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Motion extrapolation in Sport Expertise: Representational Momentum and Representational Gravity in Volleyball Athletes

Extrapolação do movimento em Perícia Desportiva: Momento Representacional e Gravidade Representacional em atletas de Voleibol

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Psicologia da Saúde e Neuropsicologia, realizada sob a orientação científica do Doutor Nuno de Sá Teixeira, Professor Auxiliar Convidado do Departamento de Educação e Psicologia da Universidade de Aveiro.

Dedico este trabalho aos meus pais pelo incansável apoio.

o júri

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palavras-chave

voleibol, perícia desportiva, perceção do movimento, momento representacional, gravidade representacional

resumo

Quando as pessoas indicam a localização onde um alvo em movimento desaparece repentinamente, surge um erro sistemático para frente, na direção do movimento, e para baixo, na direção da gravidade. Esses desfasamentos espaciais foram denominados, respetivamente, Momento Representacional e Gravidade Representacional, e acredita-se que reflictam a internalização de invariantes físicos ecologicamente relevantes, úteis para a antecipação de estados futuros de um evento. Pesquisas anteriores mostraram que os especialistas, particularmente para eventos dentro da sua área de especialização, exibem um Momento Representacional aumentado, que representa capacidades de antecipação e extrapolação de movimento aprimoradas. No entanto, a influência da perícia na Gravidade Representacional, particularmente em contextos onde a antecipação de objetos em movimento vertical é crucial, permanece pouco estudada. Este estudo visa colmatar esta lacuna centrando-se no Voleibol como contexto de especialização devido à prevalência de bolas de movimento vertical rápido. Atletas e não atletas de voleibol indicaram a localização de desaparecimento de um alvo que se movia a uma velocidade constante ou sujeito a padrões de aceleração/desaceleração, inserido num contexto de voleibol ou neutro. Os resultados revelaram que, para o contexto do Voleibol, os atletas, mas não os não-atletas, revelaram uma tendência significativa de perceber erroneamente os alvos que se movem ao longo da diagonal esquerda para serem desfasados para diante e além do que seria esperado devido apenas ao Momento Representacional. Esse achado é discutido em relação às estatísticas naturais dos jogos de Voleibol, onde as trajetórias de bola cruzada, principalmente pelo atacante de zona 4, são mais prevalentes, rápidas e ofensivas, exigindo melhor antecipação para serem intersetadas com eficiência.

keywords

Volleyball, Sports Expertise, Motion Perception, Representational Momentum, Representational Gravity

abstract

When people indicate the vanishing location of a moving target that suddenly disappears, a systematic error forward, in the direction of motion, and downward, in the direction of gravity, emerge. These spatial displacements were coined, respectively, Representational Momentum and Representational Gravity, and are believed to reflect internalized ecologically relevant physical invariants useful for the anticipation of future states of an event. Previous research has shown that experts, particularly for events within their area of expertise, exhibit increased Representational Momentum, indicating enhanced motion extrapolation and anticipation. However, the influence of expertise on Representational Gravity, particularly in contexts where anticipation of vertically moving objects is crucial, remains understudied. This study aimed to address this gap by focusing on Volleyball as a context of expertise due to the prevalence of fast vertically moving balls. Volleyball athletes and non-athletes indicated the perceived offset location of a smoothly moving target, which moved at a constant speed or experienced acceleration/deceleration, embedded either in a Volleyball or neutral context. Outcomes revealed that for the Volleyball context, athletes, but not non-athletes, revealed a significant trend to misperceive targets moving along the left diagonal to be further displaced forward beyond what would be expected due to Representational Momentum alone. This finding is discussed in relation to the natural statistics of Volleyball games, where crossed ball trajectories, particularly by the outside hitter, are more prevalent, fast and offensive, requiring better anticipation to be efficiently dealt with.

CONTENTS

INTRODUCTION

Studies developed around the human visual perception of movement, highlight the presence of systematic errors in the spatial identification of moving objects, called Representational Momentum and Representational Gravity (Hubbard, 2005, 2015). These phenomena arise due to internalized mental representations of physical principles, including gravity (Lacquaniti et al., 2013; Zago & Lacquaniti, 2005), which prove to be useful in anticipating the perceived dynamics, and thus, facilitating possible future motor interactions (Kerzel & Gegenfurtner, 2003; Zago et al., 2009). Previous research highlights that these perceptual displacements, particularly Representational Momentum when measured for apparent or implied motion, are heightened for experts when exposed to dynamic events of their areas of expertise (Blättler et al., 2010, 2012; Chen et al., 2021; Jin et al., 2017; Ménétrier et al., 2017; Nakamoto et al., 2015). The present work aims to clarify up to what degree these effects of expertise extend to smooth continuous motion, more akin to actual events, and to other spatial perceptual displacements, such as Representational Gravity. We start by briefly overviewing relevant literature both in what refers to spatial mislocalisation phenomena and how expertise impacts on those.

Spatial Mislocalisation Phenomena: Representational Momentum and Representational Gravity

When people indicate the perceived vanishing location of a moving target, a systematic error forward in the direction of motion, and downward in the direction of gravity, systematically emerge. These phenomena are called, respectively, Representational Momentum and Representational Gravity (for reviews see Hubbard, 2005, 2015, 2020).

Representational momentum was first reported by Freyd and Finke (1984) and taken as an empirical instance of a Dynamic Mental Representation. In that seminal study, observers were shown a sequence of three rectangles undergoing apparent rotation. Afterwards, a fourth rectangle (mnesic probe) was presented with either the same or a different orientation than the last one in the inducing sequence. Observers were found to more likely accept as having the same orientation a rectangle which was actually further rotated in the direction of implied motion. To account for this outcome, the authors raised the hypothesis that, after the sudden halting of a visual dynamic event, its visual representation could not be stopped instantaneously and the continuity of the physical movement was assumed, leading to a dynamic mental analogue of the object's expected physical dynamics (Freyd, 1983, 1987). Accordingly, the magnitude of Representational Momentum was found to increase with increases in the implied speed (Finke et al., 1986; Freyd & Finke, 1985) and with increases in the retention interval between the halting of the inducing sequence and probe's onset (until a maximum at about 300 ms; Freyd & Johnson, 1987; Kerzel, 2000). Furthermore, it was reported that cognitive expectations affected Representational Momentum – for instance, target's which the observers were led to believe to represent a space rocket resulted in bigger Representational Momentum for implied upward motion, in comparison with the same target when interpreted as a church building (Reed & Vinson, 1996). Finally, Representational Momentum was reported even for static pictures implying motion (Freyd, 1983) and to be increased for downward apparent motion (Bertamini, 1993; Nagai et al., 2002). Over the last decades, these spatial displacement phenomena, in general, and Representational Momentum, in particular, came to be increasingly interpreted as reflecting the functioning of motion extrapolation perceptual mechanisms (De Sá Teixeira, Bosco, et al., 2019; Hubbard, 2005; Kerzel & Gegenfurtner, 2003), in the form of Internal Models and so as to overcome neural delays in the relay of dynamic information (Nijhawan, 1994, 2002, 2008), and which embody ecological relevant physical invariants (such as momentum, friction, and gravity; Hubbard, 2005).

