect or interaction (Face visibility main effect: [$F(1,23) = 3.61$, $p = 0.07$, $\eta^2 = 0.13$]; Face visibility by Directionality: [$F(1,23) = 2.59$, $p = 0.12$, $\eta^2 = 0.10$]).

Experiment 2

In an attempt to ensure that indeed there is no temporal looming-receding asymmetry for more complex stimulation, a second experiment was conducted. The design of Experiment 2 was inspired by previous studies (e.g., Grassi & Pavan, 2012; van Wassenhove et al., 2008) and was based on literature that supports that: a) auditory information modulate direction discrimination (e.g., Schouten, Troje, Vroomen, & Verfaillie, 2011; Sutherland, Thut, & Romei, 2014), b) motion processing is multisensory in nature (e.g., Kaya & Kafaligonul, 2019), and c) audiovisual presentations seem to be perceptually prioritized as compared to unisensory conditions (e.g., Cappe, Thut, Romei, & Murray, 2009). In Exp. 2, therefore, we added congruent, incongruent, and control sound stimulation in the previously utilized visual stimuli in an identical experimental set up as Exp. 1. We hypothesized that the mere addition of sound (congruent or control) will lead to a temporal looming-receding asymmetry, in agreement with the multisensory integration literature, where a behavioral facilitation has often been reported for audiovisual as compared to unimodal stimulation (e.g., Juan et al., 2017; Stein, Meredith, & Walace, 1993; see also Kayser, Philiastides, & Kayser, 2017, on the facilitation of motion discrimination in congruent audiovisual conditions). For incongruent sound conditions, however, we expected participants' performance to be auditory driven given the temporal nature of the task, where the auditory stream is considered to be a more reliable source of information when compared to visual stimulation (i.e., modality appropriateness hypothesis; e.g., Grondin, Meilleur-Wells, Ouellette, & Macar, 1998; Rock & Victor, 1964; Welch & Warren, 1980; Westheimer, 1999). Thus, visual receding presentations with concurrent looming sounds would be judged as lasting longer than visual looming presentations with concurrent receding sounds.

Methods

The same 24 participants from Exp. 1 volunteered to take part in this experiment after an approximate two-month period (participants were not informed about potential participation in this second session). Exp. 2 was identical to that of Exp. 1 apart from the addition of an auditory stream in the video clips presented. The auditory stream utilized was looming, receding, or without directionality (i.e., control). The sounds were created in Audacity 2.0 using white noise (frequency range: 0.1-20 kHz, 16 bit depth; amplitude peak: -23dB) in the ‘Fade in’ and ‘Fade out’ mode for the looming and receding stimulation, respectively, while for the control condition, a constant white noise was utilized (sample rate: 44.1kHz; https://drive.google.com/drive/folders/16nvG8ReEuGLUi5lBnEPODR9I3Es0NVN3?usp=sharing, for stimulus download). The sounds were chosen to match the sliding movement of the foot performing a step and to be of equal duration. The alignment of the visual and auditory streams was made using Adobe Premiere Pro CS5.5. Constant white noise was provided from the beginning of each video clip in every condition with the sound change (i.e., looming or receding in terms of sound intensity) starting with the onset of the frame of the foot’s initial movement and ending exactly when the female stopped moving. Three different conditions were created: a) congruent [congruency], where the auditory stream was looming or receding matching the visual stream, b) incongruent [incongruency], where the auditory stream was in conflict with the visual stream (e.g., the looming visual stimulus was paired with the receding auditory stimulus), and c) control, where the auditory stream had no directionality, while the visual stream was looming or receding.

Results

Analyses were performed using repeated measures ANOVA with the factors of Sound Direction (congruent, incongruent, control), Visual Stream (looming, receding), and Duration (960, 1200, and 1440 ms). The analysis showed a main effect of Sound Direction [$F(2,46) = 20.40$, $p < 0.001$, $\eta^2 = 0.47$], where the control stimuli were overestimated ($M = 0.95$) as compared to congruent ($M = 0.87$) and incongruent ($M = 0.88$) presentations (cf. Grassi & Darwin, 2006, for auditory-only stimulation). A main effect of Visual Stream was also obtained [$F(1,23) = 54.81$, $p < 0.001$, $\eta^2 =$

