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Time Perception and Biological Motion: the role of configural information of social cues in temporal processing

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INTRODUCTION

Time is not just a physical dimension measured by clocks, rather it constitutes a subjective phenomenon actively constructed by the brain, influenced and shaped by factors such as attention, emotion, and the nature of the stimuli we encounter. The present thesis explores the relationship between time perception and biological motion, focusing on how this highly socially relevant category of visual stimuli influences or judgement of duration.

The first chapter provides a theoretical framework by tracing the study of time perception from its philosophical origins to contemporary neuroscientific accounts. Key theoretical models are reviewed, including the pacemaker-accumulator framework and Scalar Expectancy Theory, alongside the main experimental paradigms used to assess temporal judgments. The neural substrates of temporal processing are then examined, with particular attention to the roles of the basal ganglia, cerebellum, and prefrontal cortex. Additionally, the chapter explores how timing abilities vary across the lifespan and in clinical populations such as Parkinson's disease, ADHD, and schizophrenia.

The second chapter shifts focus to the social dimension of time perception, examining how social stimuli such as emotionally expressive faces, eye gaze direction, body postures, and vocal expressions, systematically modulate perceived duration through attentional and arousal-based mechanisms. Within this context, biological motion emerges as a particularly powerful social stimulus: evolutionarily ancient, mediated and processed by dedicated neural networks, and capable of conveying information about identity, emotion, and intention with minimal visual cues.

The third chapter presents an empirical study conducted with healthy adults completing a time bisection task. The task used point-light display stimuli depicting a human figure oriented leftward, rightward, or frontally, under a Static condition in which the dots were fixed in a standard walking posture without any movement. The study also manipulated the spatial mapping of response keys to examine the Spatial-Temporal Association of Response Codes (STEARC) effect. The findings are discussed in relation to the role of configural and kinematic properties of biological motion in shaping temporal judgments.

CHAPTER 1: TIME PERCEPTION: THEORETICAL MODELS, NEURAL BASIS, AND INDIVIDUAL DIFFERENCES

1.1 Time perception: definition and theoretical models

Time perception refers to the subjective experience and estimation of temporal intervals, playing a crucial role in human cognition as it allows individuals to interact effectively with the surrounding environment. Humans seem to be unable to live without the concept of time. Throughout history, different philosophical traditions have attempted to define the nature of time and its relationship to human experience. René Descartes (1596–1650), a central figure in the rationalist tradition, addressed the ancient problem of the origin of ideas, including that of time. Later, Immanuel Kant (1724–1804), offered a new perspective to the epistemological problem of time, arguing that time is not an objective, physical entity but rather a "pure form of sensible intuition" through which we perceive and interpret experiences. Another influential contribution was provided by Henri Bergson (1859-1941), who introduced a distinction between measurable, quantitative time and *durée*, or lived time, emphasizing the continuous and qualitative nature of subjective temporal experience. In the second half of the 19th century, a shift toward empirical psychology emerged and provided new approaches to understanding the nature of time. With the rise of psychophysical theories, pioneered by Gustav Theodor Fechner, psychologists began conducting experiments to study the relationship between time as subjectively perceived and time as measured in physics.

Unlike physical time, which can be objectively measured through clocks, psychological time is inherently flexible and shaped by various cognitive, emotional, and contextual influences (Grondin, 2010). This distinction between objective and subjective time has been central to the development of theoretical models aimed at explaining how humans perceive and process temporal information. From a psychological standpoint, time perception can be conceptualized as consisting of three major aspects: succession, duration, and temporal perspective (Block, 1997). *Succession* refers to the sequential occurrence of events, from which an individual can perceive both successiveness and temporal order. *Duration* refers to several distinct characteristics of events. Each event unfolds over a certain period of time, which an individual can encode, process, and retain in memory. Moreover, events are delineated by intervals, periods of time separating them, during which additional events may occur. The perceived length of these intervals can influence temporal judgment. A relatively unified and coherent sequence of events constitutes an episode, which is characterized by a defined temporal structure and can be encoded and remembered by the individual. The third component of psychological time, *temporal perspective*, refers to an individual's cognitive representation of past, present, and future time, reflecting how individuals organize and interpret their experiences across time. Another key aspect of time perception research concerns the different temporal scales at which

timing mechanisms occur. Millisecond timing is typically associated with motor coordination and low-level sensory processing, while interval timing (ranging from seconds to minutes) is more closely related to cognitive functions such as attention and working memory (Buhusi & Meck, 2005). These distinctions suggest that time perception is not a unitary process, but rather a set of mechanisms that vary depending on the temporal range and the cognitive demands of the task.

Within this framework, the concept of time emerges not as a fixed and objective entity, but rather as a flexible and context-dependent construct. This paves the way for a broader reflection on the nature of time itself, incorporating insights and contributions from various disciplines. Notably, parallels have frequently been made between psychological research and the concept of temporal relativity found in physics, highlighting the non-absolute nature of time. The idea that time is not an absolute entity, but rather a dimension that varies with the individual's subjectivity, was famously formalized in Albert Einstein's theory of relativity. Although this theory addresses temporal variations occurring under extreme physical conditions and is not directly applicable to everyday psychological experience, its broader implication, that time is not fixed but dependent on the observer's frame of reference, resonates conceptually with findings in cognitive psychology. In psychological terms, these "frames of reference" may include emotional states, attentional focus, and environmental context (Droit-Volet & Gil, 2009; Zakay & Block, 1996). Moreover, the relativity of time perception is closely tied to the brain's predictive function. Rather than passively registering temporal information, the brain actively constructs and shapes our sense of time by integrating sensory input with prior knowledge and expectations (Buonomano & Maass, 2009; Eagleman, 2008), further reinforcing the idea that time perception is inherently dynamic and subjective. Building on the idea that subjective time is influenced by internal states and contextual factors, it becomes essential to expand on the specific cognitive mechanisms that underlie temporal processing. Among these, attention and memory, play a central role in shaping temporal experience, influencing both the encoding and the estimation of duration. Rather than reflecting objective time, duration judgments emerge from the dynamic interplay between these cognitive systems (Block & Zakay, 1997; Grondin, 2010). According to attentional models, the amount of cognitive resources allocated to temporal processing directly influences duration judgments (Zakay & Block, 1996). When individuals are focused on time, durations and intervals tend to be overestimated, whereas when attention is split between temporal and non-temporal tasks, durations are often underestimated. This effect reflects the limited capacity of attention and the competition between concurrent cognitive processes. The role of memory is crucial, especially in retrospective timing tasks. These tasks require individuals to estimate the duration of past events, relying on the quantity and complexity of information stored in memory rather than on a direct representation of time itself (Block & Reed, 1978; Block & Zakay, 1997). According

to the contextual-change hypothesis, events that are richer in detail or involve greater contextual variations, are typically judged as longer in retrospect (Block & Reed, 1978; Grondin, 2010). Prospective timing, on the other hand, relies more heavily on attentional monitoring, with cognitive load and task difficulty reducing the resources available for time tracking, thus leading to shorter perceived durations (Zakay & Block, 1996; Buhusi & Meck, 2005). Overall, these findings highlight the interaction between attention and memory and the multifaceted nature of time perception, which cannot be explained solely by a single internal mechanism.

Theoretical models have attempted to formalize how attention and arousal shape temporal experience. Among these, internal clock models, and in particular the pacemaker–accumulator model, provide a structured account of duration processing. Originally proposed within the context of internal clock theories (Treisman, 1963), this model was later formalized in Scalar Expectancy Theory (SET) by Gibbon, Church, and Meck (1984), providing a comprehensive account of how temporal intervals are encoded and judged. This model posits that an internal pacemaker emits pulses at a regular rate, which are filtered through an attentional switch mechanism and later collected in an accumulator. The number of accumulated pulses serves as the basis for estimating duration: longer intervals correspond to a greater number of pulses (Gibbon et al., 1984; Buhusi & Meck, 2005). This structure allows the model to account for the influence of both attention and arousal on time perception. Higher levels of arousal accelerate pulse emission, leading to a greater number of accumulated pulses and consequently an overestimation of duration (Droit-Volet & Gil, 2009; Buhusi & Meck, 2005). This mechanism provides a coherent explanation for the temporal distortions frequently observed in emotionally charged or high-arousal contexts. The model was further developed within Scalar Expectancy Theory (SET), which introduced the concept of scalar variability: the variability of temporal judgments increases proportionally with the length of the interval (Gibbon et al., 1984; Grondin, 2010). This property has been widely supported by empirical findings and is considered a defining feature of human timing behavior. Despite its explanatory value, the pacemaker–accumulator model has been often criticized, particularly for its reliance on hypothetical constructs and its limited neurophysiological grounding. Contemporary approaches have proposed that time perception emerges from distributed neural dynamics and state-dependent processing rather than from a centralized internal clock (Buonomano & Maass, 2009; Buhusi & Meck, 2005). Nonetheless, the pacemaker-accumulator model remains a fundamental reference point in the study of temporal cognition, particularly for its ability to integrate the role of attention, memory, and arousal into a cohesive framework.