Be it as it may, a significant expansion of the scope of Representational Momentum studies came with the finding that a similar phenomenon emerged for smoothly moving targets and direct spatial localization responses (e.g., with a computer mouse; Hubbard, 1990, 1995, 1997, 2005; Hubbard & Bharucha, 1988). Notably, in those studies, and besides a forward perceptual displacement in the direction of motion, there was also a systematic downward displacement in the direction of gravity, a phenomenon aptly coined Representational Gravity (Hubbard, 1990). The latter emerges both as a perceptual displacement downward, in a direction orthogonal to the trajectory of horizontally moving targets, but also as an increased forward displacement, in the direction of motion and beyond Representational Momentum for downward vertically moving targets (for targets moving upward in a vertical trajectory, Representational Momentum is instead decreased, disclosing the joint contribution of Representational Momentum and Representational Gravity for vertically moving targets; Hubbard, 1993, 1995)

In order to distinguish between hypothesized perceptual phenomena, such as Representational Momentum and Representational Gravity, and the empirically observed displacements thought to reflect the latter and given in terms of the difference between the actual and the indicated offset location of a moving target, it is common to refer to displacements measured along the target's motion trajectory as M-displacement and, when relevant, the displacement orthogonal to the target's trajectory as O-displacement (Hubbard, 1990). Thus, Representational Momentum is invariably reflected upon M-displacement, albeit a significant contribution of Representational Gravity might further increase or decrease M-displacement for targets moving, respectively, increasingly downward or upward (De Sá Teixeira, 2014, 2016). On the other hand, O-displacement reflects Representational Gravity solely for targets moving horizontally (Hubbard, 1990, 2001, 2005; Hubbard & Bharucha, 1988).

Importantly, that M-displacement reflects Representational Momentum plus a variable contribution of Representational Gravity, results in its magnitude to periodically vary as one considers changing orientations of target's trajectory. Starting with a rightward moving target, M-displacement reflects solely Representational Momentum. As the orientation of the target's trajectory is rotated counter-clockwise, M-displacement decreases until a minimum for an upward moving target (that is, moving against the gravitational pull). For further rotations, M-displacement increases again until reaching the same magnitude for leftward moving targets as the one found for rightward motion. Finally, as the orientation of the target is still further rotated, M-displacement continues to increase until a maximum for downward moving targets (moving along the gravitational pull). This periodicity of M-displacement as a function of the orientation of target's trajectory renders it amenable for a Fourier decomposition (Sekuler & Armstrong, 1978), where Representational Momentum is given by a constant and Representational Gravity by the first harmonic term on the Fourier series (reflecting one directional increase in M-displacement – downward – per rotation of the target's trajectory). That is, both phenomena can be disentangled from M-displacement and its magnitudes independently estimated. Employing this logic, De Sá Teixeira (2014) reported that Representational Gravity acts along the observers' main body axis (idiotropic vector), rather than the actual gravito-inertial vector (see also De Sá Teixeira et al., 2017; De Sá Teixeira & Hecht, 2014), that both phenomena possess disparate time courses (De Sá Teixeira, 2014, 2016; see also De Sá Teixeira et al., 2013), that Representational Momentum but not Representational Gravity is significantly reduced when smooth pursuit eye movements are prevented (De Sá Teixeira, 2016; see also Kerzel, 2000, 2002, 2003, 2006), and that M-displacement increases beyond Representational Momentum for targets moving along the horizon implied by the visual context (Representational Horizon; De Sá Teixeira et al., 2023; Freitas & De Sá Teixeira, 2021).

Furthermore, and based upon these studies, Representational Gravity came to be increasingly linked with putative internal models of gravity, thought as a neural structure which explicitly computes the expected dynamics due to Earth's gravity, so as to fine-tune motion extrapolation and aid sensorimotor interactions (Delle Monache et al., 2015, 2021; Lacquaniti et al., 2013, 2014; Lacquaniti & Maioli, 1989a, 1989b; McIntyre et al., 2001; Moscatelli & Lacquaniti, 2011; Zago et al., 2009; Zago & Lacquaniti, 2005). Current empirical evidence posits a critical role for a network of brain regions, in and around the Temporo-Parietal Junction (TPJ), as the neurophysiological substrate for such an Internal Model of Gravity (Bosco et al., 2015; De Sá Teixeira, Bosco, et al., 2019; Lacquaniti et al., 2013, 2014). Functionally, this region plays a role in the integration of multisensory gravitational signals (both visual, vestibular and somatosensory) and seems to be involved in visual anticipation of the effects of gravity (for a review see Delle Monache et al., 2021). Notwithstanding, all Representational Gravity studies to date used targets moving at a constant speed, in striking contrast with the dynamics of objects subjected to Earth's gravitational pull, accelerating downward at about 9.8 m/s^2. It is still to be ascertained if and how the magnitude of Representational Gravity varies for targets subjected to patterns of acceleration/deceleration, as do real-world objects.

Spatial Mislocalisations and Context Specific Expertise

To the degree that spatial localization phenomena, such as Representational Momentum and Representational Gravity, reflect the output of specialized internal models, it stands to reason that the latter could be further refined for highly specific contexts, accounting for domain-specific expertise and, consequently, for experts to be able to anticipate future dynamics further than novices (André & Fernand, 2008; Didierjean & Marmèche, 2005; Doane et al., 2004; Ericsson & Kintsch, 1995; Ferrari et al., 2006). Accordingly, and for example, expert drivers exhibit greater Representational Momentum than novice drivers (Blättler et al., 2010, 2012; Ménétrier et al., 2017), albeit solely for driving related dynamic events (see Blättler et al., 2010, experiment 2). Likewise, expert aircraft pilots, in comparison with novices, show greater Representational Momentum when shown stimuli implying a landing sequence (Blättler et al., 2011).