0.70], with looming stimuli being estimated as longer ($M = 0.93$) than receding stimuli ($M = 0.86$; see Fig. 2C). In addition, a main effect of Duration was obtained [$F(2,46) = 124.45$, $p < 0.001$, $\eta^2 = 0.84$], in line with Vierordt's law (1868; $M = 1.08$, 0.89, and 0.72 for 960, 1200, and 1440 ms, respectively). The interaction of Sound Direction by Visual Stream was significant [$F(2,46) = 12.26$, $p < 0.001$, $\eta^2 = 0.34$], where for congruent and looming stimuli the temporal estimates were longer ($M = 0.94$) as compared to the receding stimuli ($M = 0.79$). The same was true for control and looming stimuli ($M = 0.98$) as compared to receding ($M = 0.91$) presentations. This was not the case, however, for the incongruent conditions where no differences were noted between the looming ($M = 0.88$) and receding ($M = 0.88$) presentations (see Fig. 2E). All other interactions failed to reach significance (Sound Direction by Duration: [$F(4,92) = 0.37$, $p = 0.82$, $\eta^2 = 0.01$], Visual Stream by Duration: [$F(2,46) = 0.28$, $p = 0.75$, $\eta^2 = 0.01$], and Sound Direction by Visual Stream by Duration: [$F(4,92) = 0.64$, $p = 0.63$, $\eta^2 = 0.02$]).

The CV analysis showed no main effect differences (Sound Direction: [$F(2,46) = 0.59$, $p = 0.55$, $\eta^2 = 0.02$], Visual Stream: [$F(1,23) = 0.11$, $p = 0.73$, $\eta^2 = 0.02$], and Duration: [$F(2,46) = 0.79$, $p = 0.45$, $\eta^2 = 0.03$]) and no significant interactions (Sound Direction by Duration: [$F(4,92) = 1.26$, $p = 0.28$, $\eta^2 = 0.05$], Sound Direction by Visual Stream: [$F(2,46) = 2.21$, $p = 0.12$, $\eta^2 = 0.08$; see Fig. 2D], Visual Stream by Duration: [$F(2,46) = 1.38$, $p = 0.26$, $\eta^2 = 0.05$; see Fig. 2F], and Sound Direction by Visual Stream by Duration: [$F(4,92) = 0.67$, $p = 0.61$, $\eta^2 = 0.02$]).

In order to better clarify the role of modality on the temporal looming-receding asymmetry noted for audiovisual presentations, we compared the results of Exps. 1 and 2. A repeated measures ANOVA was performed with the factors of Modality (visual-only, audiovisual), Directionality (looming, receding), and Duration

(960, 1200, and 1440 ms). A main effect of Directionality [F(1,23) = 29.32, $p < 0.001$, $\eta^2 = 0.50$] and Duration [F(2,46) = 216.74, $p < 0.001$, $\eta^2 = 0.90$] was noted, whereas Modality failed to reach significance [F(1,23) = 3.20, p = 0.08, $\eta^2 = 0.12$]. In terms of Directionality, looming stimuli were overestimated (M = 0.94) as compared to the receding stimuli presented (M = 0.86). For Duration, once again the shorter durations were overestimated (M = 1.10 for 960 ms) as compared to the longer intervals tested (M = 0.89 and 0.73 for 1200 and 1440 ms, respectively). Most importantly, the interaction of Modality by Directionality was significant [F(1,23) = 17.99, $p < 0.001$, $\eta^2 = 0.43$], with audiovisual receding stimuli being underestimated (M = 0.79) as compared to the respective visual-only stimuli (M = 0.93; see Fig. 2G), while no differences were noted for audiovisual (M= 0.94) and visual-only (M= 0.95) looming stimuli. None of the other interactions reached significance (Modality by Duration: [F(2,46) = 1.29, p = 0.28, $\eta^2 = 0.05$], Directionality by Duration: [F(2,46) = 0.27, p = 0.75, $\eta^2 =0.01$], and Modality by Directionality by Duration: [F(2,46) = 0.35, p = 0.70, $\eta^2 =0.01$]).

Finally, in the CV analysis no significant main effect (Modality: [F(1,23) = 1.74, p = 0.20, $\eta^2 = 0.07$], Directionality: [F(1,23) = 2.58, p = 0.12, $\eta^2 = 0.10$], and Duration: [F(2,46) = 1.15, p = 0.32, $\eta^2 = 0.04$]) or interactions (Modality by Duration: [F(2,46) = 1.18, p = 0.31, $\eta^2 =0.04$], Modality by Directionality: [F(1,23) = 1.98, p = 0.17, $\eta^2 =0.07$; see Fig. 2H], Directionality by Duration: [F(2,46) = 0.88, p = 0.41, $\eta^2 = 0.03$], and Modality by Directionality by Duration: [F(2,46) = 0.88, p = 0.42, $\eta^2 = 0.03$]) were obtained.

