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# Examining movement as foundation for embodied player experiences and technology relationships

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ABSTRACT

Game studies and Human-Computer Interaction (HCI) research on embodied experiences and technology relationships often diverge; while game studies focus on the player–in-game character relationship, HCI emphasises sensory perception and stimulation. This paper bridges these perspectives by examining movement as fundamental to perception and interaction, exploring how movement unfolds in sequences between player(s) and technologies. The paper presents a theoretical framework that combines the neuroscientific theories of predictive processing and active inference with phenomenology to understand perception as a subjective experience along with its underlying neurobiological processes. Complemented by an autoethnographic inquiry in which the primary author played seven games over three years, we apply the theoretical framework to analyse how movement drives embodied experiences. Our findings reveal that the composition of movement sequences is a key mechanism for embodied player experiences and technology relationships. Furthermore, the study identifies four dynamics in the sequential movement compositions that shape the qualities of experience. By foregrounding movement as central to connecting players and avatars in sensory engagement, we provide a unified perspective that benefits researchers and designers across the fields of game studies and HCI.

## 1. Introduction

The significance of the body in understanding interactive technologies is widely recognised by researchers in human-computer interaction (HCI) (Dourish, 2001; Höök, 2018; Svanæs, 2013) and game studies (Calleja, 2011; Farrow and Iacovides, 2014; Klevjer, 2006). While game studies have focused on the embodied relationship between the player and the in-game character (Klevjer, 2006; Martin, 2012; O'Brien, 2018), HCI literature has focused more on sensory perception and bodily input (Höök, 2018; Loke and Schiphorst, 2018; Svanæs, 2013). While these perspectives provide essential insights into understanding embodied experiences and technology relationships, they rarely converge. This paper proposes movement as a foundational phenomenon that converges these perspectives by driving embodied player experiences and shaping player–character relationships. While the existing literature increasingly focuses on the role of movement in player experiences (Bianchi-Berthouze, 2013; Ichino and Nao, 2018; Isbister, 2016; Isbister et al., 2011; Wang, 2021), much of the existing research primarily views movement as a physical activity (Wang, 2021), an aesthetic (Höök, 2018), or a motivational tool (Buruk and Özcan, 2018; Isbister, 2016) for interaction. Drawing on phenomenology (Sheets-Johnstone, 1990, 2003, 2013; Zahavi, 2014) and neuroscience (Clark, 2016; Hohwy, 2020; Parr et al., 2022), empirically grounded in a retrospective, autoethnographic inquiry (Chang, 2008; Ellis, 2004; Ellis et al., 2011), we argue that movement underpins perception, action, and meaning-making in play. By exploring movement as the foundation of embodied experiences, we examine how experiences emerge and are shaped through movement. Particularly, we examine how bodily movement serves as an organising principle in interactive systems and contribute a framework of movement sequences as experiential structures that link internal states, bodily actions, and technologies into actionable formations. We assert that without movement, there is neither action nor interaction; embodied player experiences and technology relationships emerge within movement.

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Based on this theoretical framework, we address the following research question:

- What is the role of movement for embodied player experiences and technology relationships during play?

We focus on embodied play experiences as an autotelic activity (Apter, 1991; Csikszentmihalyi, 1975), allowing us to examine movement and its role in player-technology relationships without any external purposes (Matjeka and Mueller, 2020; Nippert-Eng, 2005). Based on this reasoning, we believe that play, as an autotelic activity, provides a more unconstrianed and intrinsically motivated context for studying subjective experiences, sensory engagement, and embodied interactions.

Our study offers a framework for understanding how embodied player experiences are structured through co-constructed movement sequences that incorporate technology. Using this framework, we identify four dynamics that influence the composition of movement sequences and, in turn, the embodied player experience and the relationships between technology and the player.

As such, this paper offers three main contributions:

- A theoretical integration of phenomenology, predictive processing, and active inference that reframes embodied experiences in interactive systems as a dynamic process emerging through movement.
- A conceptual framework of movement sequences as an organising structure for embodied player experiences and technology relationships, articulated through four perceptual dynamics that shape interaction and bodily incorporation.
- A model of bodily technology integration based on the human–computer action-perception cycle, providing a neurobiologically and experientially grounded account of how interactive technologies are incorporated through movement.

These contributions are particularly relevant to HCI and game design researchers and designers interested in embodied interaction and player-technology relationships.

The paper continues as follows: We first review related work on embodied experiences and the relationships between players and their in-game characters. We then introduce our theoretical framework, present the seven games in our empirical study, and explain our methodology. We conclude by outlining our findings, addressing the research question, discussing the study's broader implications, and reflecting on the study's limitations and future research directions.

## 2. Related work

While research in the field of embodiment and HCI has introduced terms such as embodied interaction (Dourish, 2001), embodied perception (Svanæs, 2013), embodied core mechanics (Segura, 2016), ways of being embodied (Farrow and Iacovides, 2014; Gee, 2008), and embodied being in the world (van Dijk and Hummels, 2017), game studies have emphasised how the player-technology relationship, i.e., the interplay between the player's physical body and their in-game character (Gee, 2008; Keogh, 2018; Klevjer, 2006; Martin, 2012; O'Brien, 2018), is grounded in the players' embodied experiences. This focus has led to theories surrounding natural versus vicarious embodiment (Klevjer, 2006), the surrogate body (Gee, 2008; Spiel and Gerling, 2019), and being incorporeal (O'Brien, 2018). More broadly, debates about embodiment have questioned whether we should understand embodiment as a counterpart of being not-embodied (Höök et al., 2016; Segura, 2016) or as a state of being (van Dijk and Hummels, 2017). Nonetheless, these discussions have converged into a consensus that we cannot be "disembodied" (Höök, 2018; Höök et al., 2016; Segura, 2016; van Dijk and Hummels, 2017). Building on this consensus, we first examine the presentation of embodied player-in-game character relationships in game studies.

### 2.1. Embodiment in game studies

Within game studies, several studies have investigated the perceptual connection between the player and their in-game character. For instance, Yee and Bailenson (2007) demonstrated how the appearance of the in-game character affects the player's perception of their body and behaviours. The authors highlight how players adopt the attitudes of their in-game character and the psychological and social effects it has.

Drawing on phenomenology, Martin (2012) argued that the player's relation to their in-game character is twofold; it serves as a means for both action and perception. Martin (2012) coupled Heidegger's (1996) tool phenomenology with theories explaining how an audience empathises with, e.g., a dance performer (Foster, 2011). O'Brien (2018) described the player-in-game character relationship as present versus absent, where the present in-game character is visually represented by an image, and the absent constitutes an 'incorporeal presence'.

Building on Voss' (2013; 2011) theory regarding cinematic experiences, Spiel and Gerling (2019) propose a theory of the in-game character as the player's surrogate body; a metaphorical body that emerges from the active connection between the in-game character and the player. Several years before this, Klevjer (2006) introduced the notion of the in-game character as constituting the player's vicarious embodiment. Concurrent with this development, Gee (2008) described the in-game character as the player's surrogate body. Across all three perspectives, the in-game character serves as the player's virtual proxy, acting on their behalf in the game world. While these theories each explain the player's embodied experience and relationship with technology, they also highlight the division between the physical player and the virtual in-game character.

In contrast to the division between the virtual and physical domains, Giddings and Kennedy (2008) introduced a holistic view of the player-in-game character connection as a cybernetic circuit. The authors characterised the player-in-game character relationship as a mutually constituted one, where the in-game characters and players are parts of a cybernetic circuit, including the game system and elements, each possessing their own agency. In line with Giddings and Kennedy's (2008) view that the in-game character has agency, Miller (2012) and Gee (2008) highlighted that the virtual in-game character exhibits its own behaviour that is - or should be - connected to the player's skill set. These theories challenge the boundaries between the player and their in-game character by indicating how they share skills.

To summarise, game scholars often focus on embodied player experiences as closely tied to in-game characters. For our investigation, we note that only Spiel and Gerling (2019) explicitly propose movement (as action) as essential within this constellation. As Miller (2012) and Gee (2008) focus on the player's skills as the connection between the player and in-game character. The perspective presented in this paper, however, is most closely aligned with Giddings and Kennedy's (2008) framing of the player and technologies as forming a circuit of equal importance.

### 2.2. Embodied experiences and technology relationships in HCI

Within HCI, Eriksson et al. (2019) have explored the relationship between a human and technology, specifically how two individual bodies, a human and a drone, mutually affect each other. The study (Eriksson et al., 2019) presented the idea that technology can be experienced and exert agency as an 'other', which contrasts with many other studies that focus on how humans merge with technology to create augmented embodied experiences. For instance, Loke and Robertson (2013) provided an account of the human-technology relationship from the perspective that the two can merge into extended bodily experiences, introducing the design methodology 'moving and making strange'. Additionally, Svanæs (2013) has emphasised how humans and technology merge through embodied perception, while Höök (2018) has introduced somaesthetic design, emphasizing the bodily aesthetic dimension of human-technology interaction. Our study takes a different approach by examining how the experiential merging of humans and technologies also positions technologies as perceived 'others'. We argue this difference experientially lies in how movements are employed and perceived.

### 2.3. Movement in HCI studies on games

Contrary to game studies, player's physical movement has been more frequently linked to embodied experiences within HCI studies. Here, scholars have examined how movement in embodied player experiences can work to increase player engagement, motivation and skill acquisition (Bianchi and Savardi, 2008; Bianchi-Berthouze, 2013; Isbister, 2016; Isbister et al., 2011; Mueller and Isbister, 2014). For example, Bianchi-Berthouze et al. (2013) explored the role of the player's movement compared to their engagement level in a game. They concluded that more movement could lead to higher player engagement and a greater sense of presence in the game. While their focus was principally measuring the players' levels of movement, they also introduced movement as experience by mentioning how the players adapted their movement behaviour to "get in the role" of being a guitarist, i.e., movement-based identity play (Eichberg, 2016).

Following Bianchi-Berthouze et al.'s (2013) study, Isbister et al. (2011) raised a similar question: Is more movement better? They compared levels of movement variation (low, medium, high) in three movement-based games with self-reported perceptions of energy level, fun, frustration, and happiness, and found correlations between levels of movement variations, frustration, and perceived energy levels. However, there was no indication of correlations between more movement and more fun or happiness (Isbister et al., 2011). The authors concluded that the subjective play experience is independent of measurable physical activity levels.

In addition, Isbister (2016) also examined movement in game experiences in her book, *How Games Move Us: Emotion by Design*, and refers to movement as "contagious", similar to how Yee and Bailenson (2007) explained that players take on the attitudes of their in-game characters. Based on this observation, Isbister (2016) explained how designers can trigger player emotions by adding movement as a mechanic. As such, Bianchi-Berthouze (2013), Isbister et al. (2011), and Isbister (2016) emphasised an instrumental view of movement as a material that designers can measure or add to increase player engagement or motivation.

Other researchers emphasised how the mechanics' design can influence the players' movements in various ways. Mueller and Isbister (2014) examined movement to advance game design. They presented a range of mechanics, for instance, mapping body parts between the player and their in-game character. In contrast, Matjeka et al. (2021; 2022) presented the restraints and paraphernalia mechanics emphasising designing for the player's movement possibility space. Together, these studies highlight the importance of paying attention to how movement unfolds in various ways during gameplay and how to design for these possibilities effectively in game design.

### 2.4. Predictive processing and active inference in interaction design

Applying the Predictive Processing (Clark, 2016; Hohwy, 2020) and Active Inference (Friston, 2010; Parr et al., 2022) frameworks to HCI and game design research is a relatively new trend. This field applies computational neuroscience models to understand user interaction and inform adaptive system design. For instance, Murray-Smith et al. (2024) propose active inference as a framework for modelling human-computer interaction, offering tools for designing adaptive, sensor-based systems. Vertegaal et al. (2025) introduce "Interactive Inference," a neuromorphic theory applying active inference principles to HCI to predict user actions and improve interface design. Schoeller et al. (2021) demonstrate how active inference can model trust in human-robot interaction, providing a basis for designing systems that align with human expectations. These works are mainly technical and theoretical. While these frameworks are gaining traction in interaction design, they have yet to be operationalised in participatory methods, particularly with neurodivergent users.

Although active inference applications in HCI remain emergent (Murray-Smith et al., 2024; Vertegaal et al., 2025), combination of related frameworks with phenomenology is being actively explored. This approach recognises that while they (Clark, 2016; Hohwy, 2020; Parr et al., 2022) offer neurological and computational explanations of bodily perception, lived subjective experiences remain phenomenological. Some HCI studies have followed this trend to highlight its potential for creating computational models for enhancing user experiences (Bogotá and Djebbara, 2023; Murray-Smith et al., 2024). However, these insights remain largely underexplored in HCI. In particular, they have not been operationalised in understanding embodied experiences and player-technology relationships. This paper sets out to do such an investigation.

## 3. Theoretical background

While we have so far reviewed related work on designing digitally embodied experiences and the player-in-game character relationship, this section focuses on the connection between movement and bodily perception. These are central themes in our understanding of the digitally embodied experience and the emergence of the player-in-game character connection.

### 3.1. Bodily perception, as explained in the predictive processing and active inference frameworks

According to the theories of predictive processing and active inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022), movement drives perception and our understanding of, and self-awareness in, the world (Clark, 2016; Friston, 2010). Predictive processing theory (Clark, 2016; Friston, 2010) views perception as the brain's inferences from a dynamic process, where the brain continuously generates predictions to anticipate sensory input rather than passively receiving and processing sensory information. Active inference considers movement as integral to this process (Parr et al., 2022).

#### 3.1.1. Predictive processing

The predictive processing theory (Clark, 2016; Friston, 2010) explains how the brain makes inferences by predicting potential perceptions based on current models and verifying them using bottom-up information from incoming sensory signals. When the predictions do not align with the sensory input, prediction errors arise. To address and generally minimise these errors or discrepancies, the brain evaluates them according to a hierarchy of significance. Significant errors prompt the brain to update its models, whereas less significant errors are discarded as mere noise. This dynamic interplay between top-down predictions and bottom-up sensory signals ensures a stable, coherent inference of the world while being able to adapt to unfamiliar environments and situations; movement is the motor for this process (Parr et al., 2022).

#### 3.1.2. Active inference

According to the active inference (Friston, 2010; Parr et al., 2022) theory, the brain updates its predictions through movement by modulating bodily actions to align sensory input with expectations. In other words, the body interacts with the world to adjust sensory input to match these predictions and reduce prediction errors (Hohwy, 2020). For example, our need to minimise prediction errors drives us to investigate things we do not understand, such as when we wish to see what is underneath or behind an object. Moreover, this ability to predict perception also underpins the pleasure we expect, for instance, from eating our favourite cake or playing a game. From this perspective, movement sustains the alignment between internal bodily states and external environmental cues. Our experience of the world is multimodal, depending on the interplay between internal and external states, as a balance between interoceptive (e.g., heart rate, hunger, and pain), exteroceptive (e.g., vision, hearing, and touch), and proprioceptive (body location and movement) inferences (Clark, 2016). Movement is integral to these inferences (Friston, 2010; Parr et al., 2022); the predictive brain integrates interoceptive, exteroceptive, and proprioceptive inferences to make sense of the world (Clark, 2016). However, to stabilise the experience of the world as consistent and cohesive, the brain balances these inferences by suppressing some and enhancing others (Clark, 2016).

### 3.1.3. Interoceptive inferences

Interoception, the brain's perception of internal bodily states (Craig, 2002), is not static but dynamically regulated through movement (Clark, 2016). Movements such as breathing, postural adjustments, and even subtle gestures modulate interoceptive feedback, ensuring the continuity of bodily self-awareness. When interoceptive predictions become imprecise or fail to update correctly due to disrupted movement, individuals may experience a sense of alienation from their bodily sensations (Seth, 2013).

### 3.1.4. Exteroceptive inferences

Exteroception, or the processing of external sensory stimuli (vision, touch, audition), is directly influenced by movement. Active movement enhances environmental integration (Noë, 2006), allowing individuals to establish a sensorimotor loop between bodily actions and exteroceptive perceptions thereby creating exteroceptive models (Pezzulo et al., 2015). Clark (Clark, 2016) argues that a stable exteroceptive model requires constant recalibration through movement, ensuring that sensory input from the world aligns with internal predictions.

### 3.1.5. Proprioceptive inferences

While proprioception – the sense of body position and movement – forms the foundation for self-location, allowing individuals to track their movements relative to the environment (Clark, 2016), it is often an overlooked aspect of the experience of presence. Nevertheless, studies such as the rubber hand illusion (RHI) (Botvinick and Cohen, 1998) and VR studies on bodily awareness (Suzuki et al., 2013) demonstrate how manipulating proprioceptive, exteroceptive, and interoceptive predictions can disrupt the body's inferences about itself and the world.

### 3.1.6. Balancing inferences to establish coherent experiences

The brain balances interoceptive, exteroceptive, and proprioceptive inferences to create stable, coherent, and meaningful experiences of the world. To achieve this, some inferences are assigned less significance while others are prioritised. In the rubber hand illusion (RHI) experiment (Botvinick and Cohen, 1998), the subject's proprioceptive inference about the location of their physical hand is assigned less significance, allowing them to infer that the rubber hand belongs to them. At the same time, precedence is given to the exteroceptive inference, driven by visual and tactile inputs from the displaced rubber hand. This adjustment in priority between exteroceptive and proprioceptive inferences leads the subject's brain to predict that the rubber hand is theirs (Clark, 2016). Other related studies have suggested that the hand does not even need to resemble a hand to induce a similar illusion. Cardinali et al. (2021) conducted a similar experiment, replacing the hand with a "toolish" device in the form of a metal "grapper," and obtained results consistent with the RHI (Botvinick and Cohen, 1998) study.