1.2 Main theoretical accounts and experimental paradigms

Time perception research has long been driven by the observation that subjective duration does not faithfully mirror objective time. Classic psychophysical findings have revealed systematic biases in this regard: for shorter intervals, perceived duration tends to expand, whereas for longer ones it tends to compress, a pattern formalized in Vierordt's law (1868; see also Zakay & Block, 1997). A central question in the psychology of timing concerns how the mind converts physical time into subjective experience. Early accounts emphasized an internal "clock-like" mechanism operating on a continuously updated representation, where errors increased proportionally to the interval length (Treisman, 1963; Gibbon, Church, & Meck, 1984). Contemporary perspectives, while more diverse, continue to view timing as an inferential process: observers estimate duration by relying on internal timing cues that are influenced and shaped by context, task demands, and the salience of sensory input.

The scientific study of time perception has developed through a range of experimental paradigms aimed at capturing how individuals estimate, reproduce, and discriminate temporal intervals. These paradigms have been essential in identifying the cognitive and emotional factors that shape subjective time, as well as in revealing systematic distortions in temporal experience (Grondin, 2010; Wearden, 2005). Among the most influential methods for studying time perception are those of time estimation, time reproduction, and duration discrimination. Time estimation, one of the most widely used approaches, involves asking participants to judge the duration of a stimulus or interval either verbally or numerically. This paradigm allows researchers to assess how accurately individuals can translate subjective duration into objective time units. However, performance in estimation tasks is highly variable and influenced by contextual and cognitive factors (Grondin, 2010). A closely related paradigm is that of time reproduction, where participants are first exposed to a given temporal interval and are then asked to reproduce it, usually by pressing a button to indicate the perceived duration. This approach is particularly useful for studying internal representations of time, as it reduces reliance on explicit verbal or numerical encoding (Buhusi & Meck, 2005). Time reproduction tasks have been widely used to explore both short and long intervals, as well as the impact of attention and memory on temporal judgment. The third paradigm is that of duration discrimination, in which participants are asked to compare two or more temporal intervals and determine which one is longer. This method is frequently used in psychophysical research, as it allows for accurate measurement of temporal sensitivity and threshold levels (Ivry & Schlerf, 2008). A variation of this paradigm is the temporal bisection task, in which individuals categorize intervals as either "short" or "long" based on previously learned reference standards (Wearden, 2005). It's important to note how the specific method employed to assess time perception can influence the results obtained. For example, in a study

conducted by Mioni, Stablum, McClintock, and Grondin (2014) it was shown that different reproduction methods are not equivalent: among three variations tested, pressing once at the end of the interval, pressing to start and stop the reproduction, and maintaining continuous pressing throughout, the start-and-stop method achieved the highest accuracy, while the continuous press method generated the least variability. These findings highlight that methodological choices in reproduction tasks can significantly affect the interpretation of timing data and should therefore be carefully considered when comparing results across studies. Collectively, these paradigms have played a crucial role in shaping theoretical models of time perception, including internal clock models and Scalar Expectancy Theory (Gibbon et al., 1984). Importantly, they highlight that temporal judgments are not direct reflections of physical time but are constructed through cognitive processes that can be systematically manipulated in experimental settings.

A large body of research shows that time perception is strongly influenced by cognitive factors such as attention, working memory, and task demands. Attention, for instance, plays a central role: when attention is directed toward time, durations tend to be overestimated, whereas splitting attention typically leads to underestimation (Zakay & Block, 1996; Buhusi & Meck, 2005). Similarly, working memory contributes to the maintenance and comparison of temporal representations, particularly in tasks that require processing longer time intervals (Coull et al., 2011). Emotional processes also play a significant role in shaping our perception of time. High-arousal emotional stimuli, such as threatening or fear-inducing images, are often associated with a subjective sense of time dilation, leading individuals to overestimate durations (Droit-Volet & Meck, 2007; Angrilli et al., 1997). This effect has been often explained through the framework of internal clock models, which proposes that increased arousal speeds up the pacemaker rate, thereby resulting in a greater accumulation of temporal pulses. However, the relationship between emotion and time perception is more complex and depends on multiple factors, including the valence and intensity of the stimulus, as well as task characteristics (Droit-Volet & Gil, 2009). For example, some studies have shown that stimuli characterized by low arousal or positive valence may lead subjects to temporal underestimation, highlighting the importance of considering both arousal levels and attentional engagement.

Cognitive and emotional factors also significantly influence time perception, often leading to systematic distortions and illusions. One well-known phenomenon is the *oddball effect*, in which a novel or unexpected stimulus, appearing in a sequence of repetitive stimuli, is perceived as lasting longer than its actual duration (Tse et al., 2004). This effect is thought to result from heightened attentional engagement and increased neural processing associated with salient stimuli. Another example is the *filled-duration illusion*, in which time intervals filled with stimuli (e.g., sounds or visual events) are perceived as longer than empty intervals of the same objective duration (Thomas

& Brown, 1974). This illusion has been linked to the amount of information processed during the interval, consistent with memory-based accounts of time perception. Additionally, emotional and attentional manipulations can produce distortions in time perception such as temporal compression or expansion, depending on specific task demands and stimulus characteristics (Wittmann, 2009). These phenomena further support the idea that time perception is not a passive process but is actively constructed by the brain. Overall, temporal distortions and illusions provide valuable insights into the mechanisms underlying time perception, revealing how subjective time can deviate systematically from objective reality. By integrating findings from experimental paradigms, cognitive psychology, and affective neuroscience, researchers have gained a deeper understanding of the dynamic and context-dependent nature of temporal experiences.

1.3 Neural basis of time perception

Understanding how the brain encodes and processes temporal information has become a central question in cognitive neuroscience. As noted in previous sections, time perception is not mediated by a single sensory organ, nor does it appear to rely on a dedicated, centralized neural structure. Instead, converging evidence from neuroimaging, lesion studies, and electrophysiology suggests that temporal processing emerges from the coordinated activity of distributed brain networks, whose composition varies depending on the temporal scale and cognitive demands of the task (Buhusi & Meck, 2005; Coull & Nobre, 2008).

One of the key structures implicated in time perception is the basal ganglia, particularly in the processing of interval timing within the range of seconds to minutes. Neuroimaging studies have consistently shown robust activation of this brain structure during tasks involving duration estimation and reproduction, suggesting a central role in monitoring the passage of time (Meck, 2006; Coull et al., 2011). Additionally, the basal ganglia are closely linked to dopaminergic modulation, which has been shown to influence the speed of internal timing mechanisms (Meck, 1996; Buhusi & Meck, 2005). Specifically, increased dopamine levels are associated with faster internal clock dynamics, leading to temporal overestimation, whereas reduced dopaminergic activity is linked to temporal underestimation. This relationship is further supported by clinical evidence: patients with Parkinson's disease, which involves dopaminergic degeneration of the basal ganglia, show significant impairments in temporal discrimination and reproduction tasks (Malapani et al., 1998; Coull et al., 2011). Together, these findings point to a critical role of the dopaminergic system in modulating internal timing mechanisms, consistent with the pacemaker-accumulator framework of SET (Gibbon et al., 1984; Buhusi & Meck, 2005).

Beyond the basal ganglia, several other brain structures contribute to temporal processing depending on the scale and nature of the task. The cerebellum has been identified as a key structure in temporal processing, particularly for short intervals in the millisecond range (Ivry & Spencer, 2004; Ivry & Schlerf, 2008). It is thought to support precise temporal coordination in motor and perceptual tasks, though whether it functions as a general timing organ or is more specifically tied to sensorimotor coordination remains debated (Ivry & Keele, 1989; Grahn, 2009; Coull & Nobre, 2008). In addition to subcortical structures, several cortical areas contribute to time perception. The prefrontal cortex (PFC) plays an important role in higher-order aspects of temporal processing, including working memory for durations, attentional monitoring, and decision-making about temporal intervals (Coull et al., 2011; Lewis & Miall, 2003), while the parietal cortex has been associated with the representation and comparison of temporal magnitudes, as well as to attentional processes during timing-related tasks (Wiener, Turkeltaub, & Coslett, 2010). Furthermore, the supplementary motor area (SMA) has been reported to activate across timing tasks of different modalities, suggesting its involvement in the preparation and execution of temporally organized behavior (Lewis & Miall, 2003; Coull et al., 2011). Collectively, these regions constitute a dynamic fronto-parietal network that collaborates with subcortical structures to facilitate the cognitive regulation of timing.

More recent theoretical developments have moved away from the concept of a centralized timing mechanism, instead proposing that temporal information is encoded in the intrinsic dynamics of neural populations. The State-Dependent Network (SDN) model, proposed by Buonomano and Maass (2009), suggests that the brain encodes time through evolving patterns of neural activity across cortical circuits, rather than relying on specific timing neurons. According to this view, each moment in time corresponds to a unique state of network activity, allowing the brain to represent temporal information in a distributed and flexible manner, with different regions contributing depending on the nature of the task and the temporal scale involved. Supporting this perspective, electrophysiological studies showed that the firing patterns of neurons in areas such as the striatum and prefrontal cortex change systematically over the course of a timed interval, effectively functioning as a neural representation of elapsed time (Meck, 2006; Buhusi & Meck, 2005).