Of relevance to the present work, and due to its intrinsic dynamic nature ripe for being better anticipated with practice (De Azevedo Neto & Teixeira, 2011; Gorman et al., 2012; Williams & Elliott, 1999), need for careful articulation between perception and action timing (DeLucia & Liddell, 1998; Hubbard, 2005; Jin et al., 2017; Nakamoto et al., 2015; Nijhawan, 2008; Nijhawan & Wu, 2009; Tresilian, 1995), and unquestionable level of expertise involved

(Williams et al., 2000; Williams & Ericsson, 2005), sports, in general, and fast ball sports, in particular, quickly came under the focus of researchers. Chen and colleagues (2021), for instance, report greater Representational Momentum for expert dancers with scenes depicting a common ballet jump. Nakamoto and colleagues (2015) and Anderson and colleagues (2019) focused their attention, respectively, on baseball and rugby players, showing a higher Representational Momentum and, hence, further anticipation and cognitive extrapolation of dynamic events than non-athletes. Finally, Jin and colleagues (2017) not only report bigger Representational Momentum for badminton scenes by expert players, in comparison with novices, but show, through a longitudinal study, how that enhanced motion anticipation increases with training.

Taken together, these studies strongly suggest that, at least in part, expertise might be linked with enhanced cognitive extrapolation and motion anticipation, arguably due to a better refinement of internal forward models (De Azevedo Neto & Teixeira, 2011), made manifest by perceptual displacements such as Representational Momentum (Hubbard, 2005). Notwithstanding, two points are worth notice. On the one hand, most of the studies that explored Representational Momentum in sports contexts employed implied or apparent motion stimuli – it is still to be explored up to what degree similar effects emerge for smoothly moving targets, with dynamics closer to actual motion. On the other hand, and partially due to the focus on implied motion stimuli, the effects of expertise on other spatial displacement phenomena besides Representational Momentum, such as, and prominently, Representational Gravity, is still to be ascertained. The latter point is of particular relevance for it is difficult to conceive of any other activity, besides ball sports, where one is more clearly and consistently exposed to the effects of Earth's gravitational pull on mobile objects.

The Present Study

The experiment to be presently discussed has two main, although interrelated, goals. First, it was designed to explore how sports expertise, particularly Volleyball, modulates spatial mislocalisations of smoothly moving targets. Under the reasoning that expertise translates into improved motion extrapolation to the degree that the shown dynamic event is consistent with the specific context of expertise (Blättler et al., 2010; Chen et al., 2021; Jin et al., 2017; Nakamoto et al., 2015), it stands to reason that bigger Representational Momentum should be also found with smoothly moving targets (as actual volleyballs) and direct spatial localization (involving a motor action not unlike the intersection of a volleyball). Furthermore, the present study also sought to explore up to what degree expert volleyball athletes display increased

Representational Gravity, as compared with non-athletes, for stimuli specifically consistent with the Volleyball context, where balls routinely move with a non-negligible vertical vector. As a second goal, the present experiment aimed to ascertain if and how patterns of acceleration/deceleration of the target, compatible with it moving under a gravitational pull, impact on the magnitude of Representational Gravity and, in doing so, up to what degree volleyball athletes showed a heightened sensitivity to motion dynamics in their context of expertise.

To do so, volleyball athletes and non-athletes volunteered for a standard spatial localization task, where they had to directly indicate (with the aid of a trackball) the offset location of a moving target. The target was given by a circular object moving smoothly on the screen either at a constant speed, subjected to an acceleration or deceleration. For the volleyball context, the target depicted a volleyball and the background visual context a volleyball court; for the neutral context, the target was simply a uniformed coloured circle moving over a blank background. Measures of Representational Momentum, Representational Gravity and Representational Horizon were individually estimated with a Fourier decomposition procedure, and taken as the dependent variables.

METHOD

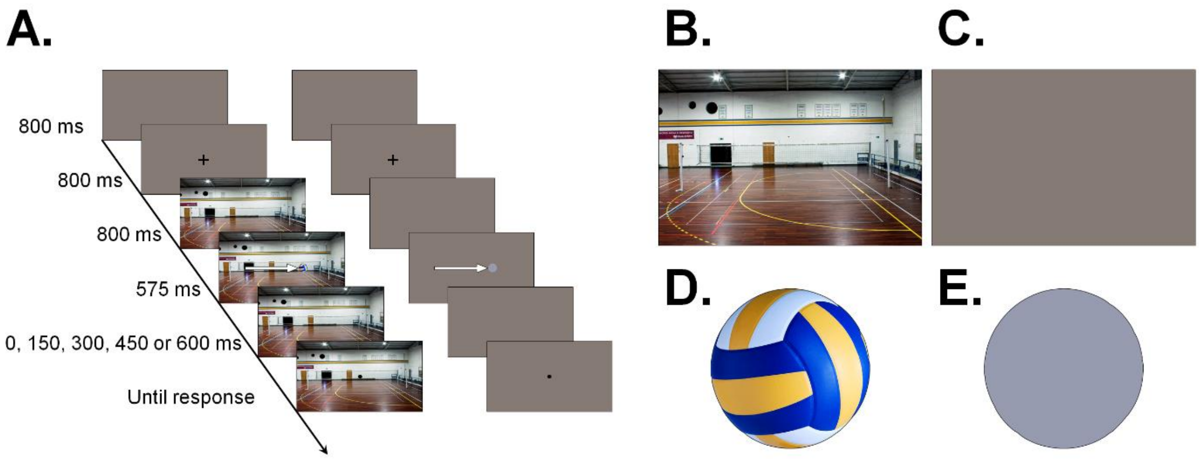
Participants.

Sixty-one participants (16 males and 45 females), with ages between 18 and 38 years old (*M* = 21.29; *SD* = 2.83), volunteered for the experiment in exchange for partial course credits or a €5 voucher. All participants were unaware of the purposes of the experiment and had normal or corrected-to-normal vision. Thirty-one of those participants (8 males and 23 females), with ages between 18 and 24 years old (*M* = 20.64; *SD* = 1.88), had no experience in fast-ball sports (e.g., football, handball, basketball, volleyball, futsal, golf, polo, tennis, etc.), henceforth referred to as the non-athletes. The remaining 30 participants (8 males and 22 females), with ages between 19 and 38 years old (*M* = 21.96; *SD* = 3.45), – the group of athletes – were all experienced volleyball players with a minimum of 5 years of intensive practice. The two groups did not significantly differ in their mean ages, $t(59) = -1.86$, $p = 0.0673$, or the sex distributions, $\chi^2(1, N = 61) = 0.0058$, $p = 0.94$. Sample size was determined a priori with a Power Analysis and based upon effect sizes of previously reported differences for Representational Momentum between expert athletes and non-athletes (Anderson et al., 2019; Jin et al., 2017; Nakamoto et al., 2015), revealing that a minimum sample of 30 participants per group was required. All participants provided written informed consent and the study was preapproved by the ethics committee of the University of Aveiro (protocol 03-CED/2020) and data collected in accordance with GDPR (General Data Protection Regulation).