Suzuki et al. (2013) employed virtual reality (VR) to explore the connection between interoceptive, exteroceptive, and proprioceptive inferences about the feeling of bodily presence in the virtual world. By visualising the pulse of a virtual hand in synchrony or out of sync with the subject's heartbeat, the researchers discovered that synchrony enhanced the subject's bodily connection to the virtual in-game hand. This experiment indicates how suppressing proprioceptive inference while aligning interoceptive and exteroceptive inferences can lead to a meaningful experience of inhabiting the virtual world. The subject inferred a bodily presence in the virtual space by suppressing the perceived location of their physical hand and aligning interoceptive heartbeat and exteroceptive inferences with the visualised pulse of the virtual hand. These findings demonstrate how the connection between the physical subject and the virtual game character emerges from the interplay of interoceptive, exteroceptive, and proprioceptive inferences, as described by the predictive processing and active inference frameworks (Friston, 2010; Hohwy, 2020; Parr et al., 2022; Pezzulo et al., 2015).

### 3.1.7. Differences in predictive strategies

As reviewed above, bodily perception arises from balancing interoceptive, exteroceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), each contributing uniquely to our interaction with the world. The brain continuously generates expectations and adjusts movements to minimise prediction errors, shaping our assumptions about ourselves and our environment (Clark, 2016). In doing so, the brain employs a predictive strategy in how it weighs some information as more significant than other. As such, the brain can employ different prediction strategies; for instance, it can weigh bottom-up information (sensory information) more heavily than top-down predictions and vice versa. When it gives more weight to bottom-up information, the person will experience heightened sensory perception, as is seen in, for instance, autism (Lawson et al., 2014; S. Van De Cruys et al., 2014).

Within the predictive processing and active inference frameworks (Clark, 2016; Hohwy, 2020; Parr et al., 2022), people may differ in how they generate, update, and weigh predictions about the world. (Clark, 2016; Lawson et al., 2014a, 2014b; Van De Cruys et al., 2013, 2014). These differences in prediction strategies can give rise to distinct perceptual styles, such as heightened sensitivity to sensory input, a stronger focus on detail, or enhanced pattern recognition. Such variations in predictive strategy are relevant to HCI and game design, because they shape how individuals engage with and interpret embodied interaction. Understanding these diverse experiential orientations – what some have termed embodied epistemologies (Bruineberg, 2017; S. Lawson et al., 2016; Van De Cruys et al., 2014) – can help researchers uncover aspects of player experience that might otherwise be overlooked (Dwyer, 2022; Nerenberg, 2020).

### 3.1.8. Active inference and Norman's "gulfs of execution and evaluation"

Our use of the active inference understanding of action and perception as a continuous, cyclic structure (Clark, 2016; Hohwy, 2020; Parr et al., 2022) builds on, but differs from, earlier cognitive models in HCI, most notably Norman's (Norman, 1987) "gulfs of execution and evaluation." Norman's model conceptualises the user interface as a bridge across two gaps: the gulf of execution (the difficulty in translating intention into action) and the gulf of evaluation (the challenge in interpreting system feedback). While this model offers an influential cognitive account of user interaction, our framing – grounded in predictive processing and active inference – reframes interaction as a continuous, embodied coupling between perception and action. Instead of viewing intention, action, and evaluation as separate steps, we adopt a neurophenomenological perspective in which sensorimotor predictions, bodily movements, and ongoing feedback form a dynamic loop. This shift fosters a more situated, movement-based understanding of interaction, particularly in immersive or embodied designs where perception is influenced not only by cognition but also by bodily presence and sensorimotor engagement.

The subsequent section examines the role of movement in embodied experiences from a phenomenological perspective. This suggests that movement is not merely a mechanical response but rather a pre-reflective, embodied negotiation of meaning between the subject, the world, and other subjects.

### 3.2. Movement as the roots of thinking

Following Sheets-Johnstone (2003; 2013), movement is our mother tongue, and we think and conceptualise the world in and through movement. This includes basic concepts such as near/far, high/low, soft/hard, and complex concepts, such as language (Sheets-Johnstone, 1990). By asserting that language evolves in movement, Sheets-Johnstone (1990; 2003; 2013) further coupled movement with thinking. The predictive processing and active inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022) frameworks, as explained in the previous section, further emphasise this connection. As Sheets-Johnstone (2003; 2013) also indicates, it is inherent to assign meaning to movement. For instance, we assign meaning to the cues we exchange when communicating through speech, gestures or, for example, the drum patterns in African drum language. We assign meanings based on conceptions of acquired movement patterns and variations: A concept that Sheets-Johnstone (1981; 2003; 2013) called movement sequences.

#### 3.2.1. Movement sequences and "I cans"

According to Sheets-Johnstone (1990), we conceptualise movement patterns, such as walking and speaking, from sequences of various movements that form a meaningful whole. We conceptualise sequences as a pattern when they create a meaningful whole, which Sheets-Johnstone (1990) further explains as our 'I can' expanding Husserl's (1982) concept of the same. An 'I can' refers to the actionable meaning of the sequence, such as walking and speaking (Husserl, 1982; Sheets-Johnstone, 1990). For example, when walking, we do not perceive this 'I can' as different leg movements and sensory stimuli but connect these movements into a meaningful sequence that we conceptualise as walking. Likewise, when we speak, we do not think about how to produce the sounds, i.e., the movements that form the words. Instead, we consider the meaning we convey. As such, we pre-reflectively distinguish each 'I can' by their unique sequences of movements (Husserl, 1982; Sheets-Johnstone, 1990) and how they form an indissoluble whole (Sheets-Johnstone, 1990) and conceptualise them as meaningful patterns, our 'I can's' integrated into our movement repertoire as readily available skills (Husserl, 1982; Sheets-Johnstone, 1990).

Sheets-Johnstone (1981; 2003; 2013) further elaborates on how combinations of movement sequences lead to distinct experiences "*in which all movements blend into an ongoing kinetic happening; a singular kinetic density evolves*" (p. 34) (Sheets-Johnstone, 2009). Sheets-Johnstone (2014) develops these ideas to understand bodily experiences as synergies of movement sequences. As we assign meaning to movement sequences through their unique combinations, we also attribute meaning to combinations of sequences as they, in synergy, form distinct experiences (Sheets-Johnstone, 2014). For instance, the experience of playing football is shaped by a series of conceptualised movement sequences (Sheets-Johnstone, 1981, 2003, 2013) such as running, kicking the ball, defending the goal, and integrating these patterns into strategies and ad hoc combinations. Thus, we delineate experiences based on their distinctive combinations of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and how they create an indissoluble whole (Sheets-Johnstone, 1990).

### 3.3. Movement, interpersonal communication and empathy

Thinking is rooted in movement, as are interpersonal communication and its variants: empathy, intersubjectivity, and mutual incorporation. Sheets-Johnstone (2017) asserted that interpersonal communication develops from movement, using the example of how a fetus in a womb communicates with its mother; as the mother moves, the fetus responds to her movements, and vice versa (Sheets-Johnstone, 2017). This represents a fundamental form of interpersonal communication in which the absence of movement conveys as much meaning as its presence.

Fuchs and De Jaegher (2009) unfolded interpersonal communication as enacted intersubjectivity. While intersubjectivity refers to the phenomenological understanding of how subjects, that is, different agents, transcend their bodily boundaries and comprehend other subjects (Beyer et al., 2018; Moran, 2017), enacted intersubjectivity explains how we connect and understand one another by enacting each other's movements (Fuchs and De Jaegher, 2009). To illustrate this argument, the authors (Fuchs and De Jaegher, 2009) referred to how baseball players enact the course of the ball's movement when they run to catch it (McLeod and Dienes, 1993). As such, we understand one another as we respond to each other's movements. While Fuchs and De Jaegher (2009) emphasise enacted intersubjectivity as interpersonal responses and include non-human agents, Leder (1990) ascertains interpersonal communication as mutual incorporation between humans:

> "Through a natural empathy, one body takes up the affective responses of another. I feel sad as I witness another's tears and am infected by their laughter. Further transmission of intentions is allowed by the use of gestures and language. In mutual incorporation, each person's capacities and interpretations find extension through the lived body of the Other" (p. 94).(Leder, 1990).

In this quote, Leder (1990) linked empathy and bodily incorporation as an exchange of feelings and movement between humans. In line with this perspective, and extending it to non-human agents, Weiss (1999) argued that embodiment is intercorporeal,[1] as it involves "*our continual interactions with other human and nonhuman bodies*" (p. 4) (Weiss, 1999) in "an exchange of bodies and body images" (p. 4). Our understanding and conceptualisation of the world emerge as a reciprocal process of mutual movement, exchanges and explorations between human and non-human agents in and with the world. These ideas align well with the predictive processing and active inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022) explanations reviewed earlier regarding the neurological processes behind these experiences as predictions that we continuously seek to refine and ascertain through movement in and with the world. In interpersonal communication, this manifests as predictions and inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) about the other – human or nonhuman – arising from the exchanges and incorporation of movements.

#### 3.3.1. Dys-appearring bodies

However, we become temporarily alienated when we encounter a disruption in our conceptualisation of the world – something we cannot enact, incorporate, or bodily conceptualise. In predictive processing theory, this occurs when prediction errors cannot be corrected, and the brain cannot make a stable inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022) about a situation. Leder (1990) refers to this phenomenon as dys-appearance. We perceive our bodies as dys-appearing, for instance, when we perceive another's gaze deviating from the expected mutuality, which leads us to view our bodies from an unfamiliar perspective (Weiss, 1999). For example, this happens when we observe a baseball suddenly altering its expected course. Such situations require us to correct our conceptualisation of the world. We need to update our predictive models (Hohwy, 2020). And, as outlined by active inference theory (Friston, 2010; Pezzulo et al., 2015), we do so through movement.

[1] Intercorporeality (or intercorporeity) was introduced by Merleau-Ponty (1968) and built on Husserl's (Beyer et al., 2018) idea of intersubjectivity as rooted in bodily processes (Zahavi, 2018).

#### 3.3.2. Perceptual differences of self and 'other'

While we understand each other in and through exchanges of movement, we also distinguish ourselves from 'others' in and through our perception and enaction of movement. For such an explanation, we turn to Zahavi (2014), who explains the perceptual differences between self and 'others': "although through a process of motor empathy, I might come to feel the movements and sensations of the other, these sensations and movements are given as belonging to the other, and are precisely brought into relief as such in contrast with my own sensations" (Stein (1964) in Zahavi (2014) (p. 158)). We recognise other beings as distinct from ourselves as we move. We make this inference precisely because we perceive the other's movements in relation to our own – as enacted intersubjectivity (Fuchs and De Jaegher, 2009) through mutual incorporation of movement (Leder, 1990).

Thanks to the discovery of mirror neurons, the concepts of intersubjectivity, intercorporeality, and mutual incorporation have gained further recognition within neuroscience as important for understanding humans as intercorporeal beings (Rizzolatti and Craighero, 2004; Vigneswaran et al., 2013; Zahavi, 2014). These studies confirm that we respond neurologically differently to our own and others' movements, (Vigneswaran et al., 2013), whether human or nonhuman (Rizzolatti and Craighero, 2004; Zahavi, 2014). Thus, we are bodily aware of which body is moving.

With the above argument in mind, we return to the phenomenological discussion. If we recognise "others" as we move differently, we also recognise ourselves when we do not. Zahavi (2014) uses the experience of observing ourselves in the mirror to explain how we can identify the mirror image as ourselves, which relies on detection of the cross-modal match and temporal contingency between our own bodily movements and the movements of the mirror image (p. 201) (Zahavi, 2014). In other words, the movements we exteroceptively perceive from the mirror image correspond to the balanced interoceptive and proprioceptive inferences (Clark, 2016) of our body's movements, similar to what occurred in the previously described RHI studies (Botvinick and Cohen, 1998; Suzuki et al., 2013). Thus, we acknowledge that it is ourselves in the mirror because it corresponds to our brain's balanced inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) about our bodily movements. Hence, these do not reflect the movements of others (Vigneswaran et al., 2013; Zahavi, 2014).

### 3.4. The absent body

In the phenomenological debate about bodily experiences and perception, Leder (1990) argues that the body is visually absent for most of its experiences. That means that many of our movements are invisible to us, too. We only perceive their consequences. An example is driving a car. We do not stare at our feet to know when we are stepping on the accelerator or break pedal. Instead, we perceive the consequences of our actions. Leder's (1990) bodily perspective on the absent body tells us that, despite our lack of visual awareness regarding our moving body parts, we still perceive them seamlessly, just as we do any visible body region.

Leder (1990) further explained how the body can "turn off" regions as temporarily absent when inactive, i.e., do not move. In such instances, the body sets the inactive parts in the background of our perception[2] to background disappearance (Leder, 1990): "Bodily regions can disappear because they are not the focal origin of our sensorimotor engagements but are backgrounded in the corporeal gestalt; that is, they are for the moment relegated to a supportive role, involved in irrelevant movement, or simply put out of play" (p. 26) (Leder, 1990). For instance, when seated, our legs are backgrounded to a supportive role.

In contrast to how body regions can fade into the background, they can also enter corporeal foci, "in which certain organs and abilities come to prominence while others recede" (Leder, 1990 (p. 42)). In other words, according to Leder's theory of the absent body (1990), we are not constantly aware of our movements or the body regions that perform them – only when they become the focus of our sensorimotor engagement do they become prominent (Leder, 1990; Sheets-Johnstone, 1990). We primarily rely on our absent body when interacting with the world.

### 3.5. Bodily incorporation of technologies

Complementing background disappearance, Leder (1990) introduced focal disappearance and explained the bodily adoption of technologies from these perspectives: "*As I gaze through the windows, they are in focal disappearance, the means from which I look upon the world*" (Leder, 1990 (pp. 34)). While the example is grounded in visual perception, Leder (1990) continued to explain focal disappearance as a process of *bodily incorporation:* "The lived body constantly transforms its sensorimotor repertoire by acquiring novel skills and habits. In its use of tools or machines, the body supplements itself through annexing artificial organs" (Leder, 1990 (p. 30)). In this quote, Leder (1990) referred to the body's acquired sensory-motor repertoire of skills and habits, akin to Sheets-Johnstone's (1990; 2013) repertoire of 'I cans' (Sheets-Johnstone, 1990). Curiously, Leder (1990) implied that the body acquires technologies through bodily incorporation, that is, based on movement. However, Leder (1990) did not develop this idea beyond acknowledging the sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) necessary for the bodily incorporation of technologies. Therefore, we continue this line of thought and propose how we incorporate and make sense of technologies based on movement. Based on the results of this investigation, we develop a theoretical framework to understand the experiential dynamics of embodied experiences and the emergence of player-technology relationships from the perspective of how movement unfolds and supports embodied experiences in digital and virtual environments. We believe such a framework is relevant for researchers and designers aiming to advance these fields.

## 4. Game exemplars

The empirical investigations start with an introduction to the seven games played and analysed for this study. All the games were available to the public or upon request. They were played over three years and were selected to represent various technologies, from pervasive to virtual reality, to emphasise different perceptual stimuli.

### 4.1. Labo robot

*Labo Robot* (*Nintendo Labo Robot Kit*, 2018) is a part of the *Labo* series designed for the Nintendo Switch console. The *Labo Robot* equipment is constructed from cardboard and assembled by the players. It includes a backpack with strings attached to handles for the feet and hands. These are mapped to the robot's feet and hands (arms); the players' feet control the robot's feet, allowing movement within the virtual world. The robot can stamp when the player stamps, causing the game world to rumble. Furthermore, the player wears a visor containing a controller that detects when the visor is lowered; the player engages in first-person perspective, and when raised, the third-person perspective is activated.

In the game, players manipulate the backpack strings to perform different actions: Crouching turns the robot into a tank, pulling arm strings enables shooting or punching, and stretching arms allows flying. When the player does not crouch, the robot walks upright. The player controls movement direction with the position of the visor, which is most likely the direction of the eyesight.

*Labo Robot* features several games, including the "destroy as much as possible within 5 min" game and the robot battle game. In the "destroy as much as possible" game, players earn points by destroying objects through shooting or punching, while on-screen stats display calories,

[2] This is also known as neural adaptation ('Neural Adaptation', 2021); no or insignificant prediction errors occur (Clark, 2016).

steps, and punches. *Labo Robot*'s battle mode involves a boxing match between robots in an arena until one is knocked out the opponent.

### 4.2. Labo VR blaster

*Labo VR Blaster* (*Nintendo Labo VR Kit,* 2018) is a first-person shooter VR game that is also part of the Nintendo *Labo* series for the handheld Nintendo Switch console. The player wields a blaster – made of cardboard – in one hand and "blasts" with the other hand by pulling the lower handle of the blaster. Inside the blaster is the console display, which enables the system to function as VR goggles, allowing the player to concentrate on aiming and shooting while also displaying the game world.

The gameplay is straightforward: the player is placed on a platform that moves them through a landscape where they are required to shoot at attacking or moving targets.

### 4.3. Beat saber

*Beat Saber* (Hrincar et al., 2018) is a VR rhythm game created by Beat Games (Hrincar et al., 2018) for the Oculus Quest (also available on Steam, PlayStation, and Windows). The Oculus Quest setup has a head-mounted display (HMD) and two handheld controllers. Players must establish a safety zone to avoid colliding with physical objects like furniture. Stepping outside the zone activates the HMD cameras to show the player's physical surroundings.

Players use lightsabers to slice through boxes to the rhythm of music. The controllers they hold govern the lightsabers, while the boxes approach the player in sync with the rhythm, necessitating precise slicing. Arrows on the boxes indicate the required slicing direction (arm movement), and the colour of each box signifies whether left or right slicing is needed. Occasionally, large blocks appear, and players must dodge them by moving sideways or crouching. Boxes may be positioned in various ways (up, down, sideways, or twisted), demanding corresponding adjustments in slicing technique. Furthermore, a hidden feature grants extra points for more substantial arm movements during and after slicing to encourage dynamic gameplay (Hayden, 2019).