Overall, current evidence supports the view that time perception emerges from the dynamic interplay of multiple brain systems, including the basal ganglia, cerebellum, and cortical networks. This distributed architecture enables the brain for flexible and context-dependent temporal processing, integrating lower-level sensory mechanisms with higher-order cognitive functions such as attention and working memory. While the basal ganglia and dopaminergic pathways appear particularly central to interval timing, other regions such as the cerebellum, prefrontal cortex, and supplementary motor area, each make unique contributions depending on the temporal scale and task demands.

1.4 Individual and population differences in time perception

The neural systems described in the previous section show considerable variability across individuals. Increasing evidence suggests that temporal processing varies substantially as a function of age, neurodevelopmental trajectory, and neurological or psychiatric condition. Considering that brain structures such as the basal ganglia, prefrontal cortex, and cerebellum undergo significant changes throughout the lifespan and are frequently affected in clinical populations, it is perhaps unsurprising that timing abilities show marked variability among different groups. Understanding these differences not only provides valuable insights into the cognitive and neural mechanisms underlying time perception but also has important practical implications for clinical assessment and intervention.

Temporal processing undergoes significant changes from early childhood through old age. In children, the ability to estimate and reproduce temporal durations improves progressively with age, reflecting the gradual maturation of prefrontal and striatal circuits involved in attentional control and working memory (Droit-Volet, 2003), with younger children tending to overestimate shorter time intervals and showing greater variability compared to adults (Droit-Volet & Wearden, 2001). Studies using bisection tasks have demonstrated that the Weber fraction, a common index used to assess temporal sensitivity, decreases systematically from childhood to early adulthood, reflecting a progressive increase in timing precision over development (Droit-Volet, Tourret, & Wearden, 2004). In older adults, the picture is more complex, and some findings suggest a U-shaped trajectory of temporal precision across the lifespan, with young adults showing the highest timing accuracy and lowest variability, while both children and older adults display greater imprecision, though for different underlying reasons, immature attentional and memory systems in the former, and their gradual deterioration in the latter. A meta-analytic review by Block, Zakay, and Hancock (1998) confirmed this pattern, finding that compared to younger individuals, older adults show reduced accuracy and increased variability particularly for longer time intervals, reflecting age-related declines in attentional and memory resources rather than a simple slowing of the internal clock. At a more subjective level, older adults frequently report that time seems to pass more quickly with advancing age, a phenomenon documented across decades of research (Kastenbaum, 1982; Joubert, 1990), and thought to be linked to changes in the density of memorable events and the reduced novelty of experience in later life, rather than to distortions in objective interval timing per se. Neurobiologically, age-related changes in dopaminergic transmission within the basal ganglia are believed to play a significant role in deceleration of the internal clock, leading to underestimation of durations. However, this relationship is modulated and influenced by task-specific demands and individual differences in cognitive reserve (Meck, 1996; Buhusi & Meck, 2005).

Differences in time perception are not limited to typical aging but are prominently observed across a range of neurological and psychiatric conditions. Parkinson's disease represents one of the most extensively studied clinical models of timing impairment. Malapani et al. (1998) showed that in the OFF state, characterized by impaired dopaminergic transmission, patients exhibited systematic distortions in temporal reproduction (specifically shorter intervals were perceived and reproduced as longer and the longer ones as shorter) while performance was comparable to healthy controls in the ON state following administration of levodopa and apomorphine. Harrington et al. (1998) investigated the involvement of the basal ganglia and its thalamocortical connections in timing operations and showed that Parkinson's disease patients were impaired in both time perception and motor timing tasks, with impaired motor timing being specifically linked to increased variability in the internal clock rather than to variability in motor execution. Building on this, Mioni et al. (2016) explored how emotional facial expressions influence time perception in individuals with Parkinson's disease. The study revealed that the patients' ability to use emotionally relevant stimuli as temporal cues was significantly compromised compared to healthy controls, suggesting that the disease affects not only basic timing mechanisms but also their interaction with emotional processing.

Traumatic brain injury (TBI) represents another condition often associated with temporal processing disruption. Damage to prefrontal and subcortical structures, common in TBI, impairs attentional and working memory mechanisms essential for prospective timing, with deficits in time reproduction and discrimination tasks being associated with broader cognitive impairments rather than a specific dysfunction of the timing system (Mioni, Mattalia, & Stablum, 2013). The importance of specific neural structures in mediating these effects is further highlighted by lesion studies, which seem to suggest the involvement of distinct neural mechanisms in different aspects of temporal processing (Noulhiane et al., 2007).

Psychiatric disorders also show characteristic alterations in time perception: depressed patients report a subjective slowing of time while manic patients report acceleration, yet both groups overestimate longer durations in objective estimation and production tasks, suggesting a dissociation between subjective time experience and measurable timing performance (Bschor et al., 2004). Mioni et al. (2016) further showed that anxious patients under-reproduce and depressed patients over-produce temporal intervals, reflecting distinct underlying mechanisms of attentional dysfunction and reduced pacemaker pulse emission rate respectively. This research offers additional support for the pacemaker-accumulator framework in explaining timing deficits associated with psychiatric conditions. In schizophrenia, timing variability is elevated across both millisecond and several-second ranges when compared to healthy controls, suggesting a fundamental and pervasive timing deficit (Carroll et al., 2009).

Finally, timing deficits have also been documented in neurodevelopmental disorders. Children with ADHD show significant impairments in time reproduction and prospective memory tasks, with timing difficulties being associated with deficits in working memory and a broad pattern of executive functions including time-monitoring behavior (Barkley et al., 1997; Mioni et al., 2017; Toplak, Dockstader, & Tannock, 2006).

Collectively, findings from both typical and atypical populations converge on the view that time perception is a highly sensitive index of the integrity of distributed neural and cognitive systems. Variability in temporal processing across the lifespan and across clinical conditions reflects the degree to which key structures, including the basal ganglia, prefrontal cortex, and cerebellum, and their associated neuromodulatory systems are functioning optimally. These population-level differences provide a valuable framework for interpreting experimental findings and highlight the importance of considering individual and clinical variability in the study of temporal cognition.

CHAPTER 2: TIME PERCEPTION AND SOCIAL STIMULI: FROM THE CONCEPT OF SOCIAL CUES TO BIOLOGICAL MOTION

2.1 Social cues in human communication: an overview

Human interaction largely depends on the exchange of social cues, signals that convey information about the intentions, emotions, and mental states of others. These cues are essential for navigating the social world, coordinating behavior, and establishing shared understanding. According to Frith and Frith (2007), social signals are non-verbal cues that allow individuals to learn and connect with others, contributing to the formation of a shared social reality. Interestingly, these signals are often emitted unconsciously by the sender while being automatically processed by the receiver, highlighting their pervasive and often implicit influence on social interactions. The ability to send and receive such signals appears to be a distinctly human trait, with evidence for higher-level social signaling emerging around 18 months of age (Frith & Frith, 2007).

Social cues encompass a broad range of signals, including body motion, eye gaze, tone of voice, and gestures, each contributing in distinct ways to the communication of social and emotional information. Among these, eye gaze stands out as particularly significant. Emery (2000) reviewed the evolutionary and neurobiological foundations of gaze processing, arguing that the eyes represent a particularly rich source of social information, conveying signals about emotional states, intentions, status, and disposition. The capacity to follow another individual's gaze, known as *gaze following*, is thought to be hardwired in the brain, and may be mediated by a circuit linking the superior temporal sulcus, amygdala, and orbitofrontal cortex. This ability is closely related to *joint attention*, the ability to share attention with another individual toward an external object or event, which typically emerges around the first year of life and represents a foundational milestone in social-cognitive development. Carpenter, Nagell, and Tomasello (1998) demonstrated that infants between 9 and 15 months of age progressively develop the ability to follow their mother's gaze and pointing gestures. Furthermore, the duration of joint engagement with the mother was found to predict the early emergence of gestural and linguistic communication skills. These findings highlight how sensitivity to gaze direction is not merely a perceptual competence but a cornerstone of social learning and communicative development. Moreover, eye gaze also plays an essential role in regulating broader social interactions. Kleinke (1986) reviewed research on gaze and eye contact within a functional framework, showing that gaze serves multiple social functions, including providing information, regulating interaction, expressing intimacy, and exercising social control and influence. These findings collectively emphasize the role of eye gaze as a complex social cue, with its meaning largely influenced by context and relational dynamics.

In addition to eye gaze, the voice represents another significant channel of social communication. Research by Banse and Scherer (1996) showed that specific vocal parameters such as pitch, intensity, and tempo are systematically associated with different emotional states. Listeners successfully recognized the vocal expressions of fourteen emotions, performed by professional actors, with accuracy above chance levels. These results suggest that vocal tone not only reflects the intensity of emotional states but also conveys qualitative information about their valence, establishing it as a highly valuable and informative social cue in everyday communication.