Figure 2 about here

Discussion

In Exp. 2 with the addition of the sound stimulation, a looming-receding temporal asymmetry was noted for congruent audiovisual stimulation in line with previous studies (e.g., Grassi & Pavan, 2012; van Wassenhove et al., 2008) and in the presence of sound stimulation but with no directional cues. For the congruent audiovisual conditions, these findings are in agreement with the predictions of the AGM framework (e.g., Allan, 1998; Zakay & Block, 1997), where the saliency of the looming stimuli (i.e., adaptive bias; e.g., Cappe et al., 2009; Harrison, 2012; Schouten et al., 2011; Sutherland et al., 2014) leads to higher arousal levels and, thus, interval overestimations (see, however, the Discussion section for potential alternative interpretations). Interestingly, the mere presence of a control sound with no directional cues also resulted in a temporal looming-receding asymmetry. This finding could potentially be related to findings in the multisensory literature showing that manipulations of static auditory stimuli (i.e., containing no directionality cues) led to changes on the perceived direction of visual motion (Freeman & Driver, 2008) and that the presence of static sound stimulation renders visual motion more salient (Kafaligonul & Stoner, 2012). For the incongruent conditions, no perceptual asymmetry was noted with the sound not exerting any differential effects in looming as compared to receding visual motion (see also van Wassenhove et al., 2008).

General Discussion

The aim of this study was to clarify whether or not the reported time dilation linked to abstract looming as compared to receding stimulation (e.g., New & Scholl, 2009; van Wassenhove et al., 2008; Wittmann et al., 2010) extended to naturalistic socially relevant stimulation. No such extension was noted in Experiment 1, where visual-only stimulation was utilized. In Exp. 2, however, the addition of sound did lead to an overestimation for looming as compared to receding congruent and control audiovisual stimulation.

In Experiment 1, the investigation of the temporal looming-receding asymmetry led to a null effect even though our stimuli (i.e., naturalistic, biological motion) were far more informative (e.g., Krishnan-Barman, Forbes, & Hamilton, 2017) as compared to the previously used abstract stimulation (see also Kline & Reed, 2013, on different results when 2D and 3D presentations were tested). Such results challenge the previously proposed perceptual prioritization of looming stimuli (e.g., Hall & Moore, 2003; Neuhoff, 1998, 2001). One could, however, argue that the neutral intentions of our approaching-receding actor were recognized as such and, thus, linked to more veridical temporal estimates and no perceptual asymmetry (see also Grassi & Pavan, 2012). Thus, even though the neutral facial expressions utilized in Exp. 1, have been considered a strong source of emotional information (e.g., Carrera-Levillain & Fernandez-Dols, 1994; Matsumoto, 1983), one could argue that differential effects would have emerged should the walker had a fearful facial expression (see also Vagnoni, Lourenco, & Longo, 2012, on how the manipulation of threat values of a looming visual stimulus affects perceived time-to-collision). However, if a looming-receding perceptual asymmetry does exist in the temporal domain, we would expect to find it even if the emotion depicted in the actor’s face and movement were neutral. In any case, future experiments could further explore the social aspects of the asymmetry by utilizing stimulation of varying degrees of emotional information in the face (see also Doi & Shinohara, 2009; Kliegl, Limbrecht-Ecklundt, Traue, & Huckauf, 2015, on the semantic value of the face) and/or body.

In Experiment 2 with the addition of sound stimulation, a temporal looming-receding asymmetry was obtained in the form of a greater underestimation for the receding motion conditions instead of an overestimation for the looming motion conditions (e.g., Grassi & Pavan, 2012). Counter to these findings, greater overestimations of looming presentations as compared to both their physical durations and the respective receding presentations have been previously reported (e.g., van Wassenhove et al., 2008). One could, thus, argue that the asymmetry observed in our results was driven by the negligibility of the receding sounds rather than the commonly referred salience of the looming stimulation (e.g., Hall & Moore, 2003; Neuhoff, 1998, 2001). Such a claim is supported by a number of studies suggesting that the ending points of receding sounds might be ignored during a temporal task leading to interval underestimations (e.g., DiGiovanni & Schlauch, 2007; Grassi & Pavan, 2012; Stecker & Hafter, 2000). From an evolutionary point of view, it could be proven quite resourceful - in terms of profitable management of attentional assets - to ignore sounds that imply motion away from a participant (as this movement potentially does not pose a threat) and rather focus attentional resources on approaching sounds, which should lead to a more veridical temporal percept in order to react appropriately (see also Grassi & Pavan, 2012).