Stimuli

Stimuli consisted of a circle (target), with 37 pixels of diameter (about 1.12º) moving over a visual context (background). The target could be a high-resolution image of a volleyball (see Figure 1, panel D) or a circle with the same average luminance (see Figure 1, panel E). Target's motion could be given by a constant acceleration, a constant deceleration or a constant speed. Acceleration/deceleration was carefully calculated such that the optical size and kinematics of the target corresponded to the optical image which would ensue from seeing an actual volleyball at a distance of about 10 m free falling downward (acceleration) or moving upward (deceleration), making sure that the final instantaneous speed was the same in both cases. For the constant speed condition, the target's velocity was equated to that same final instantaneous speed. That is, irrespective of the target's dynamics, its speed at the time it vanished was always the same (about 30.22º/s). For all target's kinematics, the motion lasted for 575 ms and, consequently, the distance covered onscreen varied for the accelerating, decelerating and constant speed targets (target's covered distance is known to have no effect on the magnitude of Representational Momentum; De Sá Teixeira & Oliveira, 2011). Furthermore, the entire trajectory for all targets in each trial was randomly displaced vertically or horizontally such that the targets vanished at a random location on screen between 0 and 108 pixels beyond the centre of the screen. After the target's offset, a retention interval of 0, 150, 300, 450 or 600 ms was imposed, before a cursor, given by a black circle with a diameter of 6 pixels (about 0.17º), appeared on the centre of the screen. As for the visual context, it could be either a picture of a volleyball court (as seen from one side of the net; see Figure 1, panel B) or a blank screen with the same average luminance (see Figure 1, panel C).

Figure 1. *A: trial structure. B and C: volleyball and neutral visual context. D and E: volley ball and uniform colour target.*



Apparatus, procedure, and design

Before their participation, all participants were briefed on the experimental procedures and signed an informed consent. Participants sat in front of a computer screen, with a resolution of 1920 × 1080 (physical size of 53 × 30 cm) and refresh rate of 60 Hz, with their heads stabilized with a custom-made chin and forehead rest and such that their cyclopean eye was aligned with centre of the screen at a distance of 50 cm. To prevent peripheral visual cues, participants' view was restricted to the computer screen with the aid of an opaque black fabric attached between the edges of the screen and the structure of the chin and forehead rest.

Prior to the experiment, participants were allowed to perform a few practice trials until they fully understood the task. Each participant performed the experimental task twice, once for the volleyball context (volleyball court as background and volleyball as target) and once for the neutral context (black background and uniform colour target), with order counterbalanced. For both tasks, each trial (see Figure 1, panel A) started with a blank screen for 800 ms, followed by a fixation cross at the centre of the screen (54 px, about 1.72º). After 800 ms, the fixation cross was replaced by the visual context. After an additional 800 ms, the target appeared onscreen already in motion. Participants were instructed to locate, as precisely as possible and once the cursor appeared onscreen, the target's offset position by moving the cursor with a trackball. Spatial localization response was confirmed by pressing one of the trackball’s buttons, with the next trial starting immediately afterward.

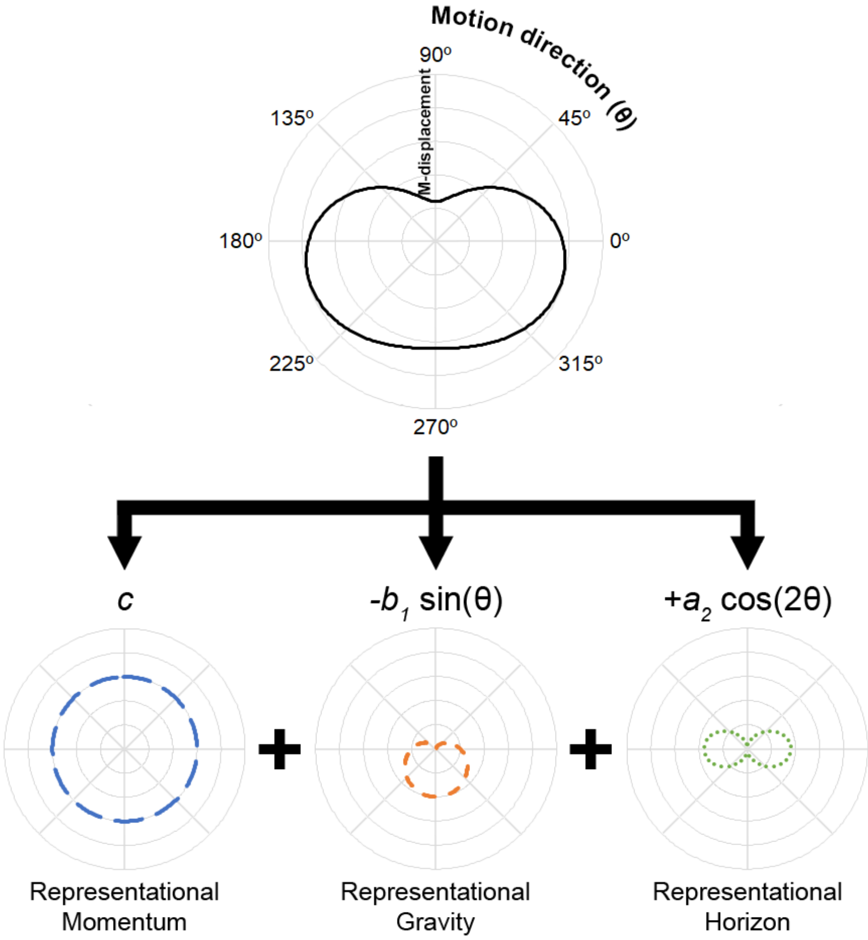
The experiment thus followed a mixed design given by 2 (context: volleyball or neutral) × 16 (orientation of target's trajectory) × 3 (target's motion dynamics) × 5 (retention intervals), with participants' volleyball expertise (athletes or non-athletes) as a between-subjects factor, with each participant performing a total of 480 trials. The entire experimental session, including briefing, instructions, practice trials, experimental tasks, a short pause in-between the main tasks and debriefing took about 1.5 hours per participant.

