Psicológica (2010), 31, 659-676.

Combined effects of Mass and Velocity on forward displacement and phenomenological ratings: a functional measurement approach to the Momentum metaphor

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Representational Momentum (RepMo) refers to the phenomenon that the vanishing position of a moving target is perceived as displaced ahead in the direction of movement. Originally taken to reflect a strict internalization of physical momentum, the finding that the target implied mass did not have an effect led to its subsequent reinterpretation as a second-order isomorphism between mental representations and principles of the physical world. However, very few studies have addressed the effects of mass on RepMo, and consistent replications of the null effect are lacking. The extent of motor engagement of the observers in RepMo tasks has, on the other hand, been suggested to determine the occurrence of the phenomenon; however, no systematic investigations were made of the degree to which it might modulate the effect of target mass. In the present work, we use Information Integration Theory to study the joint effects of different motor responses, target velocity and target mass on RepMo, and also of velocity and target mass on rating responses. Outcomes point not only to an effect of mass on RepMo, as to a differential effect of response modality on kinematic (e.g., velocity) and dynamic (e.g., mass) variables. Comparisons of patterns of mislocalisation with phenomenological ratings suggest that simplification of physical principles, rather than strict internalization or isomorphism per se, might underlie RepMo.

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The notion that invariant physical principles are somehow internalized in our minds has been a longstanding conjecture in explaining how we successfully apprehend the outside world. Fostered by the concept of *analog representation*, which was given an extended meaning by Shepard (1975; 1984), the study of *dynamic mental representations* (Freyd, 1987) and, in particular, of memory for the positions of a moving target, has become a privileged locus of debate of the internalization hypothesis (Hubbard, 2005). *Representational Momentum*, the forward displacement in memory of the final position of a moving target, has received the most attention among mislocalisation effects (Freyd & Finke, 1984). The basic paradigm goes as follows: an observer is presented with an object in motion that suddenly vanishes; the observer's task consists in locating, as precisely as possible, the point where the object vanished. The typical result is that people indicate a point slightly displaced ahead in the direction of motion. Resting on the analogy with physical momentum – the tendency of a moving object to continue moving (given by the product of mass by velocity) –, this phenomenon was coined Representational Momentum (RepMo). Ever since it was first reported, the issue of its potential relations with the naïve physics of observers has been a topic for research and theory.

The lack of an effect of mass. Representational momentum was initially described by Freyd & Finke (1984), who presented to their participants a rapid sequence of three images implying the rotation of a rectangle. Participants were then asked to make same/different discrimination judgments between the third and final orientation in the series and that of a fourth rectangle, presented some time after the sequence and used to probe memory for the last position (*mnesic probe*). In half the trials the orientation of the probe was different, for more or for less. The main finding was that the participants' point of subjective equality was displaced in the direction of implied rotation. Following the hypothesis of an internalization of momentum, the variation of RepMo with motion's velocity and acceleration was investigated (Freyd & Finke, 1985), revealing a proportional increase in the magnitude of displacement with velocity. Extending these earlier studies, RepMo was also shown to exist for pitch (Freyd et al, 1990), to vary with the retention interval (increasing until either a peak or a plateau at 300 ms; Freyd & Johnson, 1987) and to occur even with static pictures imparting a sense of movement (Freyd, 1983).

As a further test of the momentum metaphor, Cooper & Munger (1993) measured RepMo for the implied rotation of line drawn pyramids seen from above, which varied in suggested mass (as rated by an independent group of observers). They found a negative result for the effect of mass. The mass manipulation was actually done in a highly abstract and symbolic fashion, resting more on the cognitive understanding of the stimuli than on a perceptual basis, and the negative result reported by the authors is not entirely surprising, at a closer look, in light of these considerations. Anyway, the null effect of mass on RepMo was widely accepted and no further studies addressing mass were attempted in subsequent years. As for the internalization conjecture, requiring a mental analogue of physical momentum (velocity × mass), it appeared to have been met with an intrinsic limitation.