Body motion and gestures constitute another important category of social cues. Kendon (2004) conducted an in-depth examination of gestures, describing them as a form of visible bodily action that is closely tied to the activity of speaking. His analysis of everyday conversations revealed that gestures play a varied and central role in the construction of spoken utterances, enhancing and complementing verbal communication in ways that are deeply influenced by specific cultural and linguistic context. More broadly, body motion, including posture, movement, and the dynamic configuration of the body in space, conveys extensive social information that observers quickly and often automatically process and interpret.

While the ability to perceive and interpret social cues is a fundamental aspect of human cognition, it is important to note that this capacity is not uniform across individuals. Clinical populations often show marked alterations in social cue processing, providing valuable insight into the mechanisms that underlie typical social perception. Autism spectrum disorder represents perhaps the most extensively studied example of atypical social cue processing. Klin et al. (2002) used eye-tracking to measure visual fixation patterns in adolescents with autism while viewing social scenes, finding that individuals with autism devoted significantly less time to the eye region of faces and more time to mouths, bodies, and objects compared to matched controls. Reduced fixation on the eye region was the strongest predictor of autism, while fixation on mouths and objects was significantly correlated with social functioning outcomes, suggesting that atypical gaze processing in autism is not merely a perceptual anomaly but has direct consequences for social competence in everyday life. Similarly, schizophrenia is associated with a broad pattern of impairments across multiple domains of social cognition, including difficulties in identifying emotions and inferring others' thoughts and feeling, all of which interfere substantially with daily social functioning (Green, Horan, & Lee, 2015). Even in depression, where social cognitive impairments are subtler, characteristic alterations in the processing of social cues have been documented. Surguladze et al. (2004) found that patients with major depressive disorder showed subtle impairments in facial expression recognition, specifically displaying a tendency to misinterpret mildly happy expressions as something other than happy. The authors suggest that this difficulty in accurately detecting subtle positive signals in others' faces may

underlie the impaired interpersonal functioning frequently observed in depression. Across these conditions, a common theme emerges: disruptions in the ability to accurately perceive and interpret social cues, whether affecting gaze, emotional expression, or broader social cognition, have wide-ranging consequences for social functioning, underscoring the central role that social cue processing plays in everyday human interaction.

The evidence reviewed above points to social cue processing as a complex and essential component of human interaction and communication, relying on a distributed network of brain regions associated with social cognition, such as the superior temporal sulcus, amygdala, and prefrontal cortex (Frith & Frith, 2007; Emery, 2000). As discussed in the following sections, these social signals do not only shape interpersonal communication but also influence fundamental cognitive processes, including the perception of time.

2.2 The relationship between time perception and social cues

As discussed in the previous chapter, time perception is not a passive recording of objective duration but is actively influenced by internal states and contextual factors. Among these influences, emotional arousal has been shown to play a particularly significant role. A paper by Droit-Volet and Meck (2007) offered a comprehensive explanation of how emotions can alter our sense of time. Their research showed that the interaction between emotional arousal and valence can lead to variations in attentional time-sharing and clock speed, as described within the framework of internal clock models. Their work emphasizes the strong connection between affective states and temporal processing, suggesting that stimuli with intense social and emotional content can significantly influence our judgments of duration. Supporting this idea, a large body of research demonstrates that social stimuli, and in particular emotionally expressive faces, are highly effective in eliciting emotional responses. Such stimuli have been systematically studied and analyzed for their notable influence on time perception.

Droit-Volet, Brunot, and Niedenthal (2004) explored how emotional faces influence the perception of time using a temporal bisection task. Participants were first trained on short and long standard durations and were then presented with faces expressing anger, happiness, and sadness, as well as neutral faces. The results showed that the duration of emotional faces was systematically overestimated compared to neutral ones, with the bisection point shifting toward shorter values for all emotional expressions. Consistent with arousal-based models of time perception, the magnitude of temporal overestimation increased with interval duration, suggesting that emotional faces accelerate the speed of the internal clock's pacemaker. These findings stress that the social and

emotional aspects of a stimulus actively influence and shape the timing system, rather than acting only as contextual factors.

However, the relationship between social stimuli and time perception is not exclusively driven by arousal. A study by Lui, Penney, and Schirmer (2011) challenged the validity of the internal clock speed account by showing that emotional stimuli can also reduce temporal estimates. Using a temporal discrimination paradigm in which task-irrelevant emotional pictures were presented between two stimuli of varying durations, they found that participants were more likely to judge the second stimulus as shorter when the intermediate image was emotional rather than neutral. This effect persisted across different stimulus modalities and irrespective of the emotional valence of the images and was also replicated in a temporal reproduction paradigm. These findings suggest that attentional mechanisms, rather than internal clock speed alone, may play a significant role in how emotional stimuli influence time perception, pointing to a more complex relationship between social and emotional content and temporal processing.

As stated before, eye gaze stands out among social cues for its significant role in modulating time perception. The ability to detect and interpret gaze direction is a fundamental aspect of social cognition, present from the earliest stages of life (Farroni et al., 2002), and research suggests that this sensitivity has a direct impact on how we perceive duration. Doi and Shinohara (2009) found that the perceived duration of emotional faces is influenced by gaze direction, with direct-gazing faces being perceived as lasting longer than averted-gazing ones. This effect has been explained through arousal-based accounts. Direct eye contact has been shown to evoke greater physiological and psychological arousal compared to averted gaze, eliciting stronger autonomic responses and heightened attentional engagement (Ellsworth & Langer, 1976; Helminen et al., 2011). In line with the framework of internal clock models, this increase in arousal accelerates the pacemaker rate, resulting in a greater accumulation of temporal pulses and consequently an overestimation of duration (Droit-Volet & Meck, 2007). Consistent with this interpretation, Ren et al. (2023) provided additional evidence that gaze direction influences perceived duration, showing that direct-gazing faces are systematically judged as lasting longer than averted-gazing ones, with the strength of this effect varying as a function of the social relevance of the stimulus. Overall, these findings indicate that eye gaze direction constitutes a meaningful social dimension that systematically modulates temporal processing, likely operating through attentional and arousal-related mechanisms that reflect the broader influence of social stimuli on time perception.

The social nature of stimuli, beyond their emotional content alone, appears to constitute an independent dimension that influences temporal processing. Evidence for this comes from a range of social cue modalities beyond facial expressions. For example, emotional body postures have been

shown to influence perceived duration, with high-arousal postures, suggestive of greater movement, being judged as lasting longer than low-arousal, static ones (Nather et al., 2011). Similarly, emotionally expressive voices modulate time perception, with auditory emotional stimuli producing systematic distortions in duration judgments depending on their levels of arousal and valence (Noulhiane et al., 2007). Research on emotion perception across face, voice, and touch modalities has shown that each channel provides a distinct input and activates partially different neuroanatomical systems, each with specialized processing functions (Schirmer & Adolphs, 2017). Importantly, the integration of information from these modalities leads to the formation of multimodal and eventually amodal representations, facilitating comprehensive social appraisals. This multimodal nature of social cue processing suggests that the influence of social stimuli on time perception is unlikely to be reducible to a single mechanism. Instead, it arises from the engagement and coordinated activity of multiple partially overlapping neural systems that together shape the subjective experience of time duration.

All these findings collectively suggest that social cues have a strong and multifaceted impact on time perception, operating through both arousal-based and attentional mechanisms. Elements such as emotionally expressive face, the direction of another's gaze, and the multimodal complexity of social signals all contribute to shaping how duration is perceived and judged. These influences point to a deep connection between the social brain and the timing system, laying the groundwork for a more focused examination of biological motion as a particularly complex and naturalistic form of social stimulus.

2.3 Biological motion: definition, key features, and neural basis

The term biological motion (BM) refers to the movement patterns produced by living organisms, particularly humans, during actions such as walking, running, or gesturing. Unlike non-biological or mechanical motion, BM conveys an array of information about the identity, emotional state, and intentions of the moving individual. This makes it one of the most informationally dense and socially relevant categories of visual stimuli available to human observers. The systematic scientific study of biological motion began with Johansson’s groundbreaking work in 1973, who demonstrated that humans are remarkably sensitive to the motion patterns of other humans even when visual information is reduced to its most minimal form. By attaching small lights to the primary joints of individuals and filming their movements in the dark, Johansson showed that observers could immediately and effortlessly recognize human actions such as walking, dancing, or lifting from the resulting point-light displays (PLD). Remarkably, this recognition was achieved without any need for

form, color, or surface details. Johanssons's findings were striking in their implications, suggesting that the temporal and spatial patterns of motion alone are sufficient to convey the essence of human actions, and that the human visual system is specifically designed to extract and interpret such patterns.