The results of Experiment 2 also showed the absence of a temporal perceptual asymmetry for visual motion when paired with an incongruent sound. This null effect could be accounted for by the possibility that audition may not always be the privileged channel in the experience of duration. Dynamic visual events might also have a comparable temporal resolution to that of auditory stimuli’s contextual salience (van Wassenhove et al., 2008). Additional support to such an argument can be found in Harrison’s (2012) study that examined the potential interfering role of visual cues in an auditory motion direction discrimination task. He found a reduced performance in auditory direction judgments when either a looming or a receding visual cue was presented in the opposite direction (i.e., incongruent signals), even though participants were explicitly encouraged to ignore the visual stream. Consequently, it seems that our participants actually depended equally on both the visual and the auditory streams during the audiovisual presentations that conveyed conflicting directional information (i.e., incongruent conditions). The effects of the presence of concurrent unisensory mismatched streams could also be interpreted according to the unity assumption framework (e.g., Chen & Spence, 2017; Vatakis, 2013; Vatakis & Spence, 2008). This framework proposes that when two stimuli share many common amodal properties, an observer is more likely to perceive them as referring to the same multisensory event rather than multiple unisensory events (Tsilionis & Vatakis, 2016). Given the incongruency in terms of motion direction in our conditions, it is possible that optimal integration conditions were not met, which, in turn, led to the elimination or minimization of the multisensory benefits obtained in the congruent and control conditions we presented. Finally, one can speculate that our results were not related to any type of modality dominance or multisensory integration issues, but rather the result of the concurrent looming and receding stimulation mutually cancelling out the conflicting information provided.

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FIGURE CAPTIONS

Figure 1. Static frames extracted from the original video clips displaying A) a looming step with the female's face being visible and B) a receding step with the female's back of the head being visible.

Figure 2. Mean accuracy (A and C) and CV (B and D) of Directionality (looming, receding) as a function of Duration (960, 1200, and 1440 ms) for Visual-only-Exp.1 and Audiovisual presentations-Exp.2 are being displayed. Accuracy (E and G) and CV (F and H) interactions of Sound Direction (congruent, incongruent, control) by Visual stream (looming, receding) and Modality (visual-only, audiovisual) by Directionality (looming, receding) are also showed. The error bars represent the standard errors of the means. Significant differences ($p < 0.05$) are highlighted by an asterisk.