### 4.4. The eye of the temple

*The Eye of the Temple* (Johansen, 2021; Sanctum Dreams, 2018) is a VR adventure and puzzle game for the HTC Vive (HTC Vive, n.d.) (also on Steam). The HTC Vive includes a head-mounted display and two hand controllers, and external cameras track the player's position.

Players embark on an Indiana Jones-style adventure through a temple. They navigate winding hallways with moving tiles and rolling stones, creating an obstacle course. Falling off a moving tile results in a "game over" as players plunge into a waterway. Armed only with a whip, players encounter challenges such as battling giant flies and collecting resources like stars. The temple perches atop a mountain, where venturing too close to the edge can result in a perilous fall.

### 4.5. Superhot VR

*Superhot* (*Superhot (VR)*, 2016) is a VR first-person shooting and fighting game for the Oculus Quest, as well as on consoles and PCs. In *Superhot*, players engage in combat against enemies by punching, using firearms, or throwing objects. By manipulating the controllers, they can control time, which affects the speed of enemy movement. Quick movements of the controllers accelerate time, causing enemies to move more quickly, and vice versa. However, head movements do not influence this mechanic. This feature allows players to pause, strategise, and execute counter-moves. Nonetheless, a threshold for controller movement allows players to make small, slow arm movements and head motions without affecting the time. As players progress, they unlock additional weapons such as bottles, ninja stars, and guns, which require arm movements, consequently affecting time and the speed of enemies.

### 4.6. The move maker

*The Move Maker* (Matjeka, 2020) is a physical game system designed by Matjeka (Matjeka, 2020). It features objects, cards, and mini-games that promote various movement forms. It was developed as part of the EXACT research project on fall prevention for older adults (65+ years) (Vereijken, 2017).

The system comprises light cubes that change colour based on orientation, music boxes activated by proximity sensors, and laser lines connected to brightness sensors. Additionally, cards feature physical "handicaps" (Matjeka et al., 2021) to challenge players' physical abilities. The system also includes a mobile robot controlled by proximity sensors (Fig. 6), equipped with three pairs of wheels that respond independently. For instance, triggering only the left wheel (through hand movements in front of the proximity sensors) causes the robot to turn right. Activating only the middle wheel or all three will cause the device to move forward, while the distance of the hands from the proximity sensor regulates the speed.

The system includes mini-games such as guiding the robot through a maze of light cubes, navigating a laser field without disrupting the lines, claiming territories with the robot, and maintaining music playback while changing cube colours. During these games, players must adhere to at least one "restraint" card, like "keeping feet off the ground" or "glueing the left hand to the hip." The games can be played collaboratively, competitively, or as single-player experiences.

### 4.7. Space agent

*Space Agent* (Space on Earth ApS, 2015) is a primarily sound-based game (Space on Earth ApS, 2015) for smartphones that takes advantage of location-based features via GPS. The game's weapon depends on specific movements recorded by the smartphone's gyroscope and accelerometer, while enemies are spawned in a 360-degree circle around the player within a binaural soundscape.

Players take on the roles of secret agents entrusted with saving Earth from invisible aliens. Equipped with an Omnidevice (their smartphone) as the alien detector, agents must search for and capture these invisible aliens while navigating physical landscapes. Aliens, often discovered in clusters or patrolling the airspace in spaceships, can only be detected sonically through the Omnidevice. Players capture them by swiftly dragging the smartphone towards their body while aiming it in the direction of the alien.

## 5. Research design

This section introduces the empirical foundation of the study: a phenomenological analysis of gameplay experiences drawn from an autoethnographic inquiry into movement and player-technology relationships. It draws on a neuroscientific (Clark, 2016; Hohwy, 2020; Parr et al., 2022) and phenomenological (Leder, 1990; Sheets-Johnstone, 1990, 2003, 2013; Zahavi, 2014) perspective on perception and embodied experience. These theoretical approaches were informed by a retrospective autoethnographic (Ellis et al., 2011; Wall, 2006) inquiry into playing seven games during three years (2019–2022) as a source of experiential material. The autoethnographic data provided a subjective account of lived experiences related to the theoretical framework.

The combination of predictive processing and active inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022) frameworks, along with phenomenology, is an emerging trend that aims to better understand the dynamics of subjective experiences by coupling their narratives with the underlying neurobiology (Albarracin et al., 2023; Bogotá and Djebbara, 2023; Limanowski and Friston, 2020; Sandved-Smith et al., 2020). The neuroscientific theories explain how human perception processes work, while phenomenology focuses on how these processes are experienced.

Together, they can inform studies about human experience with richer and deeper accounts of the how and why of an experience (Albarracin et al., 2023; Bogotá and Djebbara, 2023; Limanowski and Friston, 2020; Sandved-Smith et al., 2020). This study follows this argument to explain embodied experiences and player-technology relationships as subjective, neurobiological processes coupled with an account of lived experience.

The autoethnographic study combined key principles of phenomenology – focusing on lived experience (Merleau-Ponty and Landes, 2012), meaning-making (Van Manen, 2014), and the essence of phenomena - with the reflective, personal, and narrative-driven aspects (Chang, 2008; Denzin, 2014; Ellis et al., 2011) of autoethnography.

Retrospective autoethnography was chosen as it allows lived experiences to be revisited with analytical distance, enabling the surfacing of structures and patterns that may not be accessible during the immediacy of interaction (Ellis et al., 2011; Muncey, 2010; Wall, 2006). The immersive and physically engaging nature of the gameplay did not allow for real-time reflections during sessions. Instead, gameplay experiences were recalled and documented retrospectively through journaling, while some sessions were video-recorded, allowing for retrospective review and capturing nonverbal cues (Smith et al., 2020). As such, the quotes used throughout the paper are thus reflective narratives rather than in-the-moment accounts of captured sensations and disruptions.

Data were analysed using an iterative, phenomenological approach (Van Manen, 2014; Zahavi, 2018) and thematic analysis (Braun and Clarke, 2021; Williams and Moser, 2019). This approach facilitated vertical analysis to explore themes and phenomena across the data while maintaining the phenomenological narrative. As such, the analysis was iterative and abductive: recurring experiential themes – such as movement coherence, sequence disruption, and the incorporation of the various technologies – were identified across entries, clustered thematically, and refined through theory-led interpretation. These reflections were revisited and interpreted retrospectively through the above-mentioned neuroscientific and phenomenological theoretical lens.

The reflective writing process emerged through iterative engagement between theoretical frameworks and lived experiences. Initial phenomenological reflections guided the identification of relevant theoretical concepts, such as predictive processing (Clark, 2016; Hohwy, 2020), active inference (Friston et al., 2017; Parr et al., 2022), and movement sequences (Sheets-Johnstone, 1981, 2003, 2013). In turn, these theories informed subsequent reflections, allowing for deeper insights into the embodied nature of the gameplay experiences. This reciprocal process aligns with established phenomenological research practices (Van Manen, 2014), where analysis emerges through a dynamic interplay between pre-reflective experience, reflective interpretation, and conceptual grounding.

To ensure scientific rigour and credibility, emerging themes and interpretations were validated through peer debriefing (informal conversations) and discussions with co-authors (Denzin, 2014). While the study primarily examines the experiences of the researcher who collected the data (Ellis, 2004), the co-authors validated the conclusions to ensure their scientific rigour and trustworthiness (Denzin, 2014). The study adhered to institutional guidelines for autoethnographic research.

## 6. Findings

The following sections present our movement-centered perspective on how embodied experiences and the interrelationships between players and technologies emerge. We also examine the underlying dynamics that lead to the specificity of each experience. The section interweaves conceptual reflection with first-person experience, where each phenomenon is introduced in general terms and then explored through concrete examples drawn from the autoethnographic material.

### 6.1. How we make sense of technologies through movement

The following sections explore how the player made bodily sense of the technologies as they moved together and interacted with one another. We achieve this by examining how movements unfolded and conjoined into sequences as they were perceived and employed between the player and technologies. Additionally, we investigate how the player-technology relationships developed from these interactions and how the player, based on their perception of movement, either integrated the technologies into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) or regarded them as external agents. We begin by analysing how the player perceived and incorporated technologies, including their in-game character, as they moved together.

#### 6.1.1. Perceiving technologies from how we and they move

People make sense of and connect with technologies through movement. As we and technologies move, we distinguish them as either part of us, incorporated into our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), or entities that we respond to and that act in relation to us. In the following report from playing *Labo Robot*, the player explained how she perceived which of the two robots represented their in-game character based on their interactions and movements around each other:

> "*I stare at two robots in a boxing arena. I don't know which one is my character. I start pulling the backpack strings and see one of the robots moving. When I move my arms or my head, it also moves its arms and head instantly. And, when I do not move, it does not move either, and nothing happens. The robot's movements seem to be linked to mine – and my movements are the robot's. I cannot shake them off. We are inextricably linked. Without the link, I would not be playing.*"

When the player moved, she could identify which robot was their in-game character because its movements mirrored theirs (Leder, 1990; Vigneswaran et al., 2013; Zahavi, 2014). The player could not "shake off" the movements, so they were inextricably linked. The player instantly perceived the robot's movements as their own and inferred that these movements belonged to them. The player connected the robot's movements to their own (Leder, 1990; Vigneswaran et al., 2013; Zahavi, 2014) mainly from their visual perception, much like we associate our movements with those of our mirror image (Zahavi, 2014). However, we also make this connection without directly viewing our body as part of our absent body (Leder, 1990).

The following examples of playing the VR game *Beat Saber* and the sound-based AR game *Space Agent* reported similar experiences, albeit without directly seeing their in-game character.

> *"I stare into the open hall with the "box" runway. I see a pair of lightsabers and look down to see where I stand. There is nothing! I have no legs or feet. I feel like I am collapsing as I momentarily feel like I have lost my legs. I make a step and feel that they are still there. I focus on the lightsabers that move synchronously when I move my arms. While I cannot see my arms, I sense they are connected to the lightsabers. Yes! I controlled the lightsabers and started slicing boxes. While I am somehow without a visual body, I can still avoid the large blocks coming at me as I move to the sides and duck down. The lightsabers start to feel like mine, and I am soon fully concentrated on slicing boxes."*

Despite the player having no visual confirmation of their physical body parts, she perceived how the lightsabers' movements mirrored their own. She sensed she could slice boxes, shift to the sides, and duck down without visual confirmation of any other body part besides the lightsabers. Unlike the earlier *Labo Robot* example, the player could not associate the lightsaber movements with their own, as if reflecting a mirror image, since she lacked visual confirmation. Instead, she could correlate the lightsabers' movements with those of their absent body (Leder, 1990). Like how we can drive a car without visually confirming our legs and foot movements, we perceive movements as inherently linked to our own based on their outcomes – that is, as part of our absent body (Leder, 1990). Phenomenologically, the player perceived their in-game character's movements as inextricably linked to them through their perceptions (Zahavi, 2014) of their absent body's movements (Leder, 1990), coupled with the consequential slicing of boxes and lateral movements.

Unlike the two examples above, in *Space Agent* the player had visible assurance of their physical body but no visual indication of any virtual movements, as there were only audible representations of the aliens' movements.

> "*As I twisted and turned while moving the smartphone in different ways, I learned how to capture the aliens by listening. As the aliens were invisible, I had to rely on my hearing to locate them, their distance, speed and position relative to mine. Furthermore, I had no visual affirmation of the results of my attempts, only audible feedback. Nevertheless, I gradually focused more and more on capturing the aliens than on how to do so. After a while, I had forgotten that I lacked a visual representation of the aliens' movements. I was fully focused on capturing them and not being hit. The smartphone had transformed from merely a device into my captivator, enabling me to detect and capture invisible aliens.*"

As the quote suggests, the player perceived that the audible-only capture events were inextricably linked to their visible movements with the smartphone (Leder, 1990; Sheets-Johnstone, 2017). From this combination of perceived movements, the player incorporated their in-game character's invisible movements, which were partially perceived through their absent body (Leder, 1990) movements. Additionally, the player's twisting and turning with the smartphone, along with the audible cues, provided the experience of capturing invisible aliens. While the player received visual confirmation of their actions with the smartphone, it receded to the focal background (Leder, 1990), becoming integrated as part of their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) as she connected their visible movements with their in-game character's audible capturing movements.

This section highlighted how we connect with technologies as we perceive their movements to be inextricably linked to ourselves. As the examples indicate, when the player recognised the technology's movements as a reflection of their own, she incorporated them into their actions. Together, their movements formed meaningful sequences manifested in specific doings (Verbeek, 2005), such as capturing aliens or boxing with robots, that the player integrated into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). Moreover, she did so through a mix of various perceptual perspectives, including visual, auditory, and tactile, and their perceived consequences (Leder, 1990). The following section provides a detailed examination of this process.

#### 6.1.2. Technology incorporation and the action-perception cycle

In this section, we propose that our ability to embody technologies stems from the brain's capacity to balance exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), thereby creating and maintaining a stable, coherent model of the world. Rooted in the action-perception cycle (Parr et al., 2022) (Fig. 1), the brain makes inferences about the world, including technology. When the player perceives the technology as inextricably linked and thereby bodily "annexe" (Leder, 1990) them, we suggest this perception occurs through the action-perception cycle. This process unfolds in motion (Pezzulo et al., 2015) as meaningful movements. We detail this process below.

Referring to the report in Section 6.1.1 from playing *Space Agent*, the player, by employing the instructed capturing movements, experientially transformed the smartphone into an omnidevice through which she could interact within the virtual world. We attribute this phenomenon to the action-perception cycle: the player executed their capturing movements with their physical arm holding the smartphone. Consequently, she perceived the smartphone moving in a similar manner. Simultaneously, she received auditory feedback from their efforts, indicating success or failure. By balancing the blend of exteroceptive (visual, tactile, and auditory) and proprioceptive (the capturing movements) inferences, the player perceptually incorporated the smartphone into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003).

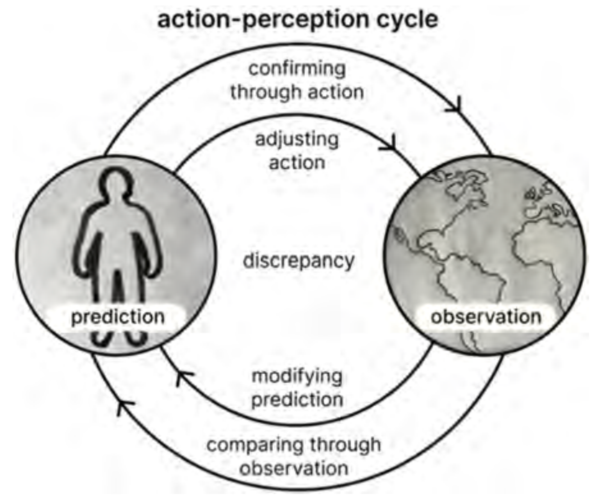


**Fig. 1.** The action-perception illustrates the neurological cycle of human perception. Humans predict perceptions of the world and then move to confirm them. They get sensory feedback from their movements that they compare to their prediction. Suppose the prediction and sensory information do not align. In that case, the brain adjusts its movements to get new sensory information and modifies its prediction model to better align with the sensory information.

We can further detail this phenomenon by examining how the player inferred she was wearing stone gloves in *Superhot*. The specific combination of the exteroceptive inferences about their tactile and visual perception and their proprioceptive inferences led to the player experiencing a perceptual sensation of wearing stone gloves.

> "*Only a pair of hands are visible. As the hands have a stone-like look, I start to perceive the movements as if I am wearing stone gloves, and my feeling of moving my hands starts to adopt this feeling. As I am unfamiliar with wearing stone gloves, I start boxing randomly into the air when the enemies attack. I cannot see how I move; I can only see the stone gloves. However, as the hands seem to be mine as they punch when I punch, I realize it must be my doing when an enemy dissolves into pieces after a series of punches.*"

This quote indicates how the player, while conceptually knowing that she is not physically wearing stone gloves, starts to feel as if she is. We contend that this illusion occurs as the brain turns its exteroceptive, interoceptive and proprioceptive inferences into stable and coherent experiences by hierarchically balancing them (Clark, 2016): The player can see a pair of stone gloves. In addition, she can tactilely perceive the physical controllers that, based on her proprioceptive perception, she infers come from their hands. When the player starts to move her hands, the stone gloves also move. We explain how the player makes sense of this situation using the predictive processing and active inference frameworks (Clark, 2016; Hohwy, 2020; Parr et al., 2022); the brain compares the stone gloves' movements to their own and sees a connection; they are inextricably linked. Conceptually, the brain is familiar with a similar model from physically wearing gloves, which can serve as a prediction model (Clark, 2016; Hohwy, 2020; Parr et al., 2022). This way, the player infers that the stone gloves are part of their hands as gloves. Simply put, the player sees the stone gloves and wants to know how they relate to her. She cannot predict if they belong to her or not and starts to move to confirm one of the predictions. However, there is a discrepancyrelated to the visual and tactile perceptions misaligning, and, according to the predictive processing theory (Clark, 2016; Hohwy, 2020), fire prediction errors. Following the active inference theory (Friston, 2010; Parr et al., 2022), the brain attempts to minimise prediction errors and confirm predictions through action. Thus, as the player moved to resolve this discrepancy into a coherent and meaningful experience, the brain hierarchically ordered the inferences by giving precedence to some (Clark, 2016). In this case, precedence was given to the visual inference of stone gloves; the player experientially resolved that their hands were wearing stone gloves. Consequently, from this hierarchical order of inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), the brain generated the prediction model of wearing stone gloves, and the player started to move accordingly. Experientially, once the player's inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) stabilised into a coherent experience, the technologies slit to the focal background, bodily annexed (Leder, 1990) by the player. The player had bodily incorporated the technologies into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) as an omnidevice and stone gloves.