Forward displacement in memory as a second-order isomorphism. RepMo was given a second breath through the work of Hubbard (Hubbard et al, 2001; Hubbard & Ruppel, 2002). Three differences with the earlier studies are noteworthy: (i) smooth moving stimuli were used instead of implied movements; (ii) the movement trajectory was linear (either horizontal or vertical) instead of rotational; (iii) participants responded by placing a cross shaped cursor over the perceived location of the vanishing point. Hubbard's results supported in general the main findings of Freyd: perceived final position was displaced in the direction of movement, and the magnitude of displacement was a proportional function of velocity. In addition to this, however, a whole new set of effects was unveiled, which revived the topic of mental analogues of physical principles. For instance, a tendency to locate the last seen position below the movement trajectory, together with the finding of increased displacements for vertically descending targets, was interpreted as a mental analogue of gravity – Representational Gravity (Hubbard & Bharucha, 1988). The finding of smaller displacements in memory for objects moving in contact with surfaces was suggested to reflect the operation of an analogue of friction – Representational Friction (Hubbard, 1998). Finally, for the so called *launching effect* (Michotte, 1954), the launched target systematically presented a reduction in RepMo (when compared with an isolated target moving at the same speed), which was understood to reflect the ancient notion of a dissipation of impetus (Hubbard, 1995).

The revival of dynamic mental analogues eventually encompassed the notion of mass, whose effects on RepMo were investigated by Hubbard using object's size as a manipulation of mass. In partial agreement with the negative result of Cooper and Munger (1993), no effect was found with horizontally moving stimuli, but an effect of implied mass on vertical movements, i.e., on movements aligned with the direction of implied gravity, was established (Hubbard, 1998). As suggested by Hubbard, for mass to have an effect on RepMo it appears that it would need to operate as a weight, through its phenomenological consequences in a world of gravity; or, as he also puts it, RepMo appears to reflect the effects of subjectively experienced weight rather than those of objective mass (Hubbard, 2005). A derived theoretical implication was that the representation of the physical world was accomplished via a second-order isomorphism with experienced effects, and not through internalization of the objective kinematic and dynamic properties of objects (Hubbard, 2005; see also Shepard, 1975). The theory-neutral expression *forward displacement* was accordingly favored by Hubbard over the more theory-laden *RepMo* designation. As for the place to look for correspondences, it was set out to lie not between forward displacement and the physical laws, but between the former and the phenomenological grasp of those laws (for a review, Hubbard, 2005). As it happens, the conjecture of a second-order isomorphism has not inspired systematic investigations of the relations between phenomenological ratings and displacement effects: alleged correspondences between phenomenology and RepMo have thus rested for the most part on *a priori* understanding of the researchers.

Revisiting the Momentum Metaphor. An alternative account of forward displacement in memory is illustrated by the work of Kerzel, which emphasizes low level perceptual mechanisms (2000; 2003a; 2003b). The hypothesis that the overshooting of pursuit eye movements might underlie RepMo was for some time the most serious objection raised against the momentum metaphor. However, a number of empirical outcomes have drastically reduced its impact. The finding that RepMo may actually occur with static images is hardly accountable by Kerzel's explanation. The same is true of the effects of conceptual/symbolic variables (e.g., pictures of rockets *vs.* pictures of scale weights used as moving targets) on the magnitude of forward displacement (Reed & Vinson, 1996). Finally, constraining eye movements has been shown to eliminate RepMo in tasks using the probe technique, but not in those where direct localization is the required response (Ashida, 2004). This last result is not only at odds with eye movements overshooting as a general explanation of RepMo; it also suggests that motor engagement of the observer (be it through movements of the head and eyes) is a crucial determinant of the phenomenon. An increasingly accepted conceptualization of RepMo actually draws on the proposal of distinct (though interdependent) visual pathways for action and recognition to underscore its close relationship with perception-for-action

(Goodale & Milner, 1992; Kerzel & Gegenfurtner, 2003; Kerzel & Müsseler, 2008).