Figure 1

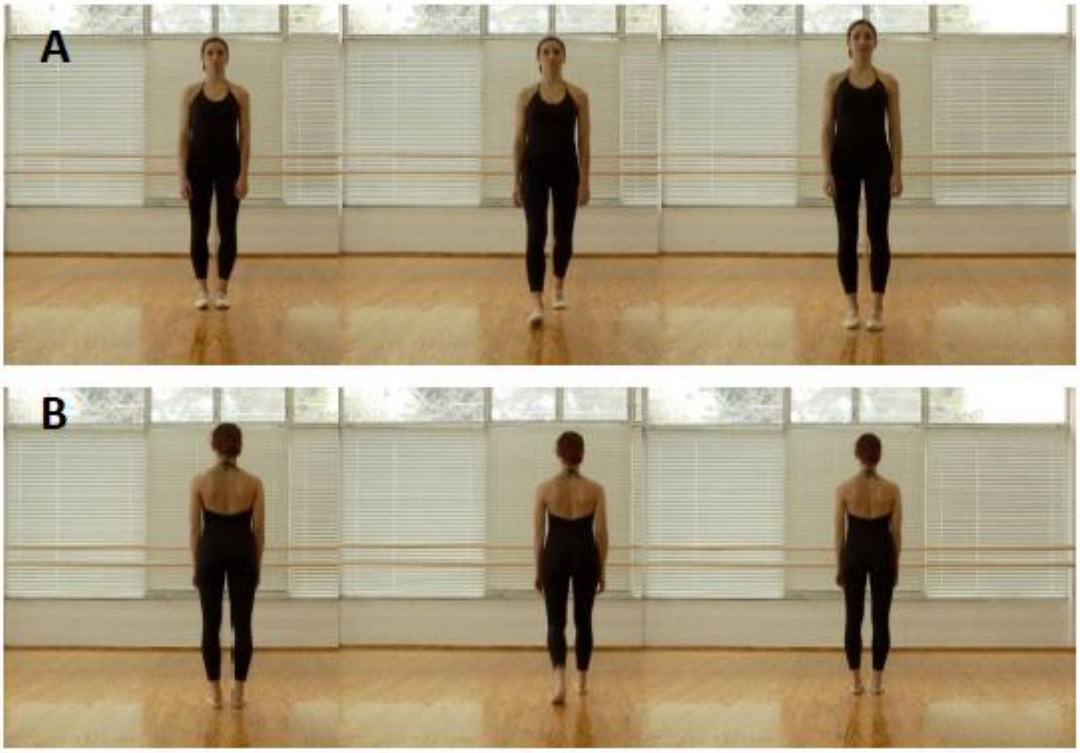
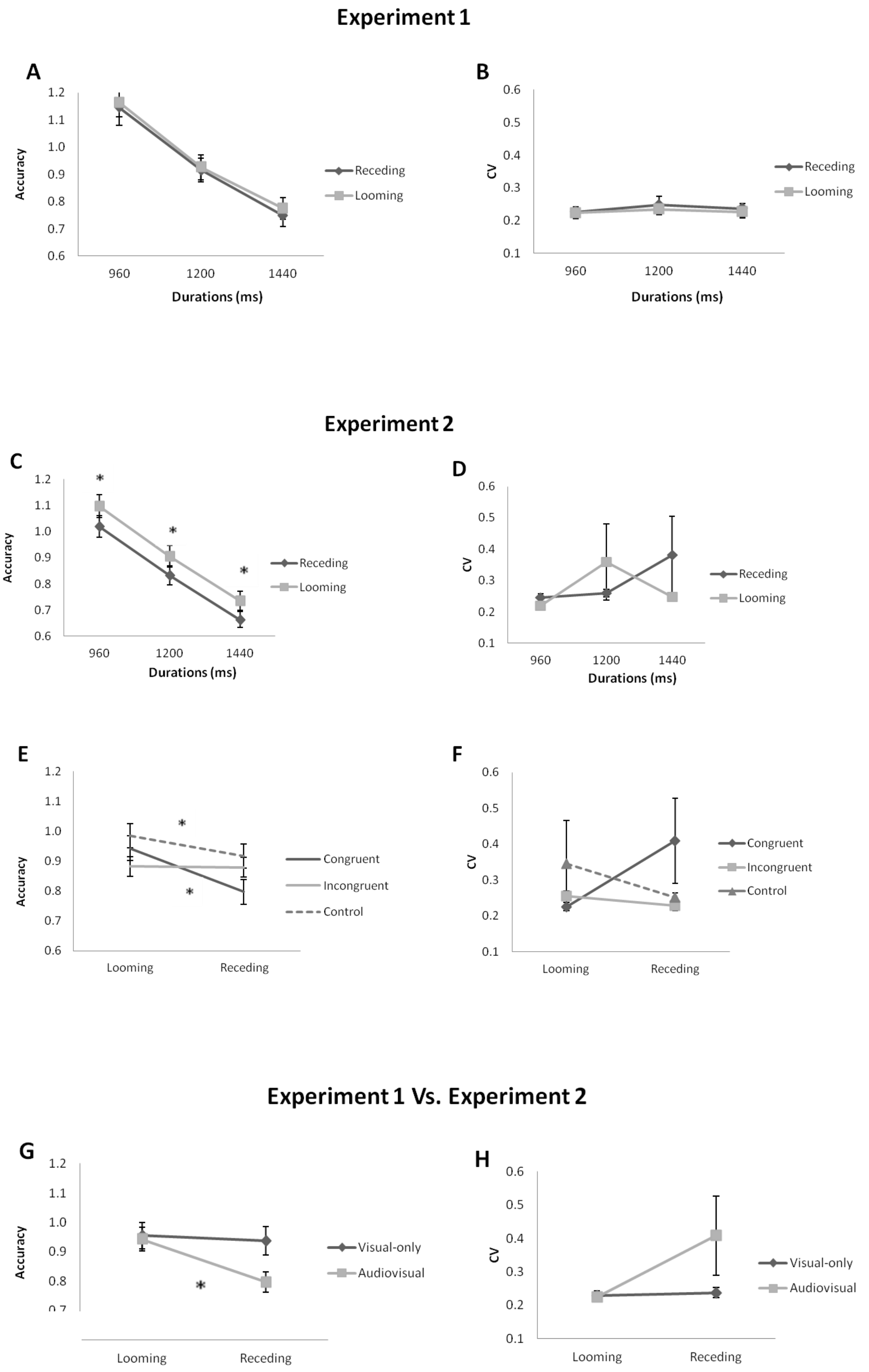