While the above examples detail how the player bodily annexes (Leder, 1990) technologies through the action-perception cycle, they have mainly focused on the body's exteroceptive and proprioceptive inferences. However, as Suzuki et al. (2013) put forth, the interoceptive inferences also play a role in this process. For instance, in our examples, the player's pulse rose and fell as she moved, and her breathing got heavier. While we have no exact records of the player's pulse, except in a few instances in the reports, we can observe from the videos that the player's breathing was generally affected in most instances, particularly during intense action. While these records suggest that interoceptive perceptions are also affected during these activities, we cannot directly link this observation to specific perceptions, as Suzuki et al. (2013) do by connecting the subject's pulse to the in-game character. However, we can confirm that interoceptive inferences also play a part in the hierarchical order of inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) that make up coherent and stable experiences.

In this section, we have described how the player perceptually annexes (Leder, 1990) technologies through the action-perception cycle. Based on the action-perception cycle, the body interpreted the technology's movements as inextricably linked to it and, therefore, integral to its movements. Because the player perceived the technology's movements as integral to hers, she incorporated them into her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). In this way, the player bodily annexed (Leder, 1990) the technologies, allowing them to become part of her bodily perception, as Leder (Leder, 1990) explains. We term this cycle, in which the human body annexes technologies (Leder, 1990), the human-technology perception cycle (Fig. 2). We detail this in the next section.

### 6.1.3. *The human-technology action-perception cycle*

The human – technology action-perception cycle (Fig. 2) is an adaptation of the action-perception cycle based on active inference theory (Parr et al., 2022; Pezzulo et al., 2015) and illustrates how a human subject incorporates technologies. When players interact with technology, they draw on their prior experiences to predict the interaction. As illustrated in Fig. 2, humans move according to their predictions when interacting with technology. They then receive sensory input from the technology and compare it to their prediction model. Any discrepancies in this comparison are resolved dynamically in a cycle where they adjust their movements to confirm their predictions further and modify their prediction model to fit the new information. This is an ongoing cycle in which a human subject, when perceiving a technology that reflects their movements, bodily incorporates it into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). In our case, the player incorporates technologies that enable her to play games.

The following report on playing *Labo Robot* illustrates how the player incorporates the technology and adapts her prediction model through action accordingly:

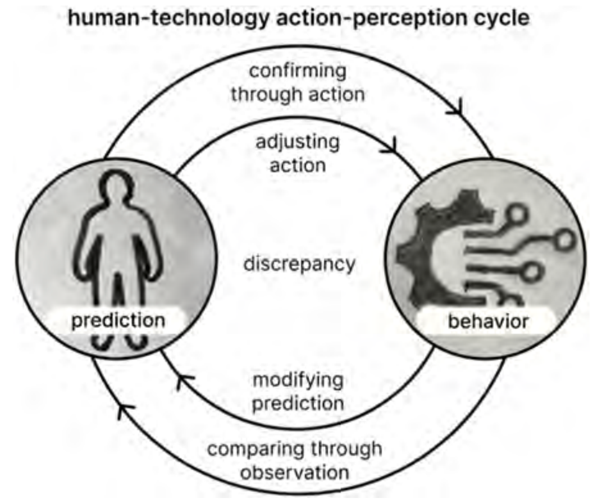


**Fig. 2.** The human-technology action-perception cycle dynamically loops between confirming predictions about the technology through actions and comparing observations of its behavior. When the player experiences a discrepancy in this process, they adjust their movements and modify their predictions to resolve the discrepancy.

> "*I controlled my robot's direction by turning my head wearing the cardboard visor. At the beginning of playing, I felt awkward as I was pulling the strings, and I could hear the controllers banging in response inside the cardboard backpack. I made walking movements in place, and the robot moved. I punched, and it punched. I crouched, and it started driving. I moved much faster as a tank than as a robot. I tried to stretch out my arms to fly, and the robot took off. It was cool to fly around the landscape. As I gradually got used to these behaviours, I stopped thinking about how to do them. The noisy banging and demonstrative gestures with the strings became a natural part of being a Labo Robot. Instead, I had the experience of driving like a tank or flying, without noticing that I was physically 'only' manipulating strings*".

The player's flying and driving combined several movements she perceived as belonging to her: manipulating the backpack strings, coordinating direction through the visor, and perceiving the in-game character's movements, that is, seeing what she expected to see when flying and driving. To act in the game, the player predicted the technologies' doings (Verbeek, 2005) and acted accordingly. In this process, the player adjusted her movements while also modifying her prediction model to smoothly incorporate the technologies into her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) - residing in the focal background (Leder, 1990). Perceptually, the technologies became integral to her abilities to fly and drive in the *Labo Robot* environment in the human-technology action-perception cycle (Fig. 2).

In summary, the action-perception cycle (Parr et al., 2022) (Fig. 1) explains why movement and perception are inseparable: We move to perceive and perceive to move. Expanding this theory, we argue that we bodily annexe (Leder, 1990) technologies in this cycle into our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). We illustrated this process through the human-technology action-perception cycle (Fig. 2). However, while we can explain how we bodily annexe (Leder, 1990) technologies using the human-technology action-perception cycle, it provides little insight into the experience of movements. To get this insight, we turn to phenomenology and Sheets-Johnstone's theory of movement sequences (Sheets-Johnstone, 2003; 2014). Movement sequences describe the structure and qualities of movements, shaping the subjective experience within the human-technology action-perception cycle (Fig. 2). We couple these two theories and explain how the human-technology action-perception cycle lays the groundwork for forming coherent and meaningful movement sequences - our "I cans" as a "*systematic ordering of the world*" (Sheets-Johnstone, 2003). We elaborate on these ideas below.

*6.1.4. Movement sequences emerge from combinations of exteroceptive, interoceptive and proprioceptive inferences*

Movement sequences (Sheets-Johnstone, 1981, 2003, 2013) emerge from combinations of exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) when they form an actionable whole, an 'I can' (Sheets-Johnstone, 1990, 2003). For example, we can explain how the player in *Space Agent*, in the above example, constructed her alien-capturing movement sequence (Sheets-Johnstone, 1981, 2003, 2013) from a specific blend of exteroceptive inferences (Clark, 2016) drawn from the audible and visible feedback of her actions together with her proprioceptive inferences from her twisting and turning her whole body to locate the aliens while employing different arm gestures. Additionally, there existed an interoceptive inference related to her pulse quickening due to the excitement of the situation. These movements and their specific qualities formed a sequence that the player experienced as capturing aliens in *Space Agent*. While we, in Section 6.2, take a closer look at the subjective and qualitative experience of movement sequences (Sheets-Johnstone, 1981, 2003, 2013), we here draw attention to the compositional structure of the movement sequence and its relation to the action-perception cycle (Parr et al., 2022) (Fig. 1).

In the *Labo Robot* game report above, the player composed the walking and boxing movement sequences by integrating the exteroceptive inferences from her in-game character through audio-visual perception and proprioceptive inference from her physical arm and leg movements. However, the player experienced a discrepancy between these exteroceptive and proprioceptive inferences, as the movements of the in-game character appeared dislocated from the player's physical movements. By repeatedly going through the human-technology action-perception cycle (Fig. 2), the brain adjusted its internal hierarchy of exteroceptive and proprioceptive inferences (Clark, 2016) regarding the actionable body's location in space. Ultimately, the player unified these movements into a coherent and actionable understanding of her in-game character's movements as belonging to them. In other words, the player's brain determined that its actionable body was located in virtual space, thus prioritising the exteroceptive inference (Clark, 2016). These movements became part of the player's movement sequences (Sheets-Johnstone, 2003; 2014) – walking and boxing – as she sequentially linked them to her internal models of those movement concepts. We continue the analysis using the *Superhot* report.

In the following report on *Superhot*, the player constructed movement sequences (Sheets-Johnstone, 1981, 2003, 2013) for "making a fist" and "firing a gun" as she incorporated the technology's movements, combined with several other movements:

> *"I stopped thinking consciously about the controllers. Instead, the finger press movements began to respond to how I wanted my in-game character's hands to behave. I hit with my fist and shot with the gun without perceiving the game controllers or pressing buttons. As the enemies were coming closer, I raised my arm, holding the gun and aimed at them. I shot one. Another one was too close for me to shoot, and I started boxing with my other arm. I swung my arm to hit the enemy. Back and forth until it dissolved in front of me."*

In this example, the player composed the actions of "firing a gun" and "throwing a punch" from several sequential and layered movements: her physical hand and finger movements interacting with the controllers; her physical arm movements; and the in-game character's stone hands holding a gun or forming a fist. These were integrated into coherent movement sequences that carried the intentional meaning of a doing (Verbeek, 2005), specifically the acts of shooting and punching within the *Superhot* environment (Sheets-Johnstone, 1981, 2003, 2013).

While the player fired the gun first and then punched, this order could have been reversed. Importantly, not all movements directly contributed to the moment of action – some played an indirect yet essential supportive role. Breaking this sequence down:

- The player's vision (eye movements) was coupled with the in-game character's visual field - a Human-Technology Action-Perception cycle.
- This was supported by head and torso rotation to align her perspective – a supportive movement.
- The finger press on the controller triggered either the transformation of the virtual hand into a fist or the shooting action. This connection between physical movement and virtual effect constituted another Human-Technology Action-Perception cycle, enabling the integration of the technology into the player's embodied repertoire.
- These primary movements were supported by arm movements that aimed or delivered the punch, as well as shoulder stabilisation and coordination of the elbow and wrist, allowing for precision and control.

Together, these movement components formed co-composed sequences that enabled the player to experience the actions as fluid and embodied. The supportive movements, although often backgrounded in awareness, were crucial for enacting the technology-integrated actions. This movement sequence is illustrated in Fig. 3. We note that the analysis focuses on the structural role of these movements within the sequence, not on their qualitative aspects.

Likewise, in the *Space Agent* example, the twisting and turning movements were not about incorporating technologies but rather about locating enemies. Nevertheless, these movements are equally important in forming a meaningful sequence (Sheets-Johnstone, 2003; 2014) as the technology-incorporating movements, such as the player pressing the controllers' buttons with her fingers, visually incorporating the stone hands' movements as hers, or turning a smartphone into an omnidevice. Instead, the player's experience emerged as a meaningful whole (Leder, 1990; Sheets-Johnstone, 2003) from how the movements formed a sequence stemming from a long string of balanced exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022). We can learn from this compositional breakdown of the sequences that while our technology incorporation is formed through movement, they make sense to us together with other movements. We propose that our experience with technology develops from and is shaped by these sequences. While Fig. 3 illustrates this process specifically for the boxing movement in *Superhot*, Fig. 4 illustrates the general process of a co-composed movement sequence.

As pointed out, the above example demonstrates a specific sequential movement order. However, the player could employ the movements differently (Sheets-Johnstone, 2003). For instance, the player could have boxed first and shot later, shot with her fist and hit with the gun, or held the controllers with her feet and thus connected the stone-gloved hands to her feet's movements. As such, the composition of the sequence is dynamic and situational.

Additionally, while the movement sequence (Sheets-Johnstone, 1981, 2003, 2013) is illustrated as a circular pattern of interconnected inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), this circular pattern merely indicates that the inferences are connected in sequence. In the *Superhot* example above, two conceptual meanings emerged for the player: firing a gun and boxing with a stone-gloved fist. As movements seamlessly merge into one another (Sheets-Johnstone, 2003), there are no definitive beginning or ending points in these sequences - only the subjective meanings they convey. Because the player dynamically shapes the specific structure of a sequence, it is somewhat subjective, resulting in fluid endpoints where one sequence flows into another (Sheets-Johnstone, 2003), and technologies integrate dynamically into our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) and movement sequences (Sheets-Johnstone, 1981, 2003, 2013). This is also how technologies disintegrate and are perceived as external to our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). The following section examines how we perceive external technologies

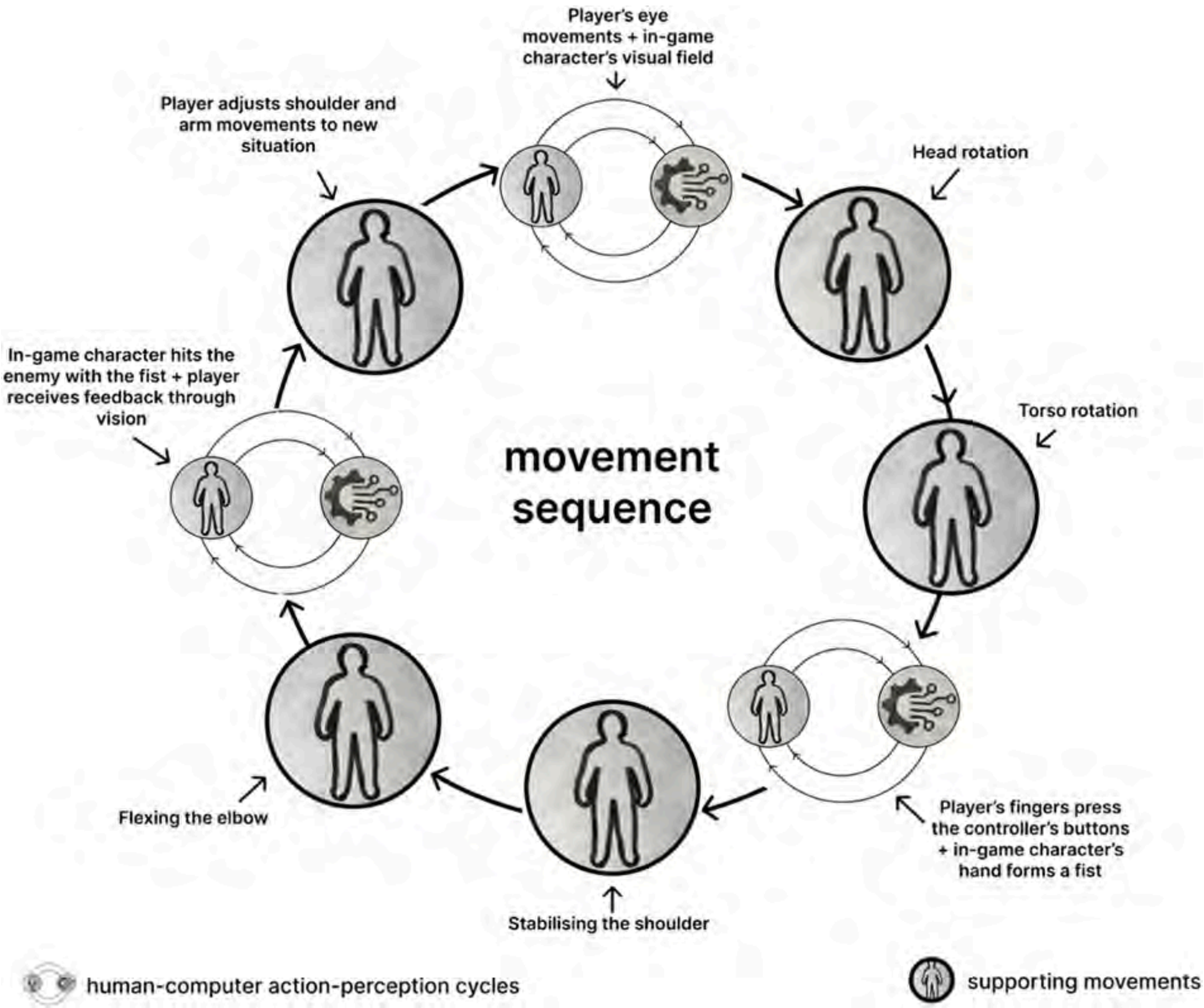


**Fig. 3.** Illustration of a movement sequence in *Superhot* showing how sequential and layered physical and virtual movements - such as visual orientation, finger presses, and arm movements combine to form the co-composed movement sequence of punching. The figure also highlights the role of supportive movements (e.g., torso rotation, shoulder stabilisation) in enabling fluid, embodied interaction to support the human–technology action–perception cycle in a co-composed movement sequence.

through movement, distinguishing them from ourselves.

#### *6.1.5. Perceiving technologies as external entities by employing our own movement sequences*

As we incorporate technologies into our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), perceiving their movements as inextricably linked to ours, we also recognise them as external when they are not. In these instances, they appear as external entities (Fuchs and De Jaegher, 2009) as they exert their own doing (Verbeek, 2005). We perceive the differences in their movement relative to our own. As such, we perceive the environment based on our own movement sequence (Sheets-Johnstone, 1981, 2003, 2013), including situation-specific incorporated technologies. Based on the perceptions gained from interacting with the environment, the player adjusts the movements in the sequence or updates the compositional structure of the sequence. This process is illustrated in Fig. 5 and further explained below.

Reflecting on the player's report of playing the *Labo Robot* boxing game in Section 6.1.1, the player identified which of the two robots was not her in-game character, as its movements did not align with her understanding of her own movement; they were not inextricably linked. Instead, the player viewed the other robot as an external entity exhibiting its own movement sequences (Sheets-Johnstone, 2003). For instance, as the player formed her boxing movement sequence, combining her physical movements with those of the in-game character, she observed how the other robot moved (or did not) in relation to her. In this way, the player enacted the movements of the other robot as related, much like Fuchs and De Jaegher Fuchs and De Jaegher (2009) explained how the baseball player enacts the ball's movements to catch it as calculated by McLeod and Dienes (1993). Consequently, the player perceived the external robot as possessing a sense of its own agency (Verbeek, 2005).