Troje (2013) provided a more comprehensive and updated definition of biological motion, distinguishing between different levels of analysis at which the concept can be analyzed and understood. On a broad level, biological motion refers to any motion produced by a biological organism. At a more specific level, it refers to the motion of the human body as perceived through point-light displays or similarly simplified visual representations. Troje further emphasized that biological motion is not a unitary phenomenon but consists of multiple components, including the global configuration of the moving figure, the localized motion of individual joints, and the rhythmic timing of the movement. These distinct components can be independently manipulated and adjusted in experimental settings, allowing researchers to isolate the specific contributions of each different aspect of biological motion to perception and recognition.

The point-light display paradigm introduced by Johansson has proven to be an extraordinarily powerful tool for investigating the perception of biological motion. Studies using this paradigm have revealed that observers can extract a remarkable amount of information from point-light displays, going far beyond simple action recognition. Research has demonstrated that observers could recognize familiar individuals from point-light displays of their walking gait, even in the absence of any facial or bodily cues, suggesting that individual movement patterns carry sufficient information for personal identification (Cutting & Kozlowski, 1977). More broadly, human actions naturally convey intentions and feelings, and significant advances have been made in understanding the visual, motor, and emotional factors that influence how we perceive these actions (Blake & Shiffrar, 2007). Most individuals naturally develop these perceptual skills and rely on the integration of visual, motor, and affective processing systems, highlighting the inherently social aspect of biological motion perception.

The neural substrates underlying the perception of biological motion have been extensively investigated using neuroimaging and electrophysiological methods. A consistent finding across studies is the central involvement of the posterior superior temporal sulcus (STS), a region that appears to be specifically responsive to biological motion. Grossman et al. (2000) used fMRI to isolate brain regions uniquely activated during the observation of point-light figures, finding that activation specific to biological motion was localized within a small region on the ventral bank of the occipital extent of the STS, more consistently in the right hemisphere than in the left, regardless of the visual field in which the stimuli were presented. Additionally, a small region in the medial

cerebellum also showed activation during biological-motion viewing. These results suggest the existence of neural mechanisms specialized for the analysis and processing of BM kinematics, distinct from those involved in other forms of motion perception. Beyond motion detection, the STS is involved in the processing of a broad range of biologically relevant stimuli, including simplified displays mimicking purposeful behavior, natural images of faces and bodies, and facial movements such as eye gaze deviations and mouth movements.

These stimuli generate selective neural responses that help facilitate the interpretation of complex social cues and, through connections between STS and the limbic, frontal, and parietal systems, enable appropriate affective responses and social behavior (Puce & Perrett, 2003).

The role of the superior temporal sulcus (STS) in processing biological motion extends further to encompass the analysis of the social and intentional dimensions of observed actions. With the use of event-related fMRI, Pelphrey et al. (2004) found that the right posterior STS exhibited heightened activation in response to movements that violated contextual expectations, suggesting its involvement not only in the detection of BM, but also in the analysis of the intentions behind observed actions, making it a critical structure for social perception more broadly. These findings align with a broader view of the STS as a center for the integration of social information, including gaze direction, facial expressions, and body movements (Blake & Shiffrar, 2007).

The specialization of the human brain for biological motion processing is further highlighted by evidence from clinical populations. Frith (2001) reviewed evidence showing that individuals with autism spectrum disorder show impairments in mentalizing, the ability to attribute mental states such as desires and beliefs to oneself and others, which is supported by a circumscribed neural network linking the medial prefrontal regions with the posterior STS and temporal poles. Weaknesses or disruptions in the connectivity of this network may contribute not only to the social and communicative impairments characteristic of autism but also to difficulties in the perception and interpretation of biological motion, given the central role of the STS in both processes.

Impairments in biological motion processing have also been documented in individuals with schizophrenia. A study by Okruszek et al. (2015) investigated the ability of patients with paranoid schizophrenia to read and interpret social information from point-light displays. These displays presented participants with two individuals either engaged in a communicative interaction or acting independently. Compared to healthy controls, patients performed significantly worse in both discriminating communicative from non-communicative actions and in correctly identifying the observed actions. Interestingly, impaired performance was primarily driven by a tendency to misclassify non-communicative stimuli as communicative, a pattern consistent with theories of over-mentalizing, that is, an excessive attribution of intentionality to others' actions, in schizophrenia.

These findings suggest that the capacity to perceive and interpret biological motion is closely intertwined with broader social cognitive capacities, and that disruptions in the underlying neural systems can have significant implications for social functioning.

In summary, biological motion represents a distinct and socially relevant category of visual information, defined by its origin in the movements of living organisms and characterized by its ability to convey identity, emotion, and intention from minimal visual input. The point-light display (PLD) paradigm has been instrumental in revealing the complexities of biological motion perception, and neuroimaging studies have consistently implicated the posterior STS as the primary neural region responsible for this capacity. As explored in the following section, these properties make biological motion a particularly powerful and influential social stimulus, with important implications for temporal processing and time perception.

2.4 Biological motion as a social stimulus: implications for time perception

Attention toward social stimuli plays a fundamental role in shaping cognitive and functional development from the earliest days of life. Among social stimuli, biological motion occupies a privileged position, as it carries rich information regarding the presence, identity, and intentions of other living beings in the surrounding environment. Empirical evidence suggests that sensitivity to biological motion is not acquired through experience alone but rather reflects an innate predisposition that is already operative and relevant since the first months of life (Lunghi, Di Giorgio, Benavides-Varela & Simion, 2020). Troje and Westhoff (2006) proposed the existence of a perceptual mechanism they termed "*life detector*", which functions as a low-level visual filter specifically tuned to the characteristic locomotor movements of terrestrial animals, particularly the local motion of the feet, and sensitive to the natural direction of gravitational force. This mechanism is thought to be evolutionary ancient, shared with other species, and functional from birth, thereby allowing the detection of other living beings on the basis of local motion cues alone, without dependence on configural processing or prior visual experience. Shen et al. (2025) further elaborated on this conceptual model, reviewing evidence that biological motion enjoys a unique position in visual perception as a specialized form of animate movement. They highlighted the engagement of specific perceptual mechanisms and a dedicated cortical-subcortical network designed to process such stimuli. Local motion cues, particularly those associated with terrestrial animal foot movements, are crucial for eliciting this specificity, and emerging evidence increasingly supports the existence of an innate, evolutionarily conserved “life detector” tuned to such information across vertebrate brains.

Evidence for an early predisposition toward biological motion in human newborns is compelling. Bardi, Regolin, and Simion (2014) found that just two days after birth, babies at their first exposure to PLDs displayed a spontaneous preference for biological motion stimuli resembling the legs of a walking animal. This preference was evident when compared to displays where individual dot trajectories were locally inverted to violate the direction of gravitational force. These results suggest that humans have an inborn sensitivity to gravity-dependent motion, which supports the recognition of biological motion before any significant visual experience is gained. Furthermore, Roberti et al. (2024) observed that within hours of birth, newborns showed greater visual attention to a human figure approaching them rather than one receding, suggesting an early predisposition toward social closeness likely rooted in evolutionary pressures favoring proximity to other individuals. The social relevance of BM from early in life is further supported by evidence indicating that the direction of human biological motion influences visuo-spatial orienting mechanisms. Moreover, these mechanisms appear to be associated with a functional processing advantage observable as early as three months of age (Lunghi et al., 2020). These findings highlight how biological motion shapes attentional orienting mechanisms well before the first year of life, highlighting its fundamental role in early social and cognitive development.

The perception of biological motion is not static but develops progressively over the first years of life, reflecting an interaction between innate predispositions and experiential learning. In newborns, discrimination between biological and non-biological motion primarily relies on local motion cues, such as the gravity-dependent trajectory of the feet. (Bardi, Regolin & Simion, 2014). As development progresses, sensitivity to the global configuration of the moving figure emerges, shaped both by interactions with other agents and by maturation of the infant's motor skills. Booth, Pinto, and Bertenthal (2002) provided experimental evidence for this developmental progression, showing that 3-month-old infants responded to the absolute and relative motions within a single limb, whereas 5-month-old infants responded primarily to the relations between limbs and to the bilateral symmetry between them, suggesting a progressive shift from local to more global processing strategies over the first months of life. By the time infants reach 9 to 12 months of age, they begin to identify gender through point-light animations representing human walk motion and perhaps start forming social categories based on patterns of biological motion (Johnson, Dong, Ogren, and Senturk, 2021). Pavlova (2012) reviewed evidence showing that visual processing of biological motion is of immense value for adaptive social behavior and nonverbal communication. Individuals experiencing challenges in social cognition in their daily lives, such as individuals with autism, those born preterm, and those with genetic conditions, also exhibit difficulties in processing visual body motion. This suggests that biological motion perception could be a key indicator of social cognition, with its

underlying neural mechanisms overlapping substantially with those of broader social cognitive networks.

The social richness of biological motion has important implications for both social cognition and temporal processing.