Calculations and Statistical Analyses

On each trial, the difference between the horizontal and vertical coordinates indicated by each participant and the actual vanishing location were calculated. Based on those horizontal and vertical differences, displacement along targets' motion direction – M-displacement – were calculated, such that positive values indicate a forward displacement and negative values a displacement backwards. Thus, for each condition of targets' motion dynamics (constant speed, acceleration and deceleration), context (neutral and volleyball) and retention interval, individual sets of M-displacements, with orientation of target's trajectory (θ) as parameter, were obtained and subjected to a discrete Fourier decomposition procedure (De Sá Teixeira, 2016; De Sá Teixeira & Hecht, 2014; Freitas & De Sá Teixeira, 2021; for an in-depth tutorial on the application of Fourier decomposition with psychophysical data see Sekuler & Armstrong, 1978). For each set of M-displacements, the Fourier decomposition provides individual estimates of a constant c and harmonic coefficients a_i (cosine) and b_i (sine) up to i = 4, according to:

$$M_\theta = c + \sum_{i=i}^{n} \left(a_i \cos i \frac{\theta}{2\pi} + b_i \sin i \frac{\theta}{2\pi} \right) (1)$$

Figure 2. *Polar plot depicting the typically found patterns of M-displacement as a function of the orientation of the targets' trajectories (θ; radial parameter) and the underlying harmonic terms and corresponding spatial localization phenomena, both algebraically and graphically in polar plots.*



When applied to spatial mislocalisations (see Figure 2), constant *c* in equation 1 captures the amount of M-displacement shared with all target's directions and, thus, indexes Representational Momentum (see Figure 2, leftward bottom plot). Embedded harmonic terms are specified by coefficients *a* (times a cosine function of θ) and *b* (times a sine function of θ) with increasing cycles (signalled by subscripts) per period (in this case, a full rotation counter clockwise on the frontoparallel plane – that is, orientations of target's trajectory θ for 0º [rightward], 90º [upward], 180º [leftward], 270º [downward], and intermediate directions). Of relevance, in previous studies (De Sá Teixeira, 2014, 2016; Freitas & De Sá Teixeira, 2021), a significant b_1 coefficient is commonly found, signalling a systematic trend for targets moving along one preferred direction (downward; see Figure 2, middle bottom plot) to be increased – indexing the magnitude of Representational Gravity –, along with a significant a_2 coefficient, disclosing a trend for targets moving along one axis (two opposing preferred directions) to be increased (see Figure 2, rightward bottom plot). Recently, it was shown that this latter harmonic term accompanies the horizon implied by the visual context and, henceforth, referred to as Representational Horizon (De Sá Teixeira et al., 2023; Freitas & De Sá Teixeira, 2021).

Estimated individual values for c and coefficients a_1-a_4 and b_1-b_4 were subjected to a mixed MANOVA with visual context (blank or volleyball court), target dynamics (accelerated, constant speed or decelerated) and retention time (0-600 ms) as repeated-measures factors and volleyball expertise as a between-participants variable. Whenever the sphericity assumption was not met, Greenhouse-Geisser correction to the degrees of freedom was used.