Similarly, in the following report of the Move Maker**'s** *Getting Through the Laser Field,* the player described how she enacted the laser lines based on her movements: "*Each line was positioned at different heights, so I had to figure out how to navigate around them. I moved over and under by crawling, crouching, jumping, and straddling to pass them. Their annoying beeping sound alerted me when I broke a line, and I quickly adjusted my movements to silence it.*" As the player navigated around the laser lines, she composed various movement sequences (Sheets-Johnstone, 1981, 2003, 2013) to manoeuvre around them. Instead of incorporating the laser lines as part of her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), she moved relative to the lines. This way, she perceived the laser lines in relation to her movement sequences (Sheets-Johnstone, 1981, 2003, 2013) of crouching and straddling over and under them. Like the *Labo Robot* example,

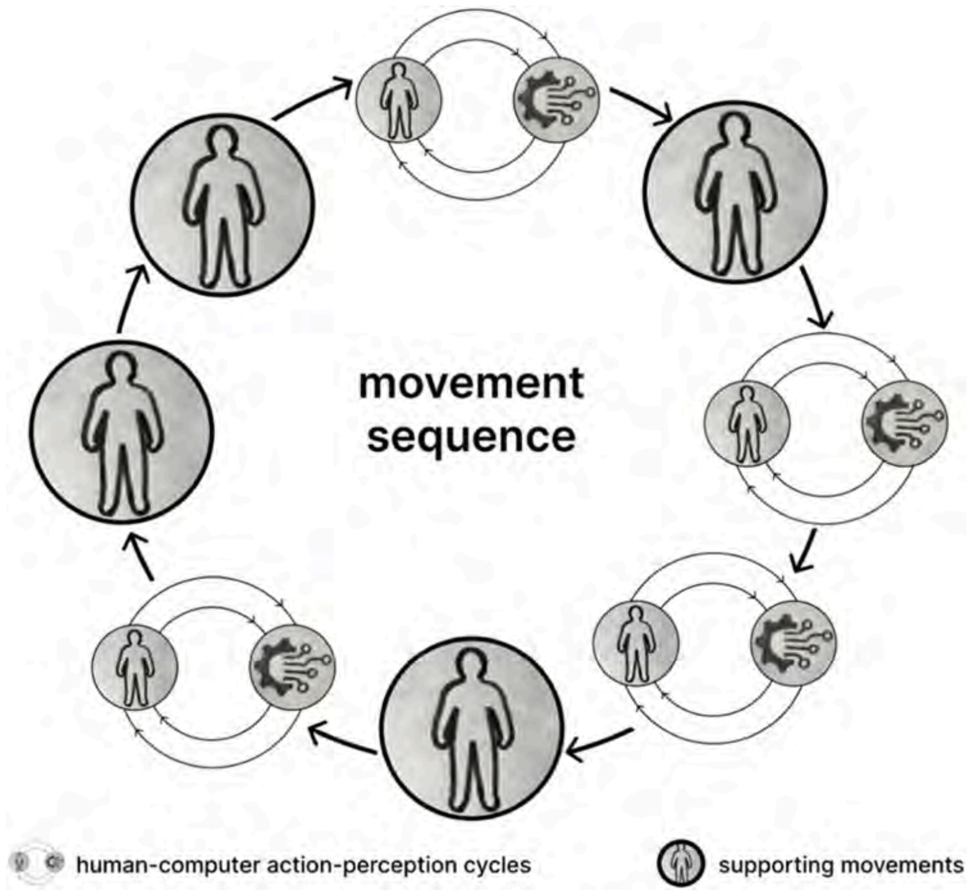


**Fig. 4.** Illustrates how a co-composed movement sequence with technologies is composed of human-computer action-perception cycles and supporting movements in a repetitive cycle forming the sequence's characteristics.

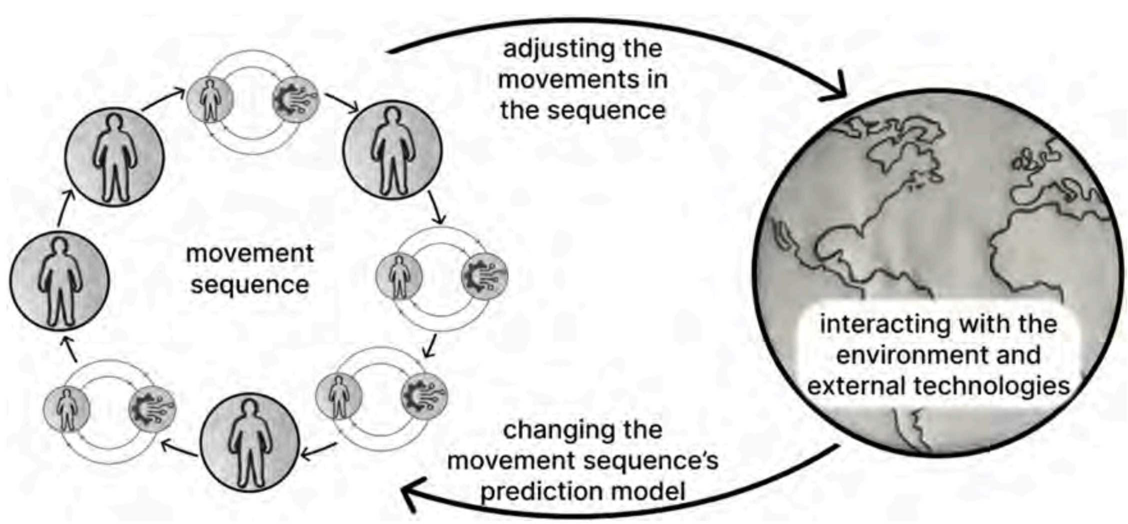


**Fig. 5.** Illustration of the interplay between the player and technologies' co-composed movement sequence and the environment. The word "environment" is used here generically and encompasses physical objects, social situations, and technologies.

the laser lines exhibited their own movement sequence (Sheets-Johnstone, 1981, 2003, 2013), which the player could navigate relative to. The lasers' movements formed the doing (Verbeek, 2005) of a laser line and its alert condition when that movement was disrupted. As this sequence did not reflect the player's own inference of movement, she perceived the technologies as external to herself.

The report in Section 6.1.1 of *Space Agent* regarding the player capturing invisible aliens also provides an example of how the player identified the different aliens as separate entities, notably how their movements formed coherent sequences that created meaningful wholes (Leder, 1990; Sheets-Johnstone, 2003) relative to the player's. In *Space Agent*, the aliens moved in three distinct ways. While all three alien types attacked from random positions, they approached the player using different and distinct movement sequences (Sheets-Johnstone, 1981, 2003, 2013). One alien type attacked in straight lines, the second attacked from above, and the third attacked in a spiralling pattern. Each alien type also emitted its own distinct sound. As the player moved to capture them and learned each alien type's unique movement sequence (Sheets-Johnstone, 1981, 2003, 2013), she dynamically formed movement sequences (Sheets-Johnstone, 1981, 2003, 2013), generating predictions and confirming them by moving and making adjustments accordingly (see the human-technology action-perception cycle above). As such, we perceive external technologies based on our prediction models. The way the player learned the aliens' movement sequences (Sheets-Johnstone, 1981, 2003, 2013) in relation to her own (Vigneswaran et al., 2013) exemplifies this process. Like Fuchs and de Jaegher's (McLeod and Dienes, 1993) baseball player enacting a ball's course by moving relative to it, the player also enacted the aliens' sequences when she employed her capturing sequence in *Space Agent*. As she conceptualised her own sequences into meaningful wholes (Leder, 1990; Sheets-Johnstone, 2003), she similarly conceptualised others' movement sequences as meaningful wholes, as a doing (Verbeek, 2005) she could respond to.

As a result, the player and aliens appeared external as they moved around each other, each representing separate yet related movement sequences (Sheets-Johnstone, 1981, 2003, 2013). This enabled the player to perceive the aliens in *Space Agent* and the other robot in the *Labo Robot* game as external entities since their movements created individual, coherent sequences that the player could meaningfully engage with. While the player had a meaningful experience of interacting with the aliens and robot, neurologically, she could enact the movement sequences of the external entities because she could anticipate their movements based on her prediction models generated in response to them. We will review this in the following section.

#### 6.1.6. Predicting the technology's movement behaviour from our own

The sequential nature of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) makes them repeatable and predictable. As we make sense of the technologies' doings (Verbeek, 2005) through our own movement sequences (Sheets-Johnstone, 1981, 2003, 2013), we can anticipate their course of action. The following *Superhot* report tells of such an example: "*The enemies were coming closer rapidly, and my anxiety grew. I prepared to fight when I remembered I could slow their movements by slowing down my own. I stopped moving, and they stopped. I laid down a plan to fight them one by one, as I could consciously figure out who would reach me first. I then planned my responses as to how to fight them both.*" The player perceived the enemies' movements through her own responses. Through these responses, the player learned how the enemies' movements formed coherent sequences as doings (Verbeek, 2005). In doing so, the player internalised the enemies' movements as her responses to them and, thereby, a bodily understanding of the external entities and their doings (Verbeek, 2005). From these inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), the player created a predictive model of the enemies' movement behaviour. This way, the player could adapt to the gameplay actions, fight the enemies, foresee their actions, and devise a strategy. While such processes happen rapidly in real-time and require pre-reflective responses, the mechanic of slowing down the speed of the enemies allowed the player to do so consciously.

As we move, we continuously adapt to our environment by confirming and updating our predictions about it, similar to what the player did in the *Superhot* and Move Maker examples. The following account of the player's experience with the Oculus safety zone[3] illustrates how she dynamically adjusted her movement responses while navigating in and out of the zone:

> "*As I was playing Superhot and the enemies came toward me, I instinctively wanted to escape as if it was a game of catch. When I moved to escape, I ended up exiting the game scene and standing in my living room. While this accident disrupted my playing momentarily, I learned that I had to obey the safety zone and pay attention to the grid as the signs of its edges if I wanted to play the game.*"

As the player perceived the zone grid responding to her movements, she incorporated her "avoid the zone" response as a sequence in her repertoire (Leder, 1990; Sheets-Johnstone, 1990). This response sequence was then employed whenever the player approached the edges. In doing so, the sequence formed a prediction model that allowed the player to anticipate the technology's reaction to her movements. Interestingly, the player responded with equal anticipation to the physical laser lines in the Move Maker as to the virtual safety zone in the Oculus technology. Consequently, the physical furniture in Move Maker, the virtual ditto in *Superhot*, and the boxing arena in *Labo Robot* were also perceived as external entities. What matters is whether we can make sense of the entities as constituting coherent responses to our movements. As such, we do not care about the specific sensory stimulation, such as interoceptive, exteroceptive, or proprioceptive senses, or the speed and size of movements, like those at light speed or eye movements. If we perceive movements as part of or responding to a coherent and thus repeatable sequence, we can predict their behaviour and course of action. Otherwise, we move in vain. We will explore these phenomena in the next section. Before doing so, we briefly summarise this section.

#### 6.1.7. Summary

In this section, we have combined the concepts of the action-perception cycle (Parr et al., 2022) with Sheets-Johnstone's (1990, 2003, 2013) movement sequences to understand how we ascribe meaning to technologies, viewing them either as part of our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) or as external entities with which we can interact and respond to. The action-perception cycle explains what and how we perceive by linking sensory input and motor output in a continuous feedback loop. It describes the process where movement informs perception, which in turn shapes movement, while movement sequences (Sheets-Johnstone, 1981, 2003, 2013) help us understand subjective, interactive experiences as a "*systematic kinetic ordering of the world*" (Sheets-Johnstone, 2003). As Sheets-Johnstone (Sheets-Johnstone1990, 2003, 2013) defines it, movement sequences depict the subjective characteristics of an experience, specifying the qualitative structure of movements that gives an experience its distinct kinaesthetic feel. Using these two concepts, we illustrated how the player incorporates readily available technologies into her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) and how movement is integral to this process. This process is further illustrated in Fig. 4. Together with supportive movements, the player dynamically integrates the technologies, constructing movement sequences (Sheets-Johnstone, 1981, 2003, 2013). While these sequences are situational and dynamic, they shape our understanding of the technologies. We also distinguish which technologies do not belong to us

[3] The Oculus safety zone is implemented as part of the headset software to avoid accidents where players collide with physical obstacles they cannot see because of the head-mounted display. When the player steps outside the zone, the display shows the physical environment as if it were through a set of color filtered glasses (The head-mounted display is equipped with cameras on the outside to register the zone's limits. The player sees what the cameras record when positioned outside the zone and wearing the display.) - and the game pauses until the player returns inside the zone.

through the movement sequences (Sheets-Johnstone, 1981, 2003, 2013) in our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). This way, external technologies contribute to the player generating movement sequences (Sheets-Johnstone, 1981, 2003, 2013) through which she can interact and respond. To conclude, the player perceives the technologies' behaviour based on how they move relative to her movement sequences (Sheets-Johnstone, 1981, 2003, 2013).

We have described how the organisation of movement provides an embodied structure for our understanding of technologies. This structure enables us to either bodily annexe (Leder, 1990) the technologies as part of our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) or develop movement sequences (Sheets-Johnstone, 1981, 2003, 2013) to deal with them as external entities. Thus, we have argued the basic structure of embodied interaction with technologies is rooted in movement and our ability to move. The following findings build on this conception. We decompose the sequences to investigate the experiential dynamics arising as part of these structures. We do so to better understand the construction of embodied experiences in and with technologies, wherein the emergence of the player-in-game character relationship is an essential part of our online presence and, thus, our experience in and with technologies.

### *6.2. Experiential dynamics in player-technology conjoined movement sequences*

In this section, we explore the compositional dynamics of the movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and how they shape the player's experiences. Since the dynamics described below are based on findings from our dataset, they are not exclusive but provide a starting point for understanding how embodied experiences emerge from the compositions of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) (Fig. 4) and the dynamics that shape them. We do so by breaking down the sequences into minor movements. We begin by examining how the movements are distributed between players and technology and the qualitative experience this dynamic affords.

#### *6.2.1. Distributed movements enable the player to transcend domains perceptually*

As the player composed her sequences from movements she perceived as inextricably linked to herself, she also incorporated movements employed in other domains into these sequences. Consequently, her movement sequences included actions from both human and technological agents across physical and virtual domains (Figs. 6 and 7).

For example, in the *Labo Robot* case (Section 6.1.3), the player physically executed a flying movement sequence (Sheets-Johnstone, 1981, 2003, 2013) by pulling the backpack strings to the sides while simultaneously triggering the controllers. This action was mirrored by the virtual robot, which continued the sequence with an in-game flying motion that was perceptually inseparable from the player's bodily actions – resulting in a coherent experience of flying.

To contextualise such experiences, the following two figures offer schematic illustrations of how movement sequences connect to different types of gameworlds. Fig. 6 shows a scenario where the player's actions are primarily situated within a virtual environment, as in many VR games. Fig. 7, on the other hand, demonstrates how movement sequences can span both virtual and physical domains, as seen in location-based or hybrid games such as *Space Agent*. These models show how movement sequences and the underlying human-technology action-perception cycles can transcend domain boundaries, depending on the game's setup and player experience.

Similarly, the "*driving as a tank*" movement sequence (Sheets-Johnstone, 1981, 2003, 2013) involved the player physically crouching, releasing the backpack strings, and activating the physical controllers while the virtual robot executed the movements, completing the sequential process of driving as a tank. Perceptually, the player and technology created a coherent movement sequence (Sheets-Johnstone, 1981, 2003, 2013) from actions technically distributed across the physical player, technologies, and virtual and physical domains. We assert that this ability to dynamically compose sequences from inextricably linked movements, regardless of their domain or agent, enabled the player to transcend virtual boundaries and experience the sensation of flying. This process is illustrated in Figs. 6, 7, 8, and 9. Figs. 6 and 7 demonstrate how the co-constructed movement sequence (Sheets-Johnstone, 1981, 2003, 2013), combining the player and her annexed (Leder, 1990) technologies, transcends the physical and virtual domains as the sequence's various physical and virtual agents merge across these environments. Furthermore, Figs. 6, 7, 8, and 9 illustrate how the sequence can operate in physical, virtual, or both game environments. While Fig. 6 illustrates how the player integrates virtual technologies to function within the combined physical and virtual environment, Fig. 7 illustrates how the movement sequence (Sheets-Johnstone, 1981, 2003, 2013) incorporates both physical and

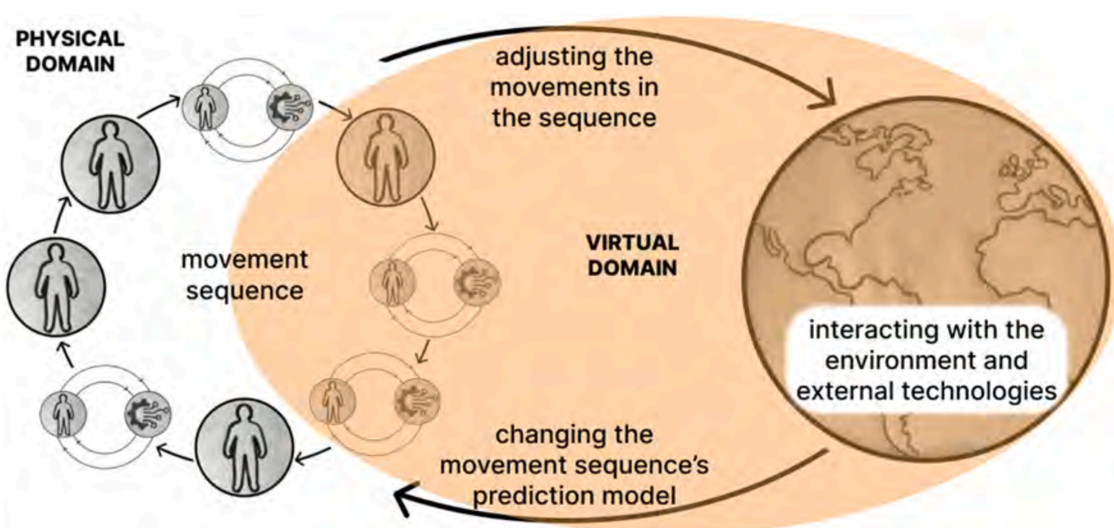


**Fig. 6.** General schematic of how a player's movement sequence interacts with a gameworld situated primarily in the virtual domain. The movement sequence consists of human–technology action–perception cycles and supporting movements that adjust dynamically in response to in-game feedback and prediction errors. This figure illustrates how the player's bodily actions are connected to and shaped by a digitally mediated environment, such as in VR games.