The current study. The present study uses Information Integration Theory (IIT) and Functional Measurement (FM: Anderson, 1981, 1982, 1996, 2008) to address several issues under debate regarding the RepMo phenomenon. As one such issue, the few studies that have addressed the effects of mass have typically taken it as an isolated variable, with ambiguous results. However, from the standpoint of the Momentum Metaphor (resting on the analogy with the normative mass × velocity rule), the crucial aspect to investigate would be the joint action of mass and velocity on forward displacement. As a second issue, the importance of the extent of motor engagement of observers in RepMo tasks has been identified as a critical determinant of the phenomenon; however, the study of the effects of different variables, namely those with a prima-facie kinematic character, such as velocity and acceleration, and those of a more dynamic (also meaning perceptually indirect) nature, such as mass, has not typically incorporated differences in response modality as a further relevant factor, with the potential for exerting differential effects on different sorts of variables. As a third issue, the conjecture that a second order isomorphism governs the relations between the phenomenology of physical principles (their experienced subjective effects) and our mental representations of those principles, surmised to underlie RepMo, would require that the structure of phenomenological judgments and of forward displacements of final positions be systematically contrasted.

To address these different issues, each participant was made to perform on a *phenomenological* rating task (selected from out of two, differing on the evaluated dimension) and on a RepMo task involving exactly the same stimuli and presentation setting (selected from out of three, differing on the type of localization response): this allowed for comparisons between subjective ratings and memory displacements. Instructions for the two rating tasks stressed different *subjective* consequences of the same dynamical process: this allowed evaluating the susceptibility of a same physical notion to shifts in experienced consequences. The stimuli consisted of combinations of both dynamic-based (mass) and kinematic (velocity) variables, with two distinct instantiations of implied mass: via manipulating size (implied volume) and via surface texture (implied density). As is typical of Integration tasks, these variables were factorially crossed, and the patterns emergent from the final integrative response were used to characterize their functional role in the integration.

One particular advantage of using IIT is that, by contrasting three sorts of integration structures, distinguishing predictions can be derived and tested from the Momentum Internalization and from the Second-Order Isomorphism hypotheses. If a strict internalization mechanism is at the source of displacements in memory, then the normative multiplying rule established in the physical realm (mass × velocity) should also govern the integration of mass and velocity in RepMo tasks. On the other hand, if a second order-isomorphism arising from the structure of our subjective experience of the physical world (of its effects on us) is at the source of mislocalisation errors, then the same integration rules established in the rating tasks should also be apparent in the RepMo tasks. Any other possible scenario will be signaling that either a third, different mechanism or a set of intertwined mechanisms actually underlie RepMo.

METHOD

Participants. One hundred and twenty seven students of the University of Coimbra (104 female; 23 male), with mean ages of 20.4 (SD: 5.03), participated in exchange for course credits. All of them had normal or corrected to normal vision and were unaware of the purpose of the experiments.

Apparatus and Stimuli. The stimuli consisted of animations depicting a 3D textured sphere moving linearly (without rotation) along the horizontal axis. The spheres traveled at 150, 300 or 450 pixels per second, and had sizes corresponding to areas of 30^2, 60^2 or 90^2 pixels on the screen. Each was filled with a shaded photographic texture, providing it with a three dimensional realistic character and the material appearance of sponge, wood or metal. Size and Texture were regarded as two ways of conveying a notion of mass, the former through implied volume, the later through implied density. The spheres emerged from the left edge of the screen and, after covering about 590 pixels, suddenly disappeared.

All stimuli were presented on a personal computer equipped with a flat touchscreen (resolution 1024 × 768 pixels), a wireless mouse and an ergonomic keyboard. Animations were created with Interactive Physics 2000, and the spheres produced and textured with 3D Studio Max. Stimuli randomization and response recording were implemented with Super Lab Pro 4.

Procedure and Design. Each participant performed one of two rating tasks and one out of three localization tasks. All tasks used the same stimuli.