BM conveys not only information about identity and action but also rich emotional content through the dynamics and kinematics of movement itself. Research has shown that even in its most reduced form, point-light displays, biological motion is sufficient to convey a broad range of emotional states. For instance, Dittrich et al. (1996) found that observers could reliably identify emotions such as fear, anger, grief, and joy from point-light displays of dancers with accuracy significantly above-chance levels. Moreover, this research showed that this recognition ability was disrupted when the displays were inverted, suggesting that the emotional information is carried by the dynamic structure of the movement rather than by static visual elements. Consistent with this, the emotional energy expressed by biological motion appears to be intrinsic to the kinematics of movement itself rather than being associated with the body's overall shape or configuration. Even simplified point-light displays of arm movements provide sufficient affective cues for observers to categorize actions along dimensions of activation and pleasantness, with the perceived level of emotional activation being directly linked to physical movement properties such as speed and intensity (Pollick et al., 2001). This affective dimension of biological motion is particularly relevant for time perception, given that arousal and emotional valence are known to modulate internal clock speed (Droit-Volet & Meck, 2007). Stimuli that convey high activation through their movement kinematics might alterate the pacemaker's speed rate, potentially leading to overestimation of duration, and thus aligning with what has been observed in prior studies involving emotional stimuli.

Taken together, all these findings converge on the view that biological motion, a stimulus of profound social relevance, exerts a powerful influence on temporal processing through multiple pathways and mechanisms. From the earliest stages of life, its high social salience effectively captures attention, while its affective dimension modulates arousal and influences the internal clock's pace. Furthermore, the richness of social and emotional information biological motion can provide, engages the same attentional and memory mechanisms that are known to shape duration judgments. The robust connection between biological motion perception and social cognition, documented across typical development and clinical populations, highlights the sensitivity of the timing system to the social characteristics of the stimuli it processes. Consequently, understanding how biological motion shapes time perception extends beyond perceptual psychology and touches upon fundamental aspects of social cognition and its development, emphasizing the importance of considering both the perceptual and affective properties of the stimuli involved.

CHAPTER 3: THE RESEARCH

As discussed in the previous chapters, time perception is a complex cognitive function shaped by a wide range of factors, including attention, arousal, and the nature of the stimuli being processed. Among these, social stimuli have received growing interest for their capacity to modulate subjective duration in ways that go beyond what simple physical motion can explain. A particularly important class of social stimuli is biological motion (BM), the movement patterns generated by living beings that humans are evolutionarily set to detect and interpret. As outlined in Chapter 2, BM is not merely a form of visual motion: it carries rich social information, from gender and emotion to identity and intention, and it activates dedicated neural networks even when reduced to its bare kinematic structure through point-light displays (PLDs). Despite the well-documented role of BM in capturing attention and driving social cognition, its specific relationship with time perception remains for the most part unexplored. Only one study prior to the present work directly investigated whether BM influences perceived duration (Wang & Jiang, 2012), finding that PLDs of human walkers, used in a duration discrimination task, produced a robust subjective time dilation compared to inverted biological motion sequence. However, despite the PLD walking in different directions, that study did not examine the role of walking direction of BM on time perception. A related line of research has shown that the direction of motion constitutes an important modulator of perceived duration: stimuli approaching the observer, so-called *looming stimuli*, are systematically perceived as lasting longer than stationary or receding ones, an effect attributed to their heightened ecological salience and the preparatory responses they demand (New & Scholl, 2009). This raises the question of whether the walking direction of a PLD figure might similarly influence temporal judgments, and whether facing the observer, as in the frontal condition, could produce effects analogous to those observed with looming stimuli.

Furthermore, a growing body of research suggests that the spatial orientation of stimuli interacts with temporal representations through the mental timeline. In Western cultures, this timeline conceptually maps time from left to right (Bonato et al., 2012; Ishihara et al., 2008), resulting in a space-time association and a phenomenon known as the Spatial Temporal Association of Response Codes (STEARC) effect (Ishihara et al., 2008). Several studies have provided convergent evidence for a left-to-right directional mental timeline in temporal processing: spatial attention oriented toward the left tends to compress perceived duration, while rightward attention expands it, and response times mirror this asymmetry, with faster left-hand responses for short durations and faster right-hand responses for long ones (Fabbri et al., 2012; Bonato et al., 2012; Frassinetti et al., 2009). Together, these considerations suggest that the directional information conveyed by a walking human figure could systematically influence how long that figure appears to last.

The present study was designed to address these questions by combining two lines of research: the modulation of time perception by social stimuli, and the spatial-temporal associations captured by the STEARC effect. It builds on a previous study by Lunghi, Di Giorgio, Mioni, and Micillo (submitted), which examined the influence of biological motion on time perception using a time bisection task with PLD stimuli of a human walker facing left, right, or frontally. Said study found that BM modulates time perception in adults, producing a statistically significant temporal underestimation for the frontally directed walker compared to lateral directions. The present work wants to extend those findings by decomposing the original biological motion condition into its two constituent components, a static condition, in which the PLD dots are held in the canonical posture of a walking figure without moving, and a scrambled condition, in which the dots move but with their structural coherence disrupted, with the aim of identifying which aspect of the biological motion stimulus drives the observed temporal effects. Using a time bisection task with PLD stimuli of a human walker facing left, frontally, or to the right, the study tested whether walking direction influences perceived duration and reaction times in healthy adults.

3.1 Research hypothesis

The first hypothesis concerned the effect of frontal walking direction on perceived duration. Although the PLD stimuli in the present study were stationary and therefore did not constitute true looming stimuli, the frontal condition was expected to carry greater social relevance compared to laterally directed walkers, as a figure facing the observer more directly implies social engagement and potential interaction. Drawing on evidence that socially relevant stimuli directed toward the observer, such as faces with direct eye gaze, produce time dilation effects through increased arousal and attentional engagement (Doi & Shinohara, 2009; Ellsworth & Langer, 1976), we predicted that a PLD facing centrally would elicit a temporal overestimation compared to laterally directed walkers, by virtue of its higher perceived social directedness rather than through a looming mechanism.

The second hypothesis concerned the effect of lateral walking direction (left vs. right) on time perception, specifically in relation to the mental timeline. In line with the STEARC effect (Ishihara et al., 2008) and evidence that spatial attention modulates temporal judgments (Frassinetti et al., 2009), we predicted that a PLD walking to the right would elicit temporal *overestimation*, while a PLD walking to the left would elicit temporal *underestimation*, reflecting the left-to-right directional mapping of duration. Additionally, we predicted a response compatibility effect: participants whose response keys were congruent with the mental timeline (short = left, long = right) should respond faster than those in the incongruent condition, providing further evidence for the spatial-temporal

association of response codes. Congruency was manipulated between participants, half of participants responded short = left and long = right (time-space congruency), vice versa the remain participants.

3.2 Methods

3.2.1 Participants

Out of the 82 participants who took part in the study, 40 were randomly assigned to the Static condition and 42 to the Scrambled condition.

In the Static condition there were 34 females and 6 males (M_{age} = 21.2 y, SD = 1.81). Among the participants, 7 were left-handed (all females: 3 in the L-B group, 4 in the B-L group) and 33 were right-handed. Participants were further divided into two groups, differing in response key mapping: 20 were placed in the time-space congruency condition (short = left, long = right) and 20 in the opposite condition (short = right, long = left).

All participants were unaware of the experimental conditions and hypotheses of the study. They all reported normal or corrected-to-normal vision, no neuroatypical characteristics and signed informed consent prior to participation, in line with the Declaration of Helsinki. The study received approval from the Ethics Committee of the Department of General Psychology at the University of Padova.

3.2.2 Stimuli

Stimuli consisted of JPEG images of a human figure depicted through a point-light display (PLD), computed as the average of motion-captured data from 50 men and 50 women (Troje, 2002, 2008) and represented by 11 markers placed at the main joints and head. The figure was presented in three directional conditions: facing leftward, facing rightward, and facing frontally. The dots were displayed in the canonical upright posture of a walking figure but remained stationary.

3.2.3 Procedure

All stimuli appeared as white dots on a black background (**Figure 1**). Stimulus presentation and response recording were controlled using E-Prime 2.0. Participants were seated approximately 60 cm from the screen in a dimly lit room where light intensity was held constant.

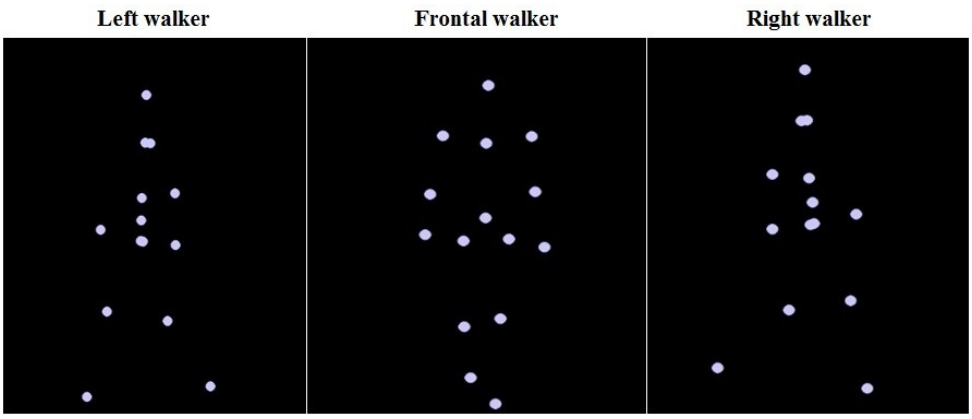

Figure 1. Example of point-light display (PLD) used in the time bisection task.