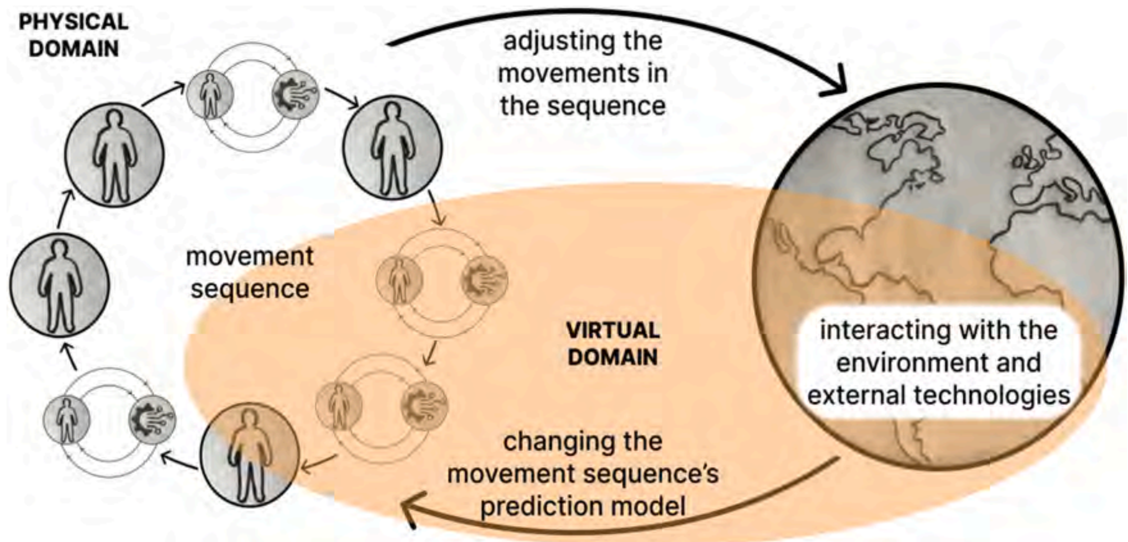


**Fig. 7.** General schematic of how a movement sequence engages with a hybrid gameworld that spans both physical and virtual domains. Compared to Fig. 6, this figure illustrates how certain movements—e.g., those involving spatial navigation or bodily movement through real-world space—are grounded in the physical domain while interacting with virtual feedback and game logic. This model is relevant for augmented reality or location-based games such as *Space Agent*.

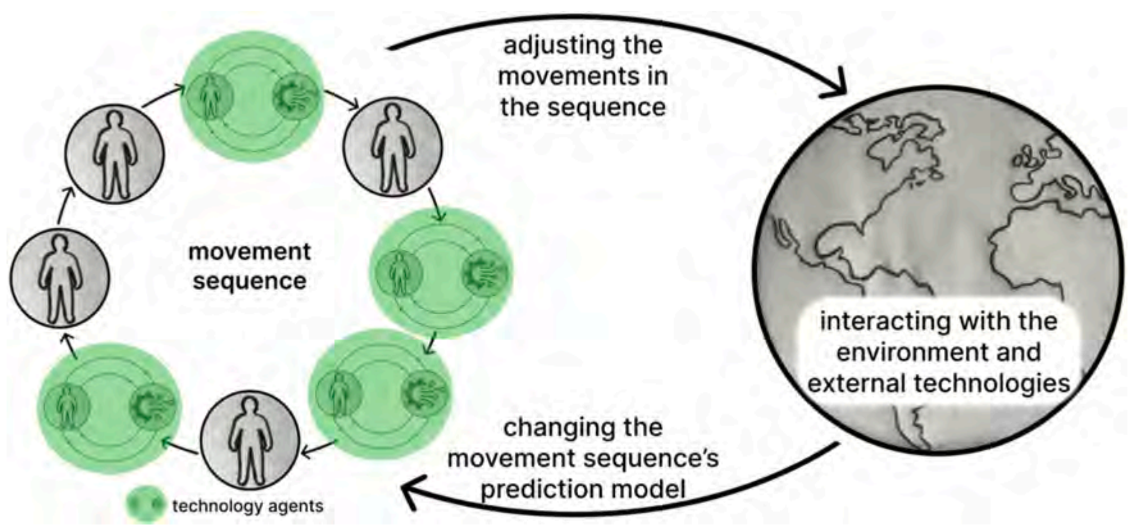


**Fig. 8.** Illustration of the distribution of movements across the human player, technologies and the physical and virtual domains.

virtual technologies, specifically, agents that act in the virtual game environment, as seen in *The Eye of the Temple*. Returning to the experiential dynamics, we now consider how the composition of movement sequence shapes the player's experience.

As the player and technologies can combine their movements to act together in a virtual domain or a combination of physical and virtual domains, this capability can also generate an illusion of self-motion ('Illusions of Self-Motion', n.d.; 'Vection', 2020). The following reports from playing the *Labo VR Blaster* and *The Eye of the Temple* games exemplify two ways to create different illusions of self-motion from movements distributed across domains.

In the *Labo VR Blaster* game, the player is instructed to sit down while their in-game character is passively moved forward, actively shooting enemies with a blaster. The in-game character can only move the blaster, which also serves as the player's physical sight perspective. In this sequence, the movements are distributed as follows: the physical player moves their arms, torso, and head, with the physical blaster inextricably linked to the character's eyesight and shooting movements. Simultaneously, the virtual in-game character moves steadily forward, creating the illusion of self-motion ('Illusions of Self-Motion', n.d.; 'Vection', 2020). Nevertheless, the player perceptually connects the physical and virtual movements into coherent sequences, perceiving as inextricably linked. The following report on playing *The Eye of the Temple* asserts the same dynamic; however, it utilises a different sequence, resulting in another experience.

> "*In The Eye of the Temple, I am encouraged to find my way through labyrinths of tiles moving in water canals. As I cannot move in the water, I can only move around by stepping on and off moving tiles or rolling on pillar-like stones. When I step onto one of the moving tiles, I am moved forward, standing on it. This is different from when I move on the rolling stones, where I have to move my feet as if I were rolling on round pillar-like stones. Learning to move on the rolling pillars takes some time as I have to physically walk backwards – while I move forward in the game. It makes sense logically that to move forward on a round pillar, I have to make a backward walking movement; nevertheless, as I do not feel the roundness under my feet, the backward walking movement feels a bit counterintuitive in the beginning. However, after some time, I start to*

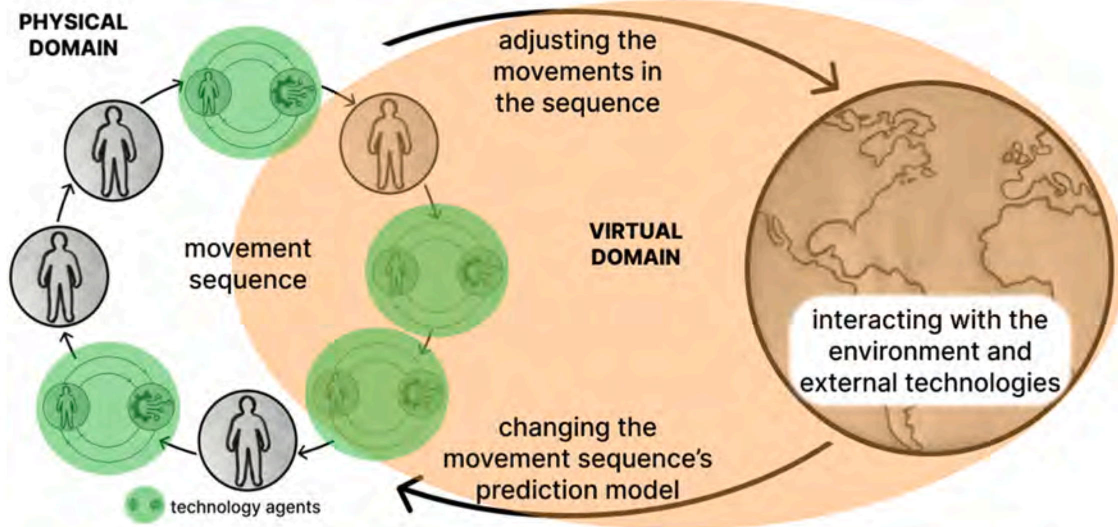


**Fig. 9.** The movement sequence framework illustrates how the player perceives and interacts with the environment, including external technologies, through their movement sequences co-composed with the involved technologies.

*combine the backwards walking movement with the forward movement into one movement*".

In this example, the perceived movement sequence (Sheets-Johnstone, 1981, 2003, 2013) of alternately distributed movements between the virtual and physical domains. For instance, when the physical player actively stepped onto a virtual tile, she felt the tile was passively moving her. Similarly, when the player walked backwards on the pillar-like rolling stones, she perceived herself as moving forward in the virtual domain. Thus, our ability to combine movements into sequences forms our "I cans" (Husserl, 1982; Sheets-Johnstone, 1990, 2003). As we do this through movements distributed across various domains, our "I can" (Husserl, 1982; Sheets-Johnstone, 1990, 2003) encompasses the involved domains, allowing us to transcend those domains perceptually. As demonstrated in the examples above, combining domain-distributed movements into coherent sequences empowered the player to transcend the physical and virtual domains and perceive her movements in both (Fig. 6 and 7).

While both experiences above illustrate how distributed movements create illusions of self-motion ('Illusions of Self-Motion', n.d.; 'Vection', 2020), they emphasise visual perception. In other words, the player's visual perception took precedence in the brain's inference hierarchy (Clark, 2016), as explained in the previous section. However, the example of catching the virtual and audible-only aliens in *Space Agent* demonstrated how auditory perception took precedence in the inference hierarchy (Clark, 2016) since the player had no visual contact with the aliens. By emphasising this mechanism, we aim to highlight how experience can be designed and altered based on how movement sequences (Sheets-Johnstone, 1981, 2003, 2013) are distributed across agents and domains, regardless of the perceptual perspective, as long as it conveys movement (Fig. 9). In the case of the *Space Agent* experience, the sequence of auditory capturing feedback from the virtual domain and the physical arm movements created the perception of movement within the virtual domain. In this sense, we can better understand the perceptual structure of distributed movement sequences (Sheets-Johnstone, 1981, 2003, 2013) by examining movements as combinations of specific sensory perceptions, i.e., as particular combinations of triggered interoceptive, exteroceptive, and proprioceptive inferences and their internal hierarchy (Clark, 2016; Hohwy, 2020; Parr et al., 2022). We will elaborate on this in the following section.

#### *6.2.2. Manipulating the brain's inference hierarchy through distributed movement sequences*

Examining the compositional structure of the movement sequences (Sheets-Johnstone, 1981, 2003, 2013) in the above example of moving on rolling pillar-like stones reveals that the combination of physical and virtual movements, distributed between the player and technology, led the player to experience moving forward on these stones while physically moving backwards. Additionally, this experience highlights the dominance of visual inference in the brain's inference hierarchy (Clark, 2016) and underscores how design can influence the player's proprioceptive inference of their own movement. In contrast to the *Labo VR Blaster* example, in *The Eye of The Temple*, the player combined their exteroceptive and proprioceptive perceptions of movement, actively initiating the sequence that resulted in the illusion of self-motion ('Illusions of Self-Motion', n.d.; 'Vection', 2020). Conversely, the *Labo VR Blaster* gameplay did not incorporate the player's proprioceptive perceptions of movement, as the player was not physically moving forward or backward. Nevertheless, it also created an illusion of self-motion ('Illusions of Self-Motion', n.d.; 'Vection', 2020), albeit as a different experience. We propose that the composition of movement distribution across perceptual stimuli can serve as an experiential dynamic that can lead to varied experiences.

The brain's willingness to combine movements into meaningful experiences, as it tends to stabilise our experience of the world, made the player resolve the incongruence between the exteroceptively perceived virtual forward movement and the proprioceptively perceived physical backward movement into the sensation of moving forward on rolling stones. Additionally, since we perceive movement through any sensory stimulus, our conceptualised movement sequences (Sheets-Johnstone, 1981, 2003, 2013) can encompass a variety of combinations, i.e., balancing exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016). This capability enables us to transcend domains perceptually. However, it also leaves us vulnerable to sensory manipulation, which can lead to exceptional experiences and abilities, such as flying, becoming a robot, and wielding lightsabers.

#### *6.2.3. (Re)configuring perceptual bodily formations as we compose movement sequences*

In the same instance, as movements of a sequence are distributed across domains and agents, they also connect the different agents into one moving body. Recalling *Labo Robot* and how the player and their in-game character formed a tank – or rather, moving like a tank. By crouching, the player loosened the backpack's strings attached to the game controllers, and the in-game character visually turned shape into a tank. These movements together formed a sequence (Sheets-Johnstone, 1981, 2003, 2013) of driving as a tank. The player then moved around, perceiving the virtual environment through the tank movement sequence (Sheets-Johnstone, 1981, 2003, 2013) as she drove into and around the houses, trees, etc.

As the player dynamically composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013) with her in-game character, she could also alter her perceptual bodily formation from a robot to a tank and back to a flying robot. The player and technology constituted the different bodily formations by connecting (Mueller and Isbister, 2014) her movements to the in-game characters in various ways. For example, when the player's in-game character flew, the movement sequences (Sheets-Johnstone, 1981, 2003, 2013) transformed into flying, visually representing a flying robot.

Similarly, the player and the *Move Maker* robot dynamically adjusted their shared moving body as they moved together in a sequence. For instance, when the player moved her foot to engage the robot's wheels, they connected (Mueller and Isbister, 2014) their movements through the proximity sensor, functioning as one cohesive entity. The player could alter her shared movement form by using her arm instead of her foot to interact with the robot's wheels through the proximity sensor. Likewise, the player synchronised her arm and hand movements in the *Superhot* and *Beat Saber* examples with the in-game character's stone gloves and lightsaber movements, respectively, forming bodily representations of wearing stone gloves or wielding lightsabers.

Although the player and the technology in the examples above did not merge into a single physical body, the technology became incorporated into the player's sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) through the coordinated movement sequence (Sheets-Johnstone, 1981, 2003, 2013) and, consequently, into her perceptual space. As they moved in unison, the player could perceive both the virtual and physical environments through feedback inferred exteroceptively from the various technologies she regarded as inextricably linked to herself. This temporarily shaped the player's perceptual range. Otherwise, the player would not have been able to drive as a tank in *Labo Robot*, slice boxes in *Beat Saber*, or navigate the maze with the robot in the Move Maker examples.

### *6.2.4. Incorporating movement characteristics*

As the player incorporated the technologies' movements into her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), she also included their movement characteristics (Yee and Bailenson, 2007). The following report from *Move Maker* demonstrates such an instance:

> "*Understanding how the robot moved was challenging as it moved very sluggishly. As I tried to make it move, my whole body adopted the sluggish movement. My arms started to move abruptly, my torso became stiff, and my head started to move in the same direction I wanted to move the robot – without any direct effect on the robot's directional movement. While the robot had no torso, arms, or head, I moved with my whole body like it did, sluggishly and abruptly. The less it moved, the less I moved - any part of my body. In this kind of slow motion, I felt annoyingly connected to the robot as slow and arbitrary as it felt, and I couldn't shake it off. I was inevitably connected to the robot if I wanted to be a player in the game.*"

In her efforts to make the robot move as desired, the player mimicked it and incorporated its movement characteristics. Leder (1990) explained this phenomenon as "*a natural empathy, where one body takes up the affective responses of another.*" (pp. 80-90) In this instance, the player adopted the robot's sluggish and abrupt movement behaviour in their effort to synchronise with it (Yee and Bailenson, 2007). Although the player was consciously aware that the robot was a technology and not a human being, she interacted with it as if it were human by taking on "*the affective responses*" (Leder, 1990) of the robot. A report from playing *Superhot* describes a similar experience:

> "*Only a pair of hands are visible; the rest of my in-game character's body is invisible. As the hands have a stone-like look, I start to perceive the movements as if I am wearing stone gloves, and my feeling of moving my hands starts to adopt this feeling. As I am unfamiliar with wearing stone gloves, I start boxing randomly into the air when the enemies attack. I cannot see how I move; I can only see the stone gloves. The rest I have to figure out myself. Strangely, I cannot feel my hands hitting anything when I box to hit an enemy. Consequently, I box as much as possible into the air when I get the attackers in range. The missing physical response when I hit the enemies – except the controllers' buzzing - makes me insecure, and I start boxing panickily. As I cannot see my arms, it isn't easy to know what I am doing. However, as the hands seem to be mine as they punch when I punch, I realize it must be my doing when an enemy dissolves into pieces after a series of punches.*"

In this example, the technology also incorporates the player's movement characteristics to some extent. While the player adopted the affective perception of the stone gloves' movement characteristics (Yee and Bailenson, 2007), the technology mirrored the player's panicky punching. In this way, they mutually incorporated each other's movements, "*taking up the affective responses of*" (Leder, 1990) one another and exchanging movement characteristics. Although the *Move Maker* robot exhibited its own sluggish and abrupt movement characteristics defined by its movement algorithm, the in-game characters in *The Eye of the Temple, Superhot*, and *Beat Saber* also displayed their unique movement characteristics influenced by their movement algorithms and technological designs – subtle as they may have been perceived. The argument is that as the player and technology join through combined movement sequences (Sheets-Johnstone, 1981, 2003, 2013), they also incorporate each other's movement characteristics (Yee and Bailenson, 2007). Moreover, these characteristics become part of the player's bodily understanding of the technology. Explained through the human-technology action-perception cycle (Fig. 2, Section 6.1.3), the player generates a predictive model of the punching movement sequence (Sheets-Johnstone, 1981, 2003, 2013) from the sum of their exteroceptive, interoceptive, and proprioceptive perceptions (Clark, 2016; Parr et al., 2022), which the brain hierarchically organises into a stable understanding of the technology. In this process, the brain perceives to move and moves to perceive. In doing so, the player adopts the affective movements of the technologies, in an effort to create a stable experience of the situation (Clark, 2016; Parr et al., 2022). These characteristics become layered in the player's predictive models of the movement sequences (Sheets-Johnstone, 1981, 2003, 2013). The following section explores instances where the brain could not balance the various inferences into stable, coherent movement sequences (Sheets-Johnstone, 1981, 2003, 2013).