In the rating tasks, participants were instructed either to rate the *effort they would have to exert to stop the motion of a sphere* or *the time it would take for a sphere to naturally come to a rest* if it continued traveling after the vanishing point. Responses were given, through a mouse click, on a graphic scale presented on the screen, anchored with *0 – No effort/No more movement after the animation* and *40 – Maximum effort/Maximum time expected for the kind of objects presented* on its left and right ends, respectively and depending upon the dimension to be evaluated. No unit constraints were imposed so that participants were free to use the scale as naturally as possible. Previous to the experimental blocks, participants were shown two animations, not presented in the experiment, depicting a simple marker (which, so was told, was coupled with an object that could not be seen) moving at either a slower or greater velocity than the slowest/fastest experimental stimuli – these example animations were thus associated with the extremes of the rating scale as *anchor instantiations*. Participants were allowed some training trials which covered the whole range of variations of the experimental set of stimuli. After the training, and immediately before the experimental task, the *anchor instantiations* were shown once again.

In the localization tasks, participants were instructed to locate the exact last seen position of the sphere on the screen, referring to its geometrical centre. Responses were given either with a wireless mouse, which controlled a plus sign cursor on the screen, with the directional keys of a keyboard, which served the same purpose, or with a softpoint pen, allowing participants to directly touch the screen.

The order of the rating and localization tasks was counterbalanced across participants, who were always given a block of training trials preceding each experiment. There were no restrictions imposed on eyes or head movements, but participants were urged to maintain a steady posture. Compliance with this instruction was monitored by the experimenter and feedback provided when necessary.

Localization experiments corresponded to a 3 (Size) × 3 (Velocity) × 3 (Texture) × 3 (Motor Response Modality) factorial design. Rating experiments obeyed a similar 3 (Size) × 3 (Velocity) × 3 (Texture) × 2 (Evaluation Dimension) factorial design. Size, Velocity and Texture where in both cases varied within subjects. Response Modality, in the localization tasks, and Evaluation Dimension, in the rating tasks, where varied between subjects. Three replications of the Size × Velocity × Texture factorial crossing were used in each experiment.

RESULTS

Forward displacement (RepMo) was calculated as the difference in pixels between the actual vanishing point and the location indicated by participants. These measures were averaged across replications and subjected to a mixed ANOVA with response modality as a between-subjects factor. Rating responses were similarly averaged across replications, and analyzed with repeated measures ANOVAs performed separately for each of the rating tasks.

Rating Tasks. Figure 1 shows the factorial plots for the two rating tasks: *Effort to Stop Motion*, on the left column; *Time to Come to a Stop*, on the right column (for convenience, these two tasks will be referred hereafter, exception made to legends, as the *Effort* task and the *Time* task). Panels A and B illustrate the mean ratings for Velocity × Size, panels C and D those for Velocity × Texture, and panels E and F those for Size × Texture.

Visual inspection of the graphs reveals parallelism between Velocity and Size with ratings of effort (Panel A), but a fanning trend towards the right with ratings of time (Panel B); as an additional qualification, while increases in Size lead to increases in effort estimates, they have an opposite, decreasing effect on ratings of time. As for patterns involving Texture (Panels C to F), rightward fanning of curves can be observed with both Velocity and Size when effort estimates were used (Panels C and E). Near parallelism is the rule, on the other hand, with time estimates (Panels D and F).

Statistical analyses concur with the outcomes of visual inspection. All main factors achieved statistical significance in both tasks: Effort – Velocity: $F(2, 154) = 102.294$, $p = 0.000$, $\eta^2 = 0.07$; Size: $F(2, 154) = 132.996$, $p = 0.000$, $\eta^2 = 0.13$; Texture: $F(2, 154) = 202.320$, $p = 0.000$, $\eta^2 = 0.42$. Time – Velocity: $F(2, 154) = 189.672$, $p = 0.000$, $\eta^2 = 0.48$; Size: $F(2, 154) = 65.530$, $p = 0.000$, $\eta^2 = 0.06$; Texture: $F(2, 154) = 5.899$, $p = 0.004$, $\eta^2 = 0.01$. This means that they all contribute to the integrated response in each task.