Participants completed a time bisection task (Allan & Gibbon, 1991) structured in three phases. In the learning phase, participants were first shown 10 presentations of a dot lasting the "long standard" duration (400 ms), followed by 10 presentations lasting the "short standard" duration (1600 ms), and were asked to memorize both durations. No feedback was provided. In the practice phase, participants completed a series of trials using PLD stimuli to get familiar with the task. In the experimental phase, PLD stimuli representing walking figures were presented for five probe durations (600, 900, 1200, 1500, and 1800 ms), each repeated across multiple trials. After each stimulus presentation, participants were asked to judge whether its duration was closer to the previously memorized short or long standard, regardless of walking direction, by pressing one of two response keys. Participants were required to press the key "B" ("B" = "Breve" = short) if the duration presented was closer to the short standard, or to press the key "L" ("L" = "Lungo" = long) if the duration presented was closer to the long standard.

Participants were randomly assigned to one of two groups differing in the physical placement of the response keys: the B-L group had the short-response key on the left and the long-response key on the right (consistent with the left-to-right mental timeline), while the L-B group had the reverse mapping. This manipulation allowed for the investigation of spatial-temporal response code compatibility (STEARC effect).

3.2.4 Data Analysis

For each participant in each directional condition (left, frontal, right), a psychometric function was traced by plotting the five probe durations on the x-axis and the percentage of "long" responses on the y-axis (**Figure 2**). The graph illustrates how effectively participants distinguished between intervals. The likelihood of answering "long" reveals whether participants are underestimating or overestimating the passage of time. The curve is expected to rise as the stimulus duration increases.

If the resulting curve shifts toward the left, it suggests that the duration feels longer, indicating overestimation; conversely, if it shifts to the right we have the opposite situation, meaning the duration feels shorter, indicating underestimation.

We then conducted a similar analysis, this time using reaction times (RTs) as our primary variable. For the purpose of the analysis, we focused exclusively on reaction times of extreme time intervals (600 and 1800 ms). While the previous analysis of the percentage of "long" responses provides us insight into what participants reported, examining reaction times reveals how challenging it was for them to make those decisions. Qualitatively the answer is the same as in the previous analysis, however, here we aim to determine whether certain factors, such as different conditions (e.g., B-L / L-B) or specific time intervals, influenced or facilitated participants in arriving at their responses.

Two key indexes that are essential for examining the effects of PLDs on perceived duration and analyzing temporal performance are the Bisection Point (BP) and the Weber Ratio (WR). The Bisection Point represents the probe duration at which an individual responds "short" or "long" with equal frequency. We can think of it as the boundary, or the "decision threshold" between the two perceptions. The smaller the BP value is, the earlier participants judge the stimulus as "long", suggesting an overestimation of time. Conversely, a higher bisection point indicates that longer durations are required before stimuli are classified as "long," reflecting an underestimation of time. This measure is particularly valuable because it provides an estimate of how participants subjectively perceive or categorize stimuli, moving beyond the plain description of their physical properties. The second index under analysis is the Weber Ratio, which serves as a measure of time sensitivity. It is calculated as the Standard Deviation (SD) of the psychometric function divided by the Bisection Point (BP). As a measure of perceptual sensitivity or precision, the Weber Ratio reflects how consistently individuals can differentiate between stimuli. In temporal bisection tasks, the WR specifically measures participants' ability to discriminate between "short" and "long" durations. The value is derived from the distribution of responses around the bisection point: a lower Weber Ratio indicates more precise and consistent judgments, whereas a higher Weber Ratio points to greater uncertainty and variability in responses. Thus, the WR provides insight into performance variability, with higher values indicating a greater degree of variability and inconsistency among participants' responses.

The data were analysed with BP and WR as dependent variables through two separate repeated-measures ANOVAs. The analyses considered *Direction* (left, frontal and right) as within-subject factor, while *Group* (Congruent *vs.* Incongruent) served as the between-subject factor. To investigate the effect of walking direction on response times, reaction times (RTs) from the offset of each stimulus were also analysed. RTs were entered into a repeated-measure ANOVA with *Direction* (left, frontal,

right) and *Duration* (600 ms vs 1800 ms) as within-subject factors, while *Group* (Congruent *vs.* Incongruent) as between-subject factor.

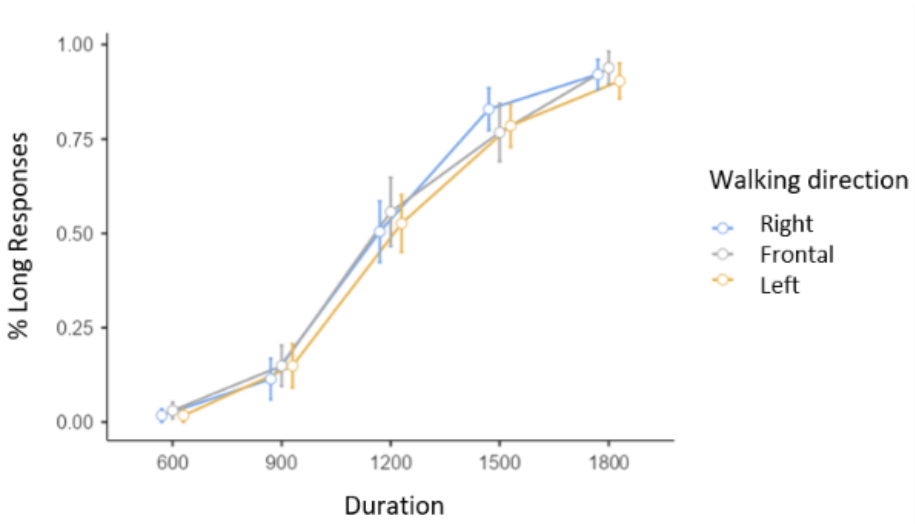

Figure 2: Proportion of "long" responses as a function of probe duration (600, 900, 1200, 1500, and 1800 ms) and walking direction (left, central, right).

3.3 Results and Discussion

3.3.1 Results

A psychometric function was traced for each participant, in each of the three experimental conditions (left, frontal, and right).

A repeated-measure ANOVA on the proportion of "long" responses revealed no significant main effect of *Direction* [$F(2,74) = 0.364$, $p = .696$], confirming that walking direction did not influence how participants categorized stimulus durations. A significant main effect of *Duration* was observed [$F(4,148) = 448.493$, $p < .001$], indicating that the proportion of "long" responses increased systematically as probe duration increased, as expected in a standard time-bisection task. No significant interaction between *Direction* and *Duration* was found [$F(8,296) = 1.138$, $p = .338$].

Analyses conducted on BP showed no significant main effect of *Direction* [$F(2,72) = 0.511$, $p = .602$] (**Figure 3**), no significant main effect of *Group* [$F(1,36) = 3.04$, $p = .090$], and no significant interaction between *Direction* and *Group* [$F(2,72) = 0.422$, $p = .657$]. These results indicate that walking direction in in the Static condition did not modulate perceived duration, and that the spatial mapping of response keys did not influence temporal judgments.

Consistently with the nature of the bisection task, reaction times were longer around the bisection point, that is, for intermediate probe durations (1200 ms), reflecting the greater ambiguity of stimuli

that fall near the boundary between "short" and "long" categories, where the decision is inherently more difficult and thus requires more time.

Figure 3: Bisection Point (ms) as a function of walking direction (left, central, right).

Analyses conducted on WR showed no significant main effect of *Direction* [F(2,72) = 1.02, p = .364] (**Figure 4**), no significant main effect of *Group* [F(1,36) = 1.55, p = .222], and no significant interaction between *Direction* and *Group* [F(2,72) = 1.21, p = .305]. These findings suggest that temporal sensitivity was not affected by walking direction or response key mapping.

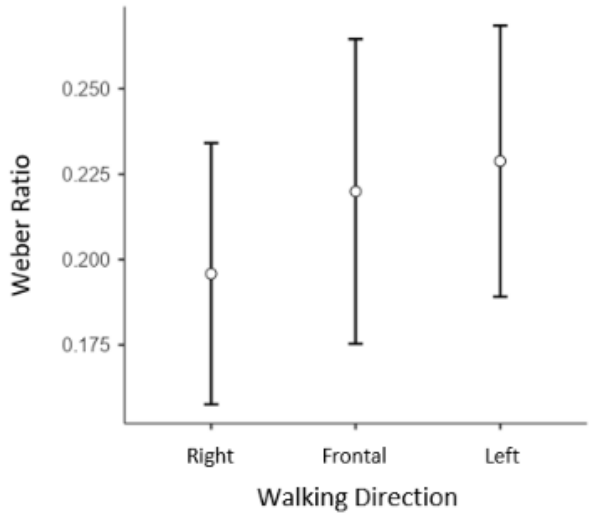

Figure 4: Weber Ratio as a function of walking direction (left, central, right).