Figure 2


Experiment 1
A
Accuracy
1.2
1.1
1.0
0.9
0.8
0.7
0.6
960
1200
1440
Durations (ms)
Receding
Looming
B
CV
0.6
0.5
0.4
0.3
0.2
0.1
960
1200
1440
Durations (ms)
Receding
Looming
Experiment 2
C
Accuracy
1.2
1.1
1.0
0.9
0.8
0.7
0.6
*
*
*
960
1200
1440
Durations (ms)
Receding
Looming
D
CV
0.6
0.5
0.4
0.3
0.2
0.1
960
1200
1440
Durations (ms)
Receding
Looming
E
Accuracy
1.2
1.1
1.0
0.9
0.8
0.7
0.6
*
*
Looming
Receding
Congruent
Incongruent
Control
F
CV
0.6
0.5
0.4
0.3
0.2
0.1
Looming
Receding
Congruent
Incongruent
Control
Experiment 1 Vs. Experiment 2
G
Accuracy
1.2
1.1
1.0
0.9
0.8
0.7
*
Looming
Receding
Visual-only
Audiovisual
H
CV
0.6
0.5
0.4
0.3
0.2
0.1
Looming
Receding
Visual-only
Audiovisual

GENERAL DISCUSSION

The main focus of this dissertation is the interplay of complex biological motion (e.g., dance) and timing. To this end**,** we presented in a form of a narrative review (Chapter 1) the knowledge gained from a large number of studies that were conducted during the past 15 years, investigating the interaction of timing and dance. In the first section, the recent dance related work on duration judgments was described. The growing interest, highlights our fallacy in objectively encoding the time during which events unfolds. These temporal distortions, which seem context and signal dependent, are pertinent to be clearly described and explained. One of the main reasons being the several applications which this knowledge could be used and more specifically in human-like robots. The understanding of the way we perceive time and mainly our misconceptions are a prerequisite for the architecture of a machine which would behave as similar as possible to us (e.g., Lacquaniti et al., 2014). Hence, timing issues besides the philosophical extensions as to how we share a sense of time, are of unique importance for our technological advancements in the foreseeable future. In the second section of synchronization and entrainment in dance, the trend of using ecologically valid set-ups in order to investigate SMS has been highlighted. Besides a great interest in the sense of basic research, the linkage of particular music features inducing specific movement is expected to contribute to the development of important applications regarding dance and music education as already discussed. In the third section the relation between social cognition and dance was established. If we accept that social interaction practices such as dance, which appear to be at the margin of our extremely competitive and individualistic societies can foster social cooperation, the indispensability of dance become evident. Dance interventions could then be proven beneficial in establishments where social connectedness is necessary, such as schools, institutions for refugees, houses for the elderly, prisons, for the social inclusion of these populations. Such premises are compatible with the contemporary ideology of “wellness” as well, according to which healthy lifestyle choices are in the center of attention in Western societies. At the final section, the multisensory nature of both timing and dance has been stressed out. Methodological plurality and the utilization of dance stimulus -given the rich visual information provided- could enlighten us on modality contribution in temporal perception.

Dance is ubiquitous across cultures and connected to several aspects of our lives (see Laland, Wilkins, & Clayton, 2016, on the evolutionary origins of dance in connection to imitation mechanisms). 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. Ample evidence that dance investigation and the brain sciences might continue along a path that is mutually informative.

In Chapter 2 we directly compared, for the first time in the timing domain, the effect of real and analogous implied dance motion resulting in an overestimation of the intervals tested for the former as compared to the latter ballet steps. This finding implies potential differential processing mechanisms or differential involvement of the same brain areas (e.g., V1 and V5) for real and implied motion in timing. Furthermore, the amount of movement contained in a stimulus was found to influence participants’ performance, but only when real motion was presented. These results corroborate the potential real and implied motion distinction in timing. Further studies are needed to further verify this distinction. These studies should explicitly test static body postures of both the starting and end point of an event, include static images without implied motion as an additional condition, and further explore the previously reported presentation order effects. The efficient depiction of a dance act via a static image and the thorough investigation of the correspondent dynamics involved for both implied and real dance versions, apart from the timing domain could also promote the emerging field of neuroaesthetics (e.g., Calvo-Merino, Urgesi, Orgs, Aglioti, & Haggard, 2010; Zeki, 1999; Zeki & Ishizu, 2013).