### *6.2.5. Dys-appearing bodies and technologies*

When the coherence of a sequence breaks, the involved agents *d-appear* (Leder, 1990) before each other, to use Leder's (1990) term of such an experience. Such experiences occurred with the slowly moving robot in the *Move Maker* (Section 6.2.4), the lack of tangible feedback from punching in *Superhot* (Section 6.2.4), *or* when the player discovered their invisible body at the start of a game of *Beat Saber*: "*I looked down at my body and saw nothing. I just saw the pedestal I was standing on and the deep surrounding it. I almost fell to the floor as I briefly disconnected from my body, believing that it was gone. But soon after, I realised that I was still standing and could move as I was used to, except that I was not sure how.*" The mismatch between the player's expectation to see her body – or any body – and the reality of seeing nothing when she "looked down at herself" caused a momentary glitch that forced the player to reassess her experience and understanding of the situation consciously – and interrelationship with the technology. Neurologically, she encountered an unresolvable prediction error in her predictive processing of the situation, which required her to assess the situation consciously. Nevertheless, phenomenologically, the player could still perceive her body even though it had visually disappeared. She did so through her absent body (Leder, 1990) as a combination of proprioceptive inferences linked to exteroceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) of any consequential actions she perceived to be inextricably linked to her. The perceptual misalignment causing the prediction error created a conscious experience of dys-appearance (Leder, 1990) that forced the player to revise her bodily understanding of the situation. In the *Beat Saber* example of the visually missing body, the player resolved the dys-appearance (Leder, 1990) by moving, thereby gaining perceptual reassurance of her absent body. A similar experience was reported while playing *Superhot*:

> "*As I was used to not having a visible body when playing VR games, I focused mainly on moving around and less on how I moved around. I had no idea how the surroundings perceived my doing and moving around. I made little sound and had no idea of how I looked. I could see my hands but not tell how my arms were construed. Did I have a hand, forearm, elbow, upper part of the arm and shoulder? The stone hands and the invisible yet capable body suddenly became very present as they differed from my perception of myself. It took a while to get used to not seeing or hearing the parts of my body that I was employing. I knew that I managed to hit the enemies with my stone hands. But exactly how it happened, I could not tell.*"

As the player lacked feedback from punching, she experienced a mismatch in her movement prediction model, which made her arm and hand movements dys-appear (Leder, 1990). Similar to the experiences described above, when the coherence of a movement sequence (Sheets-Johnstone, 1981, 2003, 2013) distributed between the player and technology breaks, it can cause their bodies or body parts to dys-appear (Leder, 1990). While the player eventually resolved the dys-appearances (Leder, 1990) in the *Superhot* and *Beat Saber* reports, as she adjusted her movements and re-incorporated them into the sequence, the player never fully resolved the dys-appearance (Leder, 1990) experienced with the robot in the Move Maker report (Section 6.1.3).

With these examples, we point out how player-technology relationships are ongoing processes that build on the player's prediction models (Clark, 2016; Parr et al., 2022) and abilities to adjust their movements to the technology. Sometimes, we perceive this process as smoothly residing in the focal background (Leder, 1990) as the player and technology combine in coherent movement sequences (Sheets-Johnstone, 1981, 2003, 2013), taking up each other's characteristics; at other times, it dys-appears (Leder, 1990) foregrounded in our awareness, forcing us to reconfigure our bodily understanding and relationship with the technology.

#### 6.2.6. Summary

This section presented four experiential dynamics derived from our findings. These dynamics illustrate how movements influence the specifics of the player's experience, complementing the analysis framework established in the previous section. We described how the dynamics lead to different experiences as they affect the composition of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) in various ways. We derived these dynamics by breaking down the sequences into movements and their origins.

We find that the player's ability to transcend domains and bodily annexe (Leder, 1990) technologies perceptually emerges from how the movements of a co-composed sequence are distributed across physical and virtual agents. However, this process is dynamic, and the composition of the sequences varies as the player and technologies interact in diverse ways. As part of this ongoing co-composition of movement sequences (Sheets-Johnstone, 1981, 2003, 2013), the player and technologies connect their movements in various ways, which leads the player to bodily annexe (Leder, 1990) technologies in different ways. We demonstrated how this dynamic enabled the player to experience the ability to perceptually transform into other formations, such as a driving tank or a robot, or possess extraordinary abilities like flying or moving on rolling stones. Moreover, as the player continually adapted her movements to those of the technologies as they co-composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013), she incorporated the technology's movement behaviour (Yee and Bailenson, 2007), as seen with the sluggishly moving robot that the player mimicked in her attempt to understand its behaviour.

While most compositions led to coherent experiences, we highlighted instances where they did not. In these cases, the player and technology dys-appeared before each other. We further interpreted these situations as momentary unresolvable prediction errors that the player had to address consciously. However, this phenomenon is an experiential dynamic that creates awareness of the technologies and the connections between the player and the technologies.

The previous section, Section 6.1, explained the role of movement as a foundation for all experiences and provided a framework for understanding how this role creates embodied experiences with technologies. The experiential dynamics presented in this section highlight how these experiences unfold depending on the specific composition of the movement sequences (Sheets-Johnstone, 1981, 2003, 2013).

In the following section, we provide an in-depth explanation of these findings as we address the research question. We present a framework for understanding how movement underpins every interaction and connection between player and technology during play, grounded in the concept of co-composed movement sequences and human-technology action–perception cycles. Based on this framework, we identify four key experiential dynamics that characterise how players engage with and through movement: (1) distributing movements across domains and agents, (2) (re)configuring perceptual bodily formations, (3) adopting movement characteristics of technological agents, and (4) disrupting co-composed movement sequences. These dynamics highlight the constitutive role of movement in shaping embodied experiences and player–technology relationships.

## 7. Answering the research question

This paper asked the following question;

- What is the role of movement for embodied player experiences and technology relationships during play?

We assert that movement forms the basis for all bodily interactions and, thus, for embodied player experiences and technology relationships during play. Based on a theoretical framework of neuroscientific (Clark, 2016; Friston, 2010; Hohwy, 2020; Parr et al., 2022) and phenomenological (Leder, 1990; Sheets-Johnstone, 1990, 2003, 2017; Zahavi, 2014) explanations for perception, movement, and experience, and empirically informed by the subjective experiences of the primary author, we argue that players make sense of technologies through movements conceptualised into coherent sequences (Section 6.1). The movement sequences serve as the organising principle for interaction in and with technologies. On a more detailed level, movement sequences consist of action-perception cycles (Fig. 1) and supporting movements. As we strive to understand the technologies we interact with, we do so through the human-technology action-perception cycle (Fig. 2)(Section 6.1.3). We theoretically base the human-technology action-perception cycle (Fig. 2) on predictive processing and active inference theories (Friston, 2010; Friston et al., 2017; Parr et al., 2022), expanding their concept of the action-perception cycle (Fig. 1), which suggests that bodily perception arises from the brain's prediction strategies inferred through movement. As we incorporate or respond to technologies through the human-technology action-perception cycle, we further organise the movements into sequential compositions conceptualised as actionable wholes, enabling us to perceive and act meaningfully with the technologies. In this way, the sequences provide a structure for our conceptualisation of technologies and the formation of our interrelationships as either bodily annexed (Leder, 1990) or externally responsive entities. These phenomena were detailed in Section 6 and are conclusively elaborated below.

### 7.1. The player structures embodied experiences in and as movement sequences

Our human body's perception and conceptualisation of movement result from the interplay of exteroceptive, interoceptive, and proprioceptive inferences, which the brain hierarchically balances into stable experiences (Clark, 2016; Hohwy, 2020; Parr et al., 2022). Any such inference results from movement by something or someone, including oneself. Our body conceptualises these perceptions into coherent movement sequences (Sheets-Johnstone, 1981, 2003, 2013) understood as wholes and materialised as distinct movement patterns incorporated into its sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). When our body infers movements to be inextricably linked to its perceptions of its own movement, it deems them as belonging, structures them into meaningful movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and incorporates them as such (Section 6.1.4). Once incorporated as prediction models, the sequences reside in our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) as readily available, recognisable and repeatable patterns. This process is illustrated in Fig. 4.

Because the human body, in the endeavour to understand technologies, organises its movements within a hierarchical balance of exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022), the composition of its movement sequences (Sheets-Johnstone, 1981, 2003, 2013) arises from various inferential combinations. For instance, it merges some movements perceived solely through proprioceptive perception with others perceived only through exteroception. For example, the player captured invisible but audible aliens in *Space Agent* through combinations of their arm movements, yielding proprioceptive perception alongside exteroceptive perception of the movements from their hearing. Similarly, the player exteroceptively perceived and linked the in-game character's movements to their proprioceptive perception of arm and leg movements in *The Eye of the Temple*, which were incorporated as the standing onto moving tiles and rolling on pillar-like stones movement sequences (Sheets-Johnstone, 1981, 2003, 2013). Fig. 4 in Section 6.1.4 illustrates how the player's composition of movement sequences (Sheets-Johnstone, 1981, 2003, 2013), in conjunction with the technologies, forms a joint ability to act and perceive in the world.

### 7.2. Our ability to bodily annexe technology into our sensorimotor repertoire

The human body momentarily integrates technologies as they are perceptually incorporated into its sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) through movement sequences (Sheets-Johnstone, 1981, 2003, 2013). This phenomenon – our ability to incorporate the technology's movements as part of our sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) – is a significant aspect of bodily technology integration, enabling us to make sense of and learn to use technologies. Additionally, as the annexed (Leder, 1990) technologies become part of the player's sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) as actionable abilities, they can also perceive the environment through these technologies. In this way, the player can perceive the virtual environment via their annexed (Leder, 1990) technologies. We have demonstrated how this phenomenon occurs in gaming scenarios, where the player, through her inextricably linked virtual body movements, for instance, can calculate when virtual enemies approach and make countermoves to anticipate contact with them as was the case in the *Superhot* game. The argument is that as long as the body perceives the movements as inextricably linked, it incorporates them into a sequence that forms an accessible skill within its sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), enabling action in the world. This process is illustrated in Fig. 8 in Section 6.2.1.

### 7.3. We understand external entities' behaviour through our movement sequences

Just as the body integrates movements it perceives as its own into it sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), it can also organise perceived external movements into coherent patterns – though as movements belonging to another body. This process is based on how it perceives external movements as sequentially coherent, forming a repeatable pattern relative to its own. We explained this process of recognising external entities in Sections 6.1.5 and 6.1.6. As part of this process, the body recognises multiple external entities– by perceiving how their movements form individual sequences that act relative to each other. Since the sequential nature of a movement sequence (Sheets-Johnstone, 1981, 2003, 2013) also makes it repeatable, we can differentiate external entities based on how they elicit their sequences as individually repeatable. When we move between externally perceived entities, we perceive them as moving differently, constituting what we usually refer to as different perspectives or, in our case, relative movement sequences (Sheets-Johnstone, 1981, 2003, 2013). Consequently, movement sequences (Sheets-Johnstone, 1981, 2003, 2013) represent a behaviour with which we can empathise – or not. Either way, this process illustrates how we perceptually (and emotionally) form our relationships with technologies.

### 7.4. We establish our perceptual boundaries by how we perceive movements in sequences

As we perceive movements as not being inextricably linked to us, we distinguish them from ourselves. In this process, the human body also establishes its perceptual boundaries. Just as the player can perceive the environment through its annexed (Leder, 1990) technologies, the co-composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013) establish their momentarily joint moving body and, with it, their perceptual boundaries against external technologies. This process defines the boundaries of bodies that can interact meaningfully as independent entities within and with the environment. However, as movement sequences (Sheets-Johnstone, 1981, 2003, 2013) dynamically form while the player and technologies move, the perceptual boundaries remain part of this dynamic. Thus, they are not rigid but relatively porous, momentarily constituted through the ongoing composition of movement sequences (Sheets-Johnstone, 1981, 2003, 2013). Consequently, bodies perceive and re-perceive themselves as they unite and separate continuously throughout this process. From our perspective on movement, this process is fundamental to understanding how human-technology relationships emerge and constitute different bodily formations across various domains and agents. In this view, bodies are perceptually delineated by their current movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and abilities, including any annexed (Leder, 1990) technologies.

### 7.5. A framework to understand embodied experiences as structures of movement sequences

In addressing the research question, we propose a framework to analyse movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and their interplay with the environment, as illustrated in Fig. 10. Since movement is foundational to any bodily perception and as we have demonstrated the bodily annexing (Leder, 1990) of technologies, understanding this dynamic in co-composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013) offers a method to analyse how embodied experiences with technologies arise. Consequently, the framework illustrates how the player co-composes movement sequences

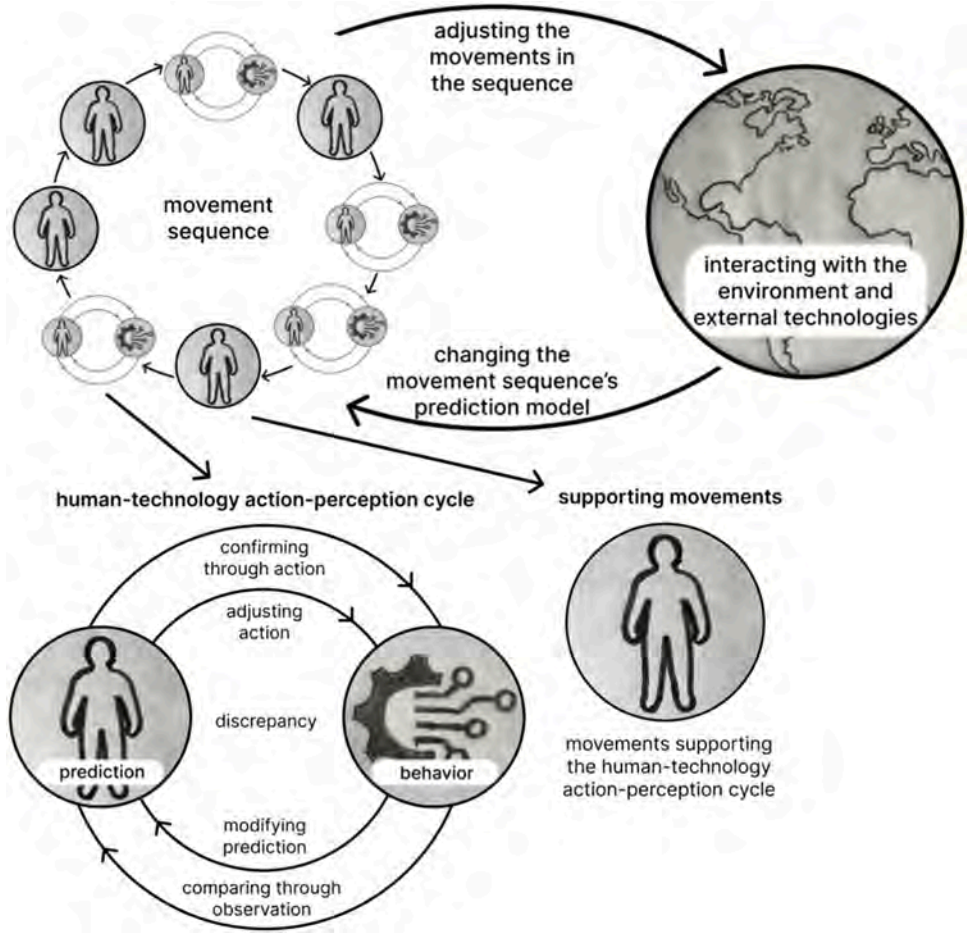


**Fig. 10.** The movement sequence framework illustrates how the player perceives and interacts with the environment, including external technologies, through their movement sequences co-composed with their annexed technologies.

(Sheets-Johnstone, 1981, 2003, 2013) with their annexed (Leder, 1990) technologies and perceives and interacts with the environment through these constellations. By decomposing a movement sequence into its component movements, we can grasp its composition and, thereby, the dynamics that shape it. Thus, understanding the structure of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) establishes a basis for comprehending the embodied structure of human-technology experiences (Fig. 10). We will refer to this framework when addressing the second research question.

### 7.6. *Experiential dynamics in movement sequences*

To further look into how movement shapes embodied experiences, we decomposed the movement sequences (Sheets-Johnstone, 1981, 2003, 2013) using the framework in Fig. 10. Doing so uncovered some of the different compositional dynamics and how they lead to different embodied experiences. Section 6.2 details the dynamics we found in our dataset. We elaborate on these here.

We identified four dynamics within the structure of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) that influenced the player's embodied experiences. The first two dynamics concern how the movements in a sequence are distributed and connected across agents and domains, allowing the player and technologies to form co-constituted acting bodies and temporarily transcend domains. The third dynamic involves how the player incorporates the technology's movement characteristics into their sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003) as part of the human-technology action-perception cycle (Fig. 2). The fourth dynamic highlights how the disruption of an incorporated sequence compels the player to reaffirm their connection with the dys-appearing technology - or body.

#### 7.6.1. *Dynamic one: distributing movements across domains and agents*

When the player, as illustrated in Fig. 9 (Section 6.2.1), annexed (Leder, 1990) technologies as part of her co-composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013), she also transcended agents and domains, at least perceptually. In this manner, the body does not distinguish between virtual, physical, human, or nonhuman agents or domains but only among compositions of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) and combinations of perceptual inferences that it organises in a hierarchical prioritisation (Clark, 2016; Hohwy, 2020; Parr et al., 2022). As the physical or virtual technologies become annexed (Leder, 1990) to the player's sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003), the player achieves a coherent experience of, for example, acting in the virtual domain or a blend of the physical and virtual domains. As we demonstrated, this dynamic can lead to various experiences of illusions of self-motion (Section 6.2.1), while also leading to experiences of altered abilities such as flying or driving as a tank.