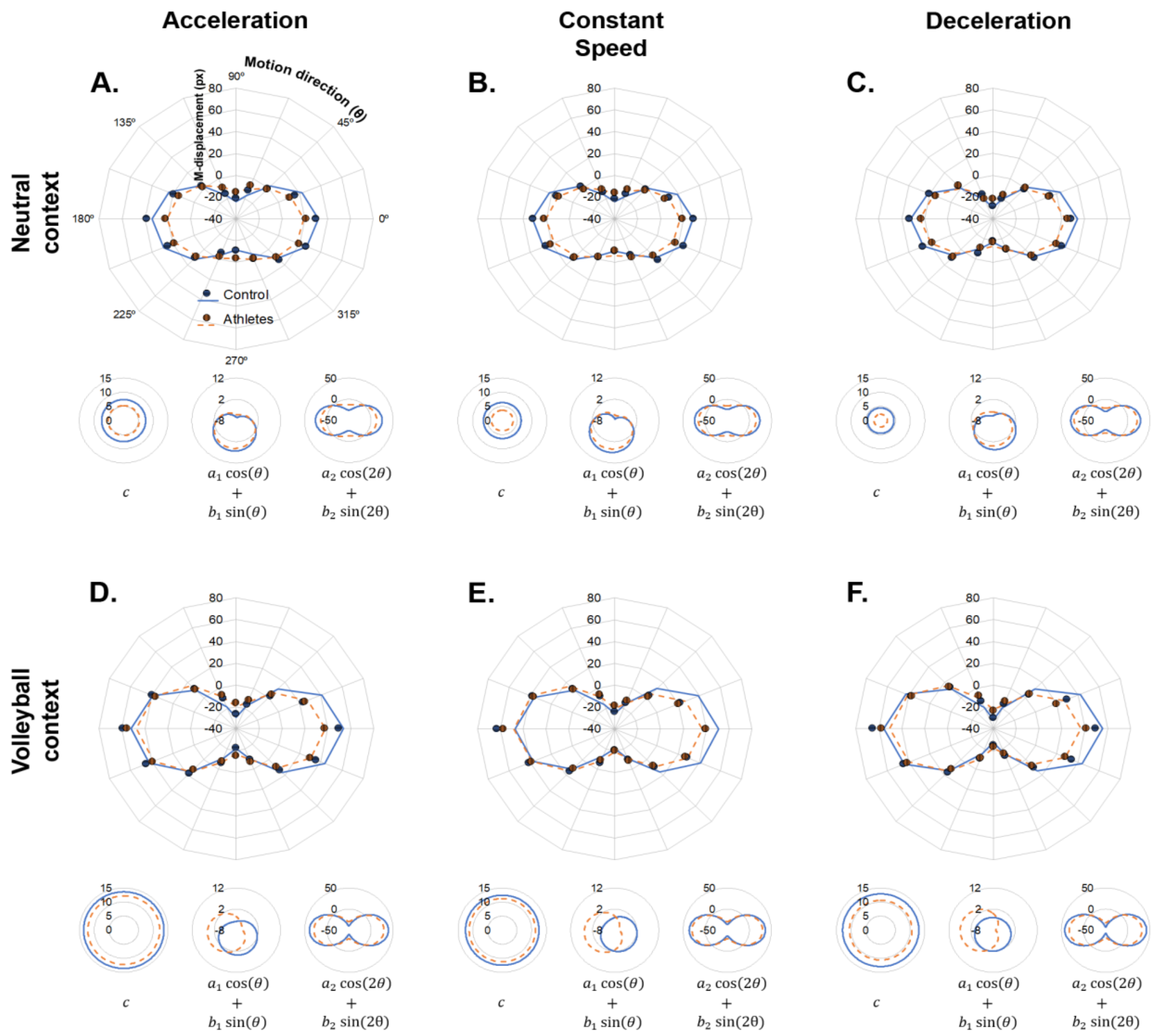
RESULTS

Mean values of *c* were found to significantly increase with retention time, $F(4, 236) = 4.865$, $p < 0.001$, *partial* $\eta^2 = 0.076$, disclosing a trend where Representational Momentum increased with time stabilizing at around 300 ms, replicating previously reported outcomes (De Sá Teixeira, 2016; De Sá Teixeira et al., 2013; De Sá Teixeira, Kerzel, et al., 2019; Freyd & Johnson, 1987; Kerzel, 2000). Likewise, mean a_2 coefficient, indexing a greater forward displacement for horizontally moving targets, was also found to increase with retention time until a maximum at around 300ms, $F(2.91, 171.683) = 52.627$, $p < 0.001$, *partial* $\eta^2 = 0.471$. Both these trends were somewhat magnified for a blank visual context, in comparison with the volleyball court: *c*, $F(4, 236) = 3.127$, $p = 0.016$, *partial* $\eta^2 = 0.05$; a_2, $F(4, 236) = 10.161$, $p < 0.001$, *partial* $\eta^2 = 0.147$. Unlike previous results, however, retention time had no effect on Representational Gravity, as indexed with coefficient b_1, $F < 1$.

In what refers to target's motion dynamics, it was found to significantly modulate mean *c* values, $F(1.681, 99.204) = 14.104$, $p < 0.001$, *partial* $\eta^2 = 0.193$, mean a_2, $F(1.728, 101.949) = 27.83$, $p < 0.001$, *partial* $\eta^2 = 0.321$, a_4, $F(1.728, 101.949) = 27.83$, $p < 0.001$, *partial* $\eta^2 = 0.321$, and b_1, $F(1, 59) = 4.888$, $p = 0.009$, *partial* $\eta^2 = 0.077$, coefficients. Overall, bigger Representational Momentum (*c*) values were found for accelerated targets while smaller values were the case for decelerated ones (those moving at a constant speed had intermediate values; see Figure 3, particularly the leftward insets below each panel). This trend was, furthermore, found mainly for a blank background, as revealed with an interaction between visual context and target dynamics, $F(2, 118) = 6.327$, $p = 0.002$, *partial* $\eta^2 = 0.097$ (see Figure 3, comparison between top and bottom row). Representational Gravity (b_1) was likewise found to be increased/decreased for accelerating/decelerating targets in comparison with those moving at a constant speed. On the other hand, bigger forward displacements for target moving horizontally (a_2) were further increased with decelerated targets, with no differences between accelerated ones and those moving at a constant speed. Finally, there was a slight trend for accelerated targets and those moving at a constant speed to result in bigger M-displacements for diagonally moving targets (a_4), in comparison with decelerating targets.

As for visual context, bigger Representational Momentum (*c*) was found when the background displayed a volleyball court, in comparison with a blank image, $F(1, 59) = 112.234$, $p < 0.001$, *partial* $\eta^2 = 0.655$ (See Figure 3, leftward insets below each plot, comparison between the top and bottom row). Similarly, forward displacement for horizontally moving targets (a_2) was further increased when a volleyball court was used as visual context, $F(1, 59) = 78.959$, $p < 0.001$, *partial* $\eta^2 = 0.572$ (See Figure 3, rightward insets below each panel), as well as for targets moving diagonally (a_4), $F(1, 59) = 33.111$, $p < 0.001$, *partial* $\eta^2 = 0.359$. Conversely, Representational Gravity (b_1) was found to be reduced for a volleyball court context, $F(1, 59) = 17.898$, $p < 0.001$, *partial* $\eta^2 = 0.233$, in comparison with a blank background (See Figure 3, middle insets below each panel). Of particular relevance, spatial localizations made with a volleyball court, but not with a blank background, led to a significant a_1 coefficient, $F(1, 59) = 6.274$, $p = 0.015$, *partial* $\eta^2 = 0.096$, chiefly due to the spatial localization judgements made by expert athletes, $F(1, 59) = 9.209$, $p = 0.004$, *partial* $\eta^2 = 0.135$ (see Figure 3, bottom row, middle insets below the panels). Coefficient a_1, together with coefficient b_1, specify one single direction towards which M-displacement is further increased (First harmonic term). Commonly, only b_1 emerges as statistically significant (see, e.g., De Sá Teixeira, 2014, 2016; Freitas & De Sá Teixeira, 2021) indexing a bigger displacement for targets moving downward, that is, Representational Gravity. In the present results, a significant a_1 coefficient found solely for expert athletes and specifically when the task is made within a volleyball context (see Figure 3, bottom row, middle insets below the panels) discloses a significant leftward bias for M-displacements for those participants in that condition.