The next research endeavor of the present dissertation (Chapter 3) examined whether or not the reported time dilation linked to abstract looming as compared to receding stimulation (e.g., New & Scholl, 2009; van Wassenhove et al., 2008; Wittmann et al., 2010) extended to naturalistic socially relevant stimulation. Video excerpts of dynamic biological motion in both unisensory (visual-only) and audiovisual versions were examined. Results showed a temporal looming-receding asymmetry for visual motion with congruent and control sound stimulation, while a null effect was obtained for incongruent stimulation and visual-only displays. The social facet of the aforementioned asymmetry could be further investigated with visual and/or auditory stimuli containing emotional information (e.g., displays of social interaction with spoken language as auditory stimulation). Such experimentation could also be extended to populations with social deficits (e.g., social phobia) given the altered attentional focus on social cues (End & Gamer, 2017). Furthermore, multisensory displays with different types of auditory stimulation could also be explored given that a number of studies have reported larger temporal looming-receding asymmetries for tonal as compared to white-noise stimulation (e.g., Maier et al., 2004; Neuhoff, 1998; Schlauch et al., 2001; but see McCarthy & Olsen, 2017). In real life, we constantly interact with people and other animals or objects that move towards or away from us, thus the potential experience of a temporal looming-receding asymmetry can have a wide impact from the critical act of driving a car to the aesthetics of coordinating one's movements with those of a partner's during dance.

In summary, our study complements a longstanding research interest in the connection of complex biological motion (e.g., dance) and timing. Our thorough investigation of the relevant literature highlights that dance and timing could be a stand-alone research topic in cognitive science and in particular time perception. We hereby focused on the section of duration judgments and performed a series of experiments in order to clarify the potential factors that influence our temporal estimates. We examined the directionality of movement, the role of expertise as well as we compared real and implied dance motion by performing reproduction tasks. The main contribution of our studies is the introduction of the aspect of social relevance, extending previous research and moving on from abstract stimulation to complex biological motion (e.g., dance).

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APPENDIX

The effect of Expertise and its interaction with looming/receding movement on duration judgments

This experiment was part of our work on the effect of looming and receding motion that is thoroughly described in Chapter 3 and it remains unpublished.

Introduction.

Alongside our aforementioned (see Chapter 3) and published work (Sgouramani, Chatziioannou, & Vatakis, under review) on the effects of Directionality (i.e., looming vs. receding motion) on duration estimations, we were also interested in the possibly modulating factor of Expertise. In relation to a social context highlighted throughout this thesis we hereby focused on dance as a suitable mean to further investigate sociocognitive parameters in interaction with temporal perception. Accumulating evidence suggests that dance viewed as interpersonal entrainment and requiring behavioral synchrony, promotes social bonding and enhances joint attention (e.g., Woolhouse, Tidhar, & Cross, 2016).

From this viewpoint, Washburn and colleagues (2014) showed that dancers outperform non-dancers in terms of synchronization in a visual-motor interpersonal coordination task. Both groups of participants were asked to synchronize with another individual during different dance styles excerpts with no auditory stimulation. The researchers corroborated that such superiority might have an impact on social connectivity in general, an argument that fits well with our selection of dance expertise as a supplementary factor in our research. Additionally, Sofianidis, Hatzitaki, Grouios, Johannsen, and Wing (2012) introducing auditory information (i.e., a pacer), demonstrated an increased interpersonal synchrony in dancers - compared to non-dancers - when haptic information is available during a rhythmical sway task (see also Miura, Kudo, Ohtsuki, & Kanehisa, 2011, on dancers' superiority in terms of sensorimotor synchronization to the beat). From a rather theoretical perspective Maduell and Wing (2007) focused on flamenco in order to investigate ensemble synchronization highlighting the sociocultural extensions such a group entails. An observational approach led the researchers propose an hierarchical network. Primarily the dancer provides cues to the singer, the guitarist and the support group, secondly the singer and the guitarist interact and provide temporal information to the group and thirdly the guitarist and the singer give feedback to the dancer, thus, apart from timing attributes, the researchers emphasized the social context of a dance ensemble.

Concentrating specifically on timing tasks and the possible difference in performance of dancers compared to non-dancers Sgouramani and Vatakis (2014) found dancers to be more consistent in their responses than non-dancers in production and reproduction temporal tasks. However, the two groups of participants were similarly influenced by the speed and size of spatial displacement which were manipulated in the video excerpts of ballet steps utilized as experimental stimuli. Thus, even though a difference in performance was noted, experts were proven as susceptible as naives when other factors were taken into account. Also Magnani and colleagues (2014) even though noted a difference in duration estimation between dancers and non-dancers, a null effect was true for a spatial task performed and more importantly spatial information affected the two groups equivalently during the timing task. Furthermore, Henley (2015) in a study where dance sequences were manipulated in terms of shape, time and space, reports a difference of performance between dancers and non-dancers for the spatial and temporal attributes but not for the shape. In a more naturalistic setup Minvielle-Moncla, Audiffren, Macar, and Vallet (2008), showed that dancers' temporal productions were modulated by attentional load as expected by the AGM, regardless their extensive spatiotempoal training. Participants in a preparatory phase were asked to walk for a specific distance while performing circular arm movements and produce a specific duration of the act. In subsequent test phases dancers had to reproduce the previous duration in different conditions (1.