Analyses of RTs showed no significant main effect of *Direction* [F(2,72) = 1.378, p = .259] and no significant main effect of *Group* [F(1,36) = 0.116, p = .735]. A significant main effect of *Duration* was observed [F(1,36) = 67.614, p < .001], indicating faster responses for long (1800 ms) compared to short (600 ms) intervals, consistent with a variable foreperiod effect (Niemi & Näätänen, 1981). A significant interaction between *Direction* and *Group* was found [F(2,72) = 3.587, p = .033]; however, post-hoc comparisons revealed no significant differences between any specific pair of conditions (all p > .05), meaning this interaction should be interpreted with caution. No significant interaction between *Direction* and *Duration* [F(2,72) = 0.691, p = .504], *Duration* and *Group* [F(1,36) = 0.463, p = .501] (**Figure 5**), or *Direction*, *Duration* and *Group* [F(2,72) = 0.236, p = .790] was observed.

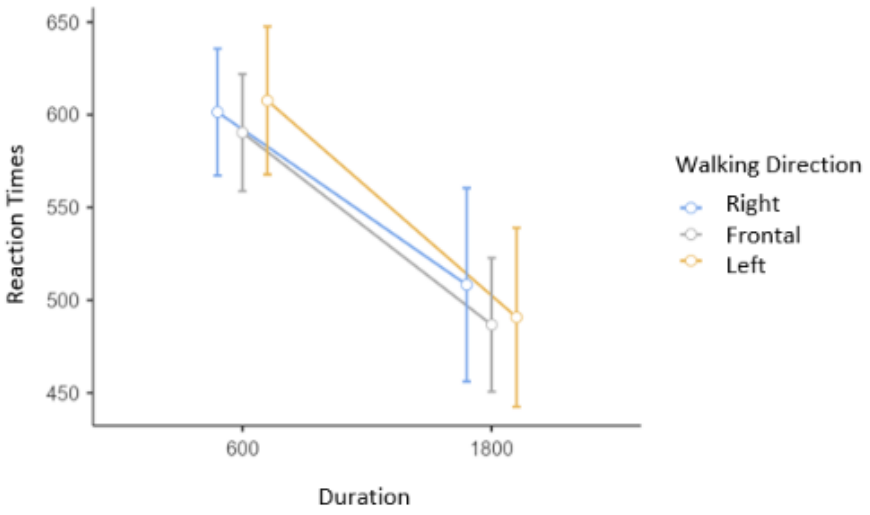

Figure 5: Reaction times (ms) as a function of probe duration (600 ms vs. 1800 ms) and walking direction (left, central, right).

3.3.2 Discussion

The present study aimed at investigating whether the static configural properties of a point-light display of a human figure, that is, the canonical upright posture of a walker without any actual motion, are sufficient to modulate time perception in adults. Specifically, we tested whether walking direction conveyed by a static PLD would influence perceived duration and whether it would elicit a spatial-temporal association of response codes (STEARC) effect. Overall, results showed no significant effect of walking direction on any of the dependent variables – BP, WR, or RT – suggesting that the static configural information alone is not sufficient to drive temporal distortions.

The absence of a significant effect of Direction on BP indicates that participants' subjective perception of duration was not influenced by the directional orientation of the static PLD. This finding stands in

contrast to the results of the original study by Lunghi et al. (submitted), in which a fully animated biological motion walker produced a statistically significant temporal underestimation for the frontally directed condition compared to lateral ones. The present null result suggests that the kinematic component of biological motion, rather than its configural structure alone, may be the critical driver of temporal distortions observed in the original study. In other words, when the dots remain stationary in a static position, the social and biological relevance of the stimulus appears to be insufficient to engage the attentional and arousal mechanisms that typically modulate time perception. This interpretation is consistent with the broader literature showing that it is the dynamic, motion-based nature of biological stimuli that makes them particularly effective in capturing attention and triggering temporal distortions (Wang & Jiang, 2012; Droit-Volet & Meck, 2007).

No significant effect of Direction on WR was observed, indicating that walking direction did not affect participants' precision in discriminating between short and long durations. The overall absence of effects on WR is in line with the pattern found in the original BM study, where temporal sensitivity was equally unaffected by walking direction.

Analyses of RTs revealed a significant main effect of Duration, with faster responses for longer (1800 ms) compared to shorter (600 ms) intervals, consistent with a variable foreperiod effect (Niemi & Näätänen, 1981). No significant main effect of Direction or Group was observed. A significant interaction between Direction and Group was found; however, post-hoc comparisons revealed no significant differences between any specific pair of conditions, meaning that this interaction should be interpreted with caution. Critically, no STEARC effect was observed, that is, the spatial mapping of response keys did not influence reaction times, indicating that the static PLD did not activate a left-to-right mental timeline representation. This null result is consistent with the original BM study, where the STEARC effect was also absent, and may reflect the stationary nature of the stimuli: the PLD figure in the present study moved neither in a lateral nor in a translational direction across the screen, which may be a necessary condition for activating a left-to-right mental timeline representation.

Overall, these findings suggest that the configural properties of a static point-light display are not sufficient to modulate time perception in adults. The absence of effects across all dependent variables points to the kinematic component of biological motion as the likely source of temporal distortion observed in the original study. These results contribute to a growing body of evidence suggesting that biological motion influences time perception not merely through its social or structural content, but through the dynamic temporal information it conveys, information that is entirely absent when the stimulus is reduced to a static posture. Future studies should directly compare static, scrambled, and

fully animated BM conditions within the same design to disentangle the relative contributions of configural and kinematic information to temporal processing.

Some limitations of the present study should be acknowledged. First, the sample size was relatively small (N = 82 total, N = 40 in the static condition), which may have limited the statistical power to detect small or moderate effects. Future studies should aim to recruit larger samples to increase the reliability and generalizability of the findings. Second, the sample was unbalanced with respect to both gender (34 females, 6 males) and handedness (33 right-handed, 7 left-handed). Since the directionality of spatial-temporal representations has been shown to vary as a function of individual and cultural factors, including reading and writing direction (Tversky et al., 1991), future studies should ensure more balanced groups with respect to handedness and cultural background to rule out potential confounding effects on the STEARC effect. Additionally, the sample consisted exclusively of university students, which represents a population with relatively limited variability in terms of age, educational background, and cognitive profile, further restricting the generalizability of the findings. Future studies should aim to include more heterogeneous samples to assess whether the present results extend across different age groups and educational backgrounds. Finally, the present thesis examined only the Static condition, leaving open the question of whether the Scrambled condition, in which low-level motion is preserved but biological structure is disrupted, would produce different patterns of temporal distortion. A direct comparison between Static, Scrambled, and fully animated biological motion conditions within the same experimental setup would be a valuable next step in trying to isolate and analyze the relative contributions of configural and kinematic information to time perception. More broadly, future research could explore whether these findings extend to other populations, such as children or clinical groups, where the processing of biological motion and temporal perception may follow different developmental trajectories. Understanding how the timing system interacts with the social aspects of biological motion across various populations could offer additional valuable insights on the broader relationship between social cognition and temporal processing.

CONCLUSIONS

The present thesis explored the relationship between time perception and biological motion, approaching the topic from both a theoretical and an empirical perspective. The first chapter highlighted time perception as a multifaceted cognitive function, influenced by attentional, memory-based, and arousal mechanisms. It also pointed out how temporal judgments differ across individuals, developmental stages, and clinical conditions. A key distinction in this context is that between prospective and retrospective timing: in prospective tasks, where participants know in advance that duration will be judged, temporal processing relies primarily on attentional monitoring, whereas retrospective tasks depend more heavily on memory-based reconstruction of elapsed time. The empirical study presented in the third chapter employed a classic time bisection task, a well-established prospective paradigm, in which participants actively track duration as stimuli unfold.

The second chapter discussed biological motion within the wider context of research on social stimuli and time perception, showing that stimuli conveying social and emotional information, such as expressive faces, direct gaze, and body postures, consistently influence perceived duration via attentional and arousal-based mechanisms. Among these, biological motion stands out as one of the most informative and relevant categories of visual stimuli, playing a particularly influential role in shaping the timing system.

The empirical study presented in the third chapter contributes to the existing literature by testing whether the configural properties of a static point-light display are sufficient to produce temporal modulation effects. Results indicated that they are not: in the absence of actual movement, the canonical static posture of a walking figure does not influence perceived duration, temporal sensitivity, or response times across any of the tested directional conditions. These findings suggest that the kinematic component of biological motion, rather than its structural configuration alone, could be the critical factor driving the temporal effects observed in the original study by Lunghi, Di Giorgio, Mioni, and Micillo (submitted). Collectively, the evidence points to a timing system that is sensitive not only to the social or structural component of stimuli but, more specifically, to their dynamic and time-varying properties, a conclusion that opens important questions for future research exploring the relationship between social cognition and temporal processing.

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