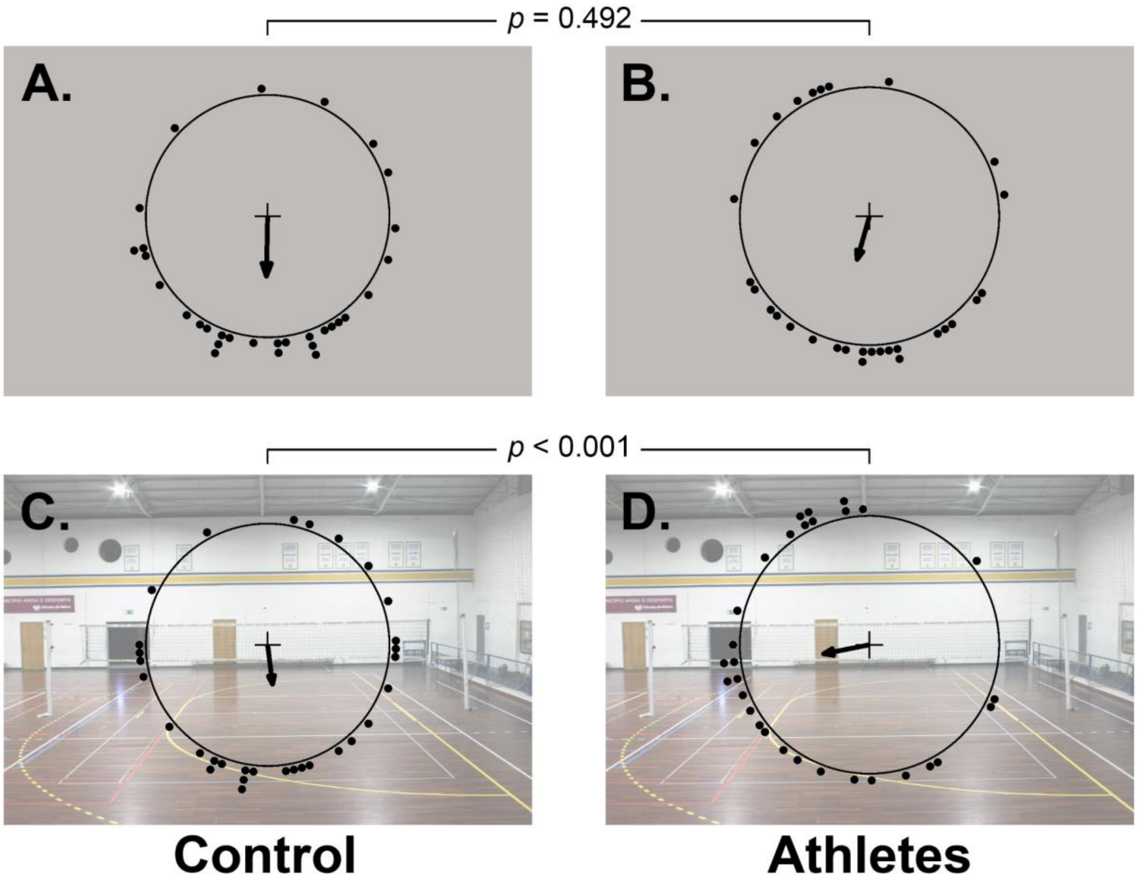
Figure 3. *Polar plots depicting mean M-displacement as a function of motion direction (radial parameters), target's dynamics (columns) and visual context (rows) for the athletes (orange markers and dashed lines) and the control group (blue markers and continuous lines). Inset plots depict, for each condition, the mean constant c, and the mean first and second harmonic terms.*



The bias resulting from the first harmonic term can be further inspected by calculating its direction, given by the arc-tangent of the ratio between sine (b_1) and cosine (a_1) coefficients. These calculations were made individually with estimated coefficients averaged across target dynamics and retention intervals. For the blank context, the mean bias direction (with respect to a 360º period, with 0º referring to the rightward direction, 180º to the leftward, 90º upward and 270º downward) was found to be of 268.837º (*SD* = 1.185º) for the non-athletes group and 254.214º (*SD* = 1.451º) for the expert athletes. In contrast, when the visual context displayed a volleyball court, the mean bias direction was found to be of 277.039º (*SD* = 1.494) for the non-athletes group but of 191.211º (*SD* = 1.429º) for the expert athletes (See Figure 4). To test for statistical differences between the two groups in the mean bias direction, one-way circular

Watson-Williams ANOVAs were conducted for each visual context. The directional bias significantly differed between expert athletes and non-athletes for the volleyball context, $F(1, 59) = 14.214$, $p < 0.001$, with a bigger displacement for targets moving to the left diagonal for the former but downward for the latter participants, but not for the blank visual context, $F(1, 59) < 1$, where all participants had a bigger displacement for targets moving downwards.

Figure 4. *Distribution and average direction of the individual first harmonic terms for the neutral (panels A and B) and volleyball (panels C and D) contexts, and for the control group (panels A and C) and athletes (panels B and D).*



Note: The p-values refer to the statistical significance of circular one-way Watson-Williams ANOVAs.

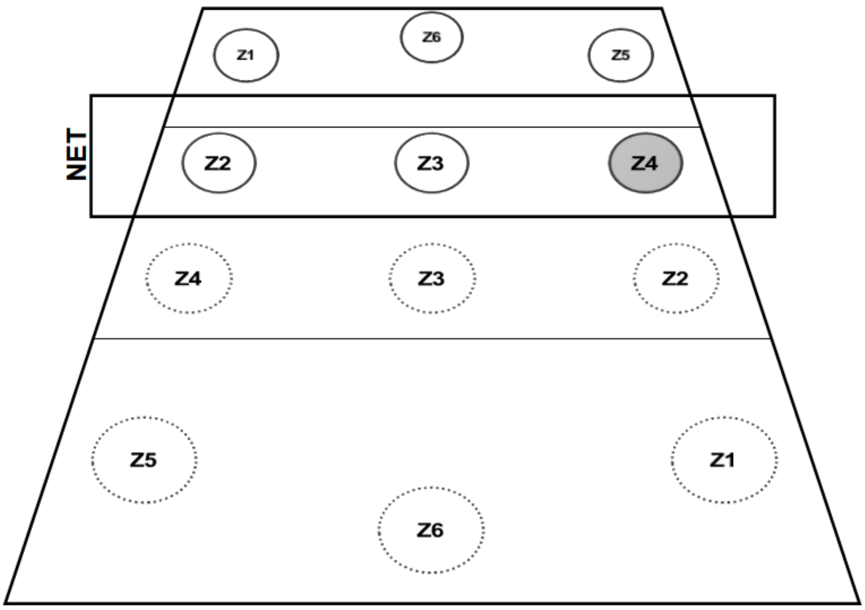
DISCUSSION AND CONCLUSION

One of the main goals of the present study was to explore the effects of sports expertise in spatial mislocalisations for smoothly moving targets. For such, a volleyball context was chosen and implemented in a standard spatial localisation task, with volleyball athletes and non-athletes as observers.