covering smaller/larger distances, 2. watching another person’s arm movements in different tempi, 3. improvise). Results showed overproduction timing errors for conditions 1 and 3 and only when an external tempo was provided (condition 2) they managed to relatively accurately reproduce the interval requested. Notably, for the first condition, dancers were actually quite accurate when larger distances were introduced in comparison to small displacements; hence, the aforementioned space-time linkage was also true in a naturalistic set up with dancers as participants. On that account, our selection of dancers as experts in the present design seems suitable and justified.

Collectively, via the above mentioned studies, converging empirical results, describe dance expertise as a modulating factor in time perception, even though certain discrepancies between findings exist (comparable results come from studies with musicians and non-musicians; e.g., Chen, Pizzolato, & Cesari, 2013; Cicchini, Arrighi, Cecchetti, Giusti, & Burr, 2012; Aagten-Murphy, Cappagli, & Burr, 2014). Therefore, in the present study we sought to determine if dancers compared to non-dancers would be asymmetrically influenced by Directionality. We hypothesize, that the group of dancers will be more consistent in their responses (e.g., Sgouramani & Vatakis, 2014) and probably more accurate in their estimations, based on the fact dance consists extremely high spatiotemporal acuity and advanced synchronization skills with sociocognitive extensions.

Methods and Results.

In an identical experimental set up (task, durations, stimuli, analysis) as described in Chapter 2 in detail, twelve professional dancers (12 females; M = 31.7 years of age, age range: 27-36) and 12 non-dancers (10 females; M = 29.6 years of age, age range: 26-33) 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 any other sort of dance experience. All participants reported normal or corrected-to-normal visual acuity.

Both the accuracy analysis [$F(1,22) = 0.307$, $p > 0.005$, $\eta^2 = 0.014$] and the CV analysis [$F(1,22) = 0.307$, $p > 0.005$, $\eta^2 = 0.014$], revealed no effect of Expertise, dancers and non-dancers did not differ in their task performance.

Discussion.

The noted null effect of Expertise was rather unexpected, as it contradicts our previous findings (Sgouramani & Vatakis, 2014), therefore a more detailed examination of the differences between these two studies is mandatory. As the task utilized is the same (reproduction) our focus is localized on the stimuli used. In our previous study (Sgouramani & Vatakis, 2014) video excerpts of two ballet steps were presented to the participants while in the present study a simple step forward (looming) or backwards (receding) was our experimental stimulus. A possible explanation could be that motor familiarity enhances time perception when the specific motifs of movement are being examined (see also Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010 on the influence of observers' familiarity with the observed action on the perception of biological motion). Hence, dancers might perform differently in a timing task compared to non-dancers but only for stimuli which are included in their personal motor repertoire.

Therefore, it is probable that a simple looming/receding step is a highly ordinary movement performed commonly by everyone in our everyday lives and this global familiarity could have overwritten the factor of expertise (i.e., we are all experts at performing a step). Under this concept a lack of generalization in terms of expertise is admitted, which is in line with the argument that the ability of actually producing an action enhances perceptional mechanisms of similar actions (e.g., Henley, 2015). Coherently with the study of Jola and Mast (2005), who reported no difference between dancers and non-dancers in an egocentric body transformation task and an impaired performance in a mental object rotation task. The researchers interpreted these results based on the idea that static pictures did not enable experts to unfold their superiority in terms of mental imagery tactics as they are used to more dynamic motion sequences and possibly these acquired abilities do not transfer to different movement types. Similarly, in a recent study where musicians and non-musicians were compared in a reproduction task, experts outperformed non-musicians but this difference was remarkably magnified only when pictures of musical stimuli (i.e., a hand playing the piano vs. a hand in finger thumb opposition and/or scrabbled pixels) were used, highlighting anew the selectivity of one's' specific domain of expertise as stimulus in order to determine the role of expertise in timing tasks.

However, studies that have reported a different performance between groups of experts and naives even when abstract stimuli (e.g., Magnani et al., 2014) and inter modal set ups are used (e.g., Aagten-Murphy et al., 2014) corroborate a different view. Therefore, the actual role of expertise in timing tasks remains inconclusive and future research via neuroimaging techniques is required in order to set light in these ambiguities.

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