#### 7.6.2. *Dynamic two: (Re)configuring perceptual bodily formations*

As the player co-composes movement sequences (Sheets-Johnstone, 1981, 2003, 2013) with the technologies, they also configure perceptually different bodily formations (Section 6.2.3). As this process is dynamic and ongoing, we refer to it as (re)configuring. As we saw, the player changed from perceiving the game environment through the moving body of a tank. We also demonstrated how the player abruptly navigated with the Move Maker robot through a maze. As the player annexed (Leder, 1990) the technology through their co-composed movement sequences (Sheets-Johnstone, 1981, 2003, 2013), the technology became part of the player's perceptual range, contributing to their perceptions. Thus, depending on the distribution of incorporated movements across agents and domains, the players extend their perceptual range to include these agents and domains. This way, the players perceptually reconfigure their bodily boundaries and formation to include their in-game character. This dynamic can lead to embodied experiences of altered bodily formations and extended perceptual range.

#### 7.6.3. Dynamic three: adopting movement characteristics

The second dynamic we discovered was how the player adopted the movement characteristics of the technologies as she incorporated them into her sensorimotor repertoire (Leder, 1990; Sheets-Johnstone, 2003). The player made this adjustment as part of the movement adjustments necessary to create a stable prediction model (Fig. 2) and, thus, a movement sequence (Sheets-Johnstone, 1981, 2003, 2013) (Fig. 4) (Section 6.1.4). We observed that the player perceived herself as wearing stone gloves or began moving abruptly and sluggishly when connecting to a robot that moved sluggishly. This dynamic can create an experience of becoming like the technology, or being the in-game character, as we adopt its movement characteristics while merging in movement sequences (Sheets-Johnstone, 1981, 2003, 2013).

#### 7.6.4. Dynamic four: disrupting co-composed movement sequences

In contrast to how the player incorporated the technology's movements in co-composed sequences, disrupting these sequences separated the player from the technology, creating an awareness of its dysfunction. We observed this dynamic when the player could not see her in-game character's body in the VR game environment (Section 6.2.5), and when the sluggishly moving robot in Move Maker moved too sluggishly or unexpectedly. Disruption of movement sequences (Sheets-Johnstone, 1981, 2003, 2013) occurs when the coherence of a sequence is broken, forcing the player to consciously adapt their movements or alter their expectations of the technology. This dynamic can lead players to make conscious choices and adjust their interactions and relationships with the technologies.

## 8. Discussion

This paper's main argument is that embodied player experience and technology relationships emerge through movement and that movements combine in distinct sequences across agents and domains. In this understanding, we do not perceive the physical player and their in-game character as moving in parallel (Miller, 2012) or producing each other in turn (Keogh, 2018). Instead, we argue that they move together in coherent movement sequences (Sheets-Johnstone, 1981, 2003, 2013) or as distinct bodies characterised by their unique movement sequences. In these endeavours, the player's body does not pre-reflectively (Merleau-Ponty and Smith, 2006) distinguish between domains or agents. Instead, it differentiates between movements and how they are perceived as belonging to them or not. Consequently, conceptualisations of the players' relationship to their in-game character as constituting a surrogate (Gee, 2008) or metaphorical body (Spiel and Gerling, 2019), or vicarious embodiment (Klevjer, 2006), belong to a higher level of reflection than the pre-reflective (Merleau-Ponty and Smith, 2006) moving body. From our movement perspective, we do not assert that the human body distinguishes between such different domains: physical, virtual, human and nonhuman. The body pre-reflectively (Merleau-Ponty and Smith, 2006) perceives and distinguishes movement as either inextricably linked to it or not. Therefore, there is no perceptual difference between the domains, only specific perceptual compositions of the player's exteroceptive, interoceptive, and proprioceptive inferences emerging in and from movements.

Viewing embodied experiences as compositions of exteroceptive, interoceptive, and proprioceptive inferences (Clark, 2016; Hohwy, 2020; Parr et al., 2022) can further illuminate the discussion surrounding players' perspectives of the in-game characters, whether perceived as first-person or third-person perspectives (Klevjer, 2006), present or absent (O'Brien, 2018) or as double perception (Martin, 2012). Based on the predictive processing and active inference frameworks (Clark, 2016; Hohwy, 2020; Parr et al., 2022), combined with a phenomenological understanding of movement (Leder, 1990; Sheets-Johnstone, 1981, 2003, 2013; Zahavi, 2014), we argue that embodied experiences and player-technology relationships emerge from the brain's hierarchical balance of perceptual inferences informed by movement. Classifying in-game characters as present or absent (O'Brien, 2018), first or third-person (Klevjer, 2006) or an image (Martin, 2012) primarily relies on visual perception. From our movement perspective, embodied experiences arise through a hierarchical balance of inferences from all available senses (Clark, 2016; Parr et al., 2022). This explanation clarifies the distinction between present, absent, first-, or third-person (Klevjer, 2006; O'Brien, 2018) in-game characters as variations in movement perceptions experienced through either our absent body (Leder, 1990) or as our mirror image (Bianchi and Savardi, 2008; Savardi and Bianchi, 2005). In this context, an absent character – one that is not visible – does not become incorporeal (O'Brien, 2018). Instead, we can explain its "absence" as movements perceived through non-visual senses, constituting part of what Leder (Leder, 1990) refers to as our absent body. From these reflections, we assert that a body's conceptuality (e.g., absent/present, first/third-person, surrogate, vicarious, or metaphorical) does not define it perceptually; instead, it is characterised by its coherently perceived movement sequences (Sheets-Johnstone, 1981, 2003, 2013), irrespective of its material composition or perceptual conveyance. Nevertheless, we can influence these elements through our designs.

### 8.1. Game mechanics provide the conditions for movement

We wish to address the notion that movement is a mechanic we can add to a design (Bianchi-Berthouze, 2013; Isbister, 2016; Isbister et al., 2011). Positioning movement as a mechanic inherently suggests that it is an element we can add and consequently do without – as if it is not already present. While we acknowledge that movement is not the sole constituent of gameplay, we maintain that it forms the foundation for gameplay. Rather than viewing movement as a mechanic, we argue that mechanics are activated through movement. The mechanics influence *how* movement unfolds and combines into sequences. Players and technologies come together in movement sequences as a collaborative effort, shaped by their specific preconditions and environmental conditions (Matjeka, 2020; Matjeka et al., 2021; Matjeka and Wang, 2022). Thus, the mechanics establish the conditions for movement (Eriksson et al., 2019; Matjeka et al., 2021; Matjeka and Wang, 2022), and the players and technologies realise them. Therefore, instead of thinking of movement as something designers can simply add to a design, designers should design for movement through the mechanics.

We demonstrated four dynamics that influence the movement sequences. Designers can create mechanics based on these dynamics. The various examples in this paper demonstrate how. For instance, the movements' connecting points (Mueller and Isbister, 2014) between the physical player and the Move Maker robot (Section 6.2.4) conditioned their combined movement sequence in a specific manner, experientially combining the player and robot in a sluggishly moving playing body. Additionally, the distribution of movements between the player and the in-game character in the *Labo VR* game (Section 6.2.1) illustrates how a mechanic can influence movement. This distribution conditioned the player to move forward in the game without any control.

Furthermore, the player adopted the technology's movement characteristics in the Move Maker example (Section 6.2.4), a phenomenon also noted by Yee and Bailenson (2007) and Isbister (2016). The robot's specific design caused the player to move in distinct ways, significantly influencing the player's possibilities for movement and, consequently, her embodied experience and relationship with the robot. These examples demonstrate how the mechanics shape the conditions for movement, while the player and technologies work together to realise these movements. However, as the mechanics exert a physical and psychological impact on the player experience, they also raise ethical issues. While an ethical discussion is beyond the scope of this paper, it holds great importance and should be a consideration in any design. We emphasise this argument and encourage all designers and researchers to engage in ethical concerns in their designs and research of movement, embodied player experiences, and their relationships with technology.

### 8.2. Revisiting the theoretical framework

The theoretical framework developed in this paper draws on predictive processing (Clark, 2016; Hohwy, 2020), active inference (Friston, 2010; Friston et al., 2017; Parr et al., 2022), and phenomenology (Leder, 1990; Sheets-Johnstone, 1990, 2003, 2017; Zahavi, 2018) to explain how movement forms the basis for embodied player-technology relationships. As the predictive processing (Clark, 2016; Hohwy, 2020) and active inference (Clark, 2016; Hohwy, 2020) frameworks provide a unified way of understanding perception and experience as a dynamic process of prediction and active correction, they do not prescribe a single "normative" method for interpreting this process. Instead, they allow for explaining the variations across different predictive strategies (Clark, 2016; Van De Cruys et al., 2014), including those related to neurodiverse profiles.

As such, the strengths of the predictive processing (Clark, 2016; Hohwy, 2020) and active inference (Friston, 2010; Friston et al., 2017; Parr et al., 2022) frameworks lie in their openness to atypical prediction strategies, allowing for the inclusion of diverse neurobiological profiles without treating them as deviations from a norm. Together, these frameworks offer insight into how individuals experience interaction differently as they employ various prediction strategies in their weighing of sensory input, prediction priors, and sensitivity to prediction errors. This is especially valuable in HCI, where experience depends on both the technology's affordances and the user's perceptual and bodily orientation. Thus, the framework provides a theoretical frame for understanding individual variability in how technologies are integrated, resisted, and sensed through movement.

The combination of phenomenology (Leder, 1990; Sheets-Johnstone, 1990, 2003, 2017; Zahavi, 2018), predictive processing (Clark, 2016; Hohwy, 2020) and active inference (Friston, 2010; Friston et al., 2017; Parr et al., 2022) theories further strengthened our theoretical framework. As phenomenology focuses on lived experience and embodied meaning-making, predictive processing and active inference provide a neurobiological account of how these experiences emerge. In this sense, this combination offers both subjective and functional perspectives on embodied player experiences and technology integration and comprehension, linking movement, perception, and experience.

However, novel frameworks also present challenges. As an emerging framework, predictive processing (Clark, 2016; Hohwy, 2020) and active inference (Friston, 2010; Friston et al., 2017; Parr et al., 2022) can be interpreted in various ways, thereby risking overgeneralisation or being applied too abstractly. As such, essential knowledge, such as specific lived contexts, particularly in relation to non-normative perceptual experiences, risks being neglected or overlooked. Nevertheless, in this study, the framework helped articulate how movement sequences become meaningful through loops of human-technology action-perception cycles, enabling us to understand the integration and comprehension of technologies through connections between bodily sensation and perceptual inference. Still, the usefulness of the frameworks ultimately relies on how it is operationalised through lived experience. This remains an area for further development in HCI and game design research.

Lastly, we would like to address a comparison to disability studies. Although the study was not conducted initially with a disability or neurodiversity framing, one of the authors later received an autism diagnosis. This has shaped how we reflect on and write about the findings, particularly in relation to embodied experience and prediction. While the paper is not positioned as autistic-led research, we recognise that aspects of the work – including its focus on sensory dynamics, embodiment, and perception across human and technological agents – may be relevant to ongoing discussions in disability studies and neurodiversity-informed HCI (Spiel and Gerling, 2019; R. M. Williams et al., 2022). We hope future work can further develop these connections.

## 9. Limitations and future research

This study has provided a structured approach to analysing embodied experiences with technology, grounded in phenomenology and neuroscience, and illuminated through empirical autoethnographic data. While this methodological approach was chosen for several reasons, it also has limits. The main limitations are related to the study's generalizability and transferability. Due to the qualitative nature of the research and the inclusion of single-person, autoethnographic, subjective data, the study results are not statistically generalisable. However, as phenomenologically described structures of embodied experience, they are transferable to other studies. The empirical autoethnographic data further exemplify possible experiences explained using this structure, but do not serve as conclusive evidence. Consequently, the structure of embodied experiences presented in this study does not offer a definitive neurological explanation of embodied experience with technology. Instead, it provides a philosophical understanding of how the body organises its experiences in and with technologies through movement. It achieves this by drawing on other phenomenological understandings of embodied and movement experience and how we can explain these using neuroscientific evidence-based theories demonstrated through subjective accounts of lived experience.

The data on subjective lived experiences was restricted to an autoethnographic inquiry conducted from the first-person perspective of an autistic researcher with a PhD in HCI and game studies and over ten years of prior professional experience as a movement teacher and performer. While this background, without doubt, has influenced the study, it is also presented to ensure transparency. Consequently, the researcher acted as both the leading investigator and subject. This combination presents its limitations. For example, the documentation of the experiences was constrained by this dual role; the experiences were reported after the playing sessions rather than during them. As a result, this constraint has led to increased reflection on experiences rather than an immediate approach. Although some sessions were video recorded, the experiences were still assessed retrospectively.

As part of a reflexive and transparent research practice, the author discloses being autistic. This disclosure is not intended to reframe the study as autistic-led or framed within disability studies, but rather to acknowledge the embodied and subjective perspective through which the research was conducted. Autism is understood here as a form of neurodivergence, a natural variation in cognitive functioning, rather than necessarily a disability. Whether or not an individual identifies as disabled is a personal and context-dependent decision; in this case, the author does not. While we recognise and value the critical contributions of disability-centred scholarship within HCI, e.g. (Spiel et al., 2022; R. M. Williams et al., 2022), this study does not utilise a disability framework; instead, it approaches the research from a phenomenological and neurocognitive perspective. Reframing the paper through a disability studies lens would require different research questions, aims, and methods than those pursued here. The inclusion of this disclosure serves to honour the epistemic standpoint of the researcher within an autoethnographic and phenomenologically-informed methodology (Kapp, 2020; Walker, 2021; Yergeau, 2018).

The empirial study was limited to a selection of seven games. While these games were selected to represent a diversity of game forms and technologies, they were restricted to include VR technologies (Oculus 2.0, HTC Vive), mobile AR (iOS, Android), console (Nintendo Switch), and physical, modular-based games (Move Maker). Moreover, they were chosen based on sensory considerations, as we aimed to include a diverse range of sensory stimulation in the games. As such, they covered hearing-emphasised technologies (binaural sound technology in combination with gesture-based interactions in the *Space Agent* game), full-body inclusion in the HTC Vive technology (*The Eye of the Temple*), and the Nintendo Labo VR and *Labo Robot* games, which combined full-body physical controllers with console gameplay. Lastly, we include the modular-based play system Move Maker, which contains different modules that stimulate the visual, tactile, auditory, and kinesthetic senses. Despite the attempt to cover a wide range of technologies and game forms, the study is still limited to these technologies. Future technologies and combinations may yield additional experiences that further illuminate and expand the results of this study.

### 9.1. Future research

Integrating predictive processing and active inference (Clark, 2016; Hohwy, 2020; Parr et al., 2022) frameworks with the phenomenology of movement establishes a conceptual bridge that can be further developed as a methodology for engaging with embodied experience in human-computer interaction (HCI) and game studies. This integration offers insights into the structures and dynamics of lived experience, aligning with the processes described in the predictive processing and active inference frameworks. Moreover, since this integration is already recognised as computational phenomenology (Limanowski and Friston, 2020; Sandved-Smith et al., 2020), this study also indicates potential future work utilising the presented structure and dynamics to create computational models that can predict and better facilitate embodied interactions and the incorporation of technologies in future interaction and game design.

Lastly, we have not included related topics regarding how embodied experiences with technologies unfold in movement, such as bodily ownership and agency. Nevertheless, since experiences and behaviour are generally rooted in movement, we recognise a close connection between movement and these topics. Therefore, investigating this connection might benefit future HCI and game design research on embodied experiences with technologies.

## 10. Conclusion

This paper has examined how we make sense of, experience and constitute our relationships with technologies through movement. Contributing to the debate around embodied experiences, embodiment and the bodily constitution of player-technology relationships in the HCI and game studies literature, we asked:

- What is the role of movement for embodied player experiences and technology relationships during play?

We approached this question by arguing that movement is the origin of all behaviour, including perception, interaction, and experience. This statement does not imply that movement is the only factor composing different experiences or that it has no connection to other layers of experience, such as culture or narrative; instead, it emphasises that the primary basis for any interaction and perception begins with movement. Game experiences, somaesthetic experiences, cultural experiences, performances, and so forth originate in movement. As these layers of experience are well-documented in the HCI and game studies literature, this paper argues that a missing piece in our puzzle of understanding the design and research of embodied experiences and player-technology relationships is comprehending the structure and dynamics that stem from movement.

Through a phenomenologically grounded, autoethnographic analysis of seven diverse games, we developed a framework that combines predictive processing, active inference and movement theory to explain how players incorporate technologies into their action-perception cycles, creating what we call human-technology action-perception cycles. This framework highlights the role of co-composed movement sequences between players and technologies in shaping the player's embodied sense of self and agency across physical and virtual domains.

From this framework, we identified four experiential dynamics: the distribution of movement across agents and domains, the (re)configuration of bodily formations, the adoption of technological movement characteristics, and the disruption of co-composed sequences. These dynamics demonstrate how movement is not just a means of interaction but a medium through which players enact, extend, and negotiate their embodied relationships with technologies.

This study presents a novel theoretical model that links neuroscience and phenomenology, providing fresh insights into the structure and dynamics of embodied play. It also introduces an autoethnographic approach to movement-based analysis in game and interaction design, demonstrating how first-person, embodied inquiry can produce both theoretical and design-relevant knowledge.

In presenting these investigations, we seek to expand the discussion of embodiment and embodied phenomena in HCI and game studies literature. We aim to inspire and advance the field of bodily experiences, player-technology relationships and understanding of embodiment and technologies in general. We recognise the importance of future debates critiquing, appreciating, and building upon this work, and we eagerly anticipate your valuable contributions to these discussions.

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## CRediT authorship contribution statement

**Louise Petersen Matjeka:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hanna Elina Wirman:** Writing – review & editing, Validation, Supervision, Conceptualization. **Beatrix Vereijken:** Writing – review & editing, Validation, Supervision. **Florian 'Floyd' Mueller:** Writing – review & editing, Validation, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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