The main, and quite unexpected, finding of the present study was a significant increase in the a_1 coefficient specifically for athletes and only within the volleyball context, disclosing a robust trend for these observers to display patterns of spatial mislocalisations where the first harmonic trend is directed diagonally leftwards, instead of downwards (as was found for the remaining conditions and participants). Usually, the first harmonic trend tends to point downwards indexing the magnitude of Representational Gravity (De Sá Teixeira, 2016; De Sá Teixeira, Bosco, et al., 2019) . Interestingly, the direction of this harmonic trend is not changed by variations of the observers' bodies (De Sá Teixeira, 2014) or of the direction of the gravito-inertial vector (De Sá Teixeira et al., 2017), consistently being aligned with the idiotropic vector (that is, the main body axis). As such, the present result is the first to ever report a change in the direction of this harmonic term. Despite its association with Representational Gravity, it is unlikely that, in the present context, this outcome reflects some change in the perceived gravitational direction, particularly given the fact that it only emerged for expert athletes and specifically when the task was performed within their area of expertise, a volleyball court. Stated differently, this finding seems to be closely associated with expertise (Blättler et al., 2010, 2012; Ménétrier et al., 2017) and might reflect some features of volleyball matches.

In volleyball, unsurprisingly, the most effective way to score is to produce a successful attack and, hence, being able to do so stands as a decisive skill, valued both in male and female volleyball. The volleyball court can be divided into six game zones and, generally, the three athletes who occupy the three zones of the net represent the main hitters (Z2, Z3 and Z4; see Figure 5; G. Costa et al., 2010; Inkinen et al., 2013; Zetou et al., 2007). Of these, outside hitter (Z4) and opposite hitter (Z2) are considered the most requested athletes in the attack, being responsible for most of the scored points. Importantly, several authors pinpoint outside hitters as the most sought-after athletes in the moment of attack, scoring most points (De Conti Teixeira Costa et al., 2014; Inkinen et al., 2013; Laporta et al., 2018; Martins et al., 2021; Rocha, 2009), and performing more powerful attacks with greater efficiency (Milián-Sánchez et al., 2015; Millán-Sánchez et al., 2017), albeit there might be differences between elite female and male sports (Drikos et al., 2023; Lima, Palao, et al., 2019; Sattler et al., 2015), with the latter favouring attacks by the opposite hitter (Araújo et al., 2010; Lima, Silva, et al., 2019).

Figure 5. *Schematic representation of a volleyball court with standard player zones.*



Note: The grey Z4 zone marks the position for the opponents outside hitter (see text for details).

Generally, the type of attack more commonly carried out by the opponent outside hitter (Z4; see Figure 5, grey region) is a powerful diagonal attack, more often than not directing the ball towards the Z5 area (left side of the court; G. Costa et al., 2010; G. C. Costa et al., 2017). Likewise, attacks carried out by the opposite hitter (Z2), perpendicular to the net and directed to the left side of the opponents' court (area Z5) have been shown to be faster and more effective (Tabor et al., 2018). Together, these observations suggest that attacks aimed at, or close to, area Z5 are, if not more prevalent, certainly the more powerful ones and, consequently, the most urgent to successfully receive in order to save the point. From the perspective of the court shown in the present experiment (attempting to mimic the common view when playing), typical outside hitter's attacks (and, to some extent, attacks from the opposite hitter), being directed to area Z5, would follow a diagonal/leftward trajectory onscreen. Given the game's rules, a player would greatly benefit from successfully anticipate those attacks which, in turn, would reflect in a greater spatial perceptual displacement for targets moving along that direction. Albeit somewhat tentative, this account neatly fits the found results and, to the degree that it holds to further scrutiny, shows how expertise might translate into a more sensitive attunement to natural statistics of the specific context of expertise (Anderson et al., 2019; Blättler et al., 2010, 2012; Chen et al., 2021; Jin et al., 2017; Ménétrier et al., 2017; Nakamoto et al., 2015).

Irrespective of the participants' expertise, and particularly for the neutral context, target's dynamics were found to significantly modulate patterns of M-displacement. Accelerated targets lead to bigger Representational Momentum, bigger Representational Gravity and bigger horizontal displacements (Representational Horizon), in comparison with target's moving at a constant speed which, with decelerated targets resulting in an overall decrease in M-displacements. That acceleration increases Representational Momentum replicates previous findings with implied motion stimuli (Finke et al., 1986; Freyd & Finke, 1985). As for the effects of acceleration/deceleration upon Representational Gravity, a previous undisclosed effect, it accords well with the extant literature (Delle Monache et al., 2021; Lacquaniti et al., 2013; Zago & Lacquaniti, 2005), suggesting that internal models of gravity embody expectations concerning the dynamics of Earth's gravitational pull. Notwithstanding, that target's dynamics indiscriminately affected all main perceptual displacements, and not solely the one linked with Representational Gravity, hinders a more sensitive interpretation of the outcomes. In part, this might be due to the fact that target's dynamics, in the present experiment, were varied irrespective of the orientation of the target's trajectory, which goes against what is typically found in natural contexts, where objects tend to accelerate downwards and decelerate when launched upwards. In sum, the disclosed outcomes suggest that Representational Gravity might be sensitive to Gravitationally coherent dynamics, although a more sensible experimental design should be carried out in the future.

Finally, retention interval was found to increase the magnitude of Representational Momentum up to a maximum at about 300 ms, replicating previous reports with both implied and continuous motion displays (De Sá Teixeira et al., 2013; Freyd & Johnson, 1987; Kerzel, 2000). However, retention interval did not, unlike previously reported outcomes (De Sá Teixeira, 2014, 2016; De Sá Teixeira et al., 2013), led to an increase in the magnitude of Representational Gravity. Albeit unexpected, this null effect is not particularly surprising. On the one hand, the relatively few repetitions of trials in the present experiment, in order to accommodate manipulations of the main factors of interest, necessarily decreases the statistical power to detect a somewhat subtle effect. On the other hand, previous studies which, like the present one, employed a visual context, also report a null effect on the time course of Representational Gravity (De Sá Teixeira et al., 2023; Freitas & De Sá Teixeira, 2021), not unlike the effect of changing the gravito-intertial vector in relation to the observers' bodies (De Sá Teixeira, 2014; De Sá Teixeira et al., 2017). A clear-cut account for when and why Representational Gravity evolves or not with retention interval, particularly when other spatial orientation cues are manifestly present (such as a visual context or vestibular signals) should await future inquiries.

As a final remark, the present work highlights how expertise might manifest in more subtle patterns when explored with spatial localization tasks, beyond the commonly found increased Representational Momentum, and particularly when smoothly continuous dynamic events are employed to probe diverse target's trajectories, which might align more or less with natural statistics from the specific context of expertise. As such, the present study paves a promising research avenue for future inquiries into motion extrapolation in sports expertise.

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