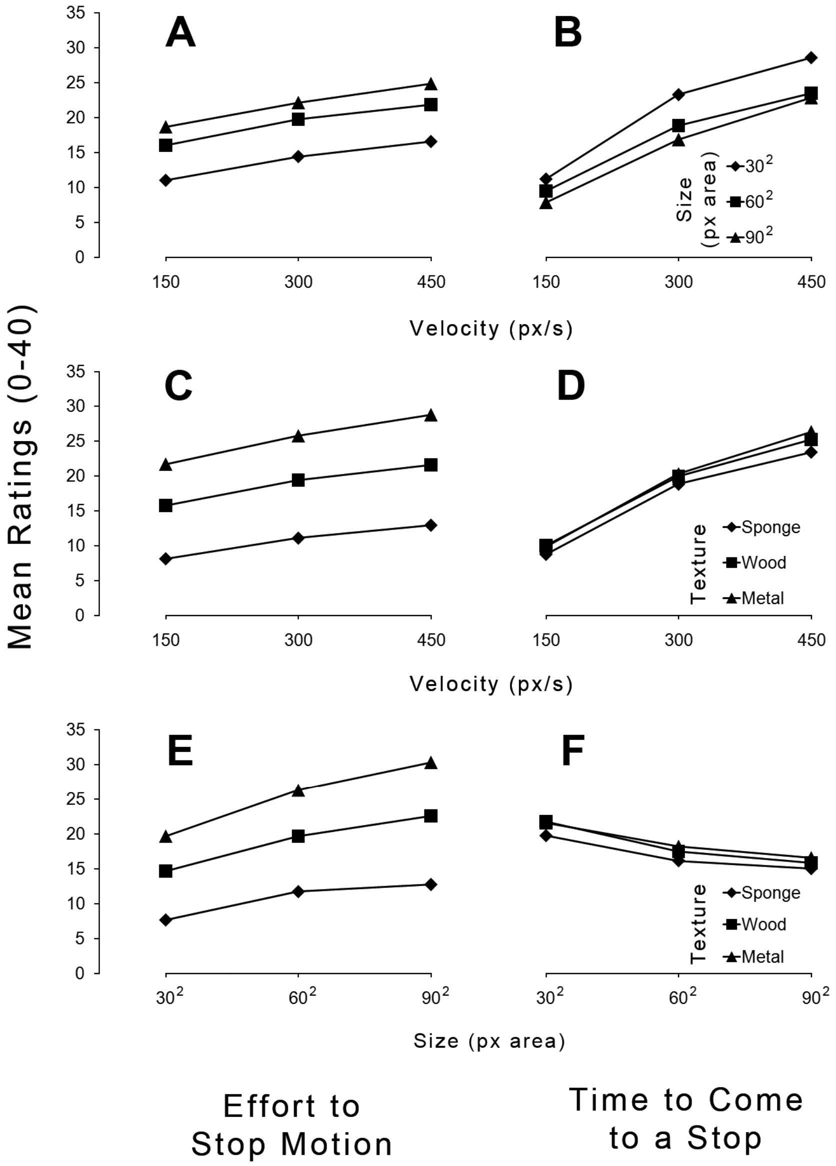

Figure 1. Factorial plots for the two rating tasks. Left column: Effort to stop Motion. Right column: Time to come to a stop. Top row: Velocity (abscissa) × Size (curve parameter); Middle row: Velocity (abscissa) × Texture (curve parameter); Bottom row: Size (abscissa) × Texture (curve parameter). Mean estimates on the ordinate.

As for statistical interactions, Velocity × Texture, $F(4, 308) = 6.166$, $p = 0.000$, $\eta^2 = 0.01$, and Size × Texture, $F(4, 308) = 29.305$, $p = 0.000$, $\eta^2 = 0.02$, were revealed significant in the Effort task, with an exclusive significant linear × linear component in both cases: Velocity × Texture, $F(1, 77) = 18{,}99$, $p = 0.000$; Size × Texture: $F(1, 77) = 65{,}704$, $p = 0.000$. This would be expectable if the suggested fanning trends were indeed present in the data. On the other hand, Velocity × Size, $F(4, 192) = 4.622$, $p = 0.001$, $\eta^2 = 0.01$, was the only interaction to achieve statistical significance in the Time task, with a marginally significant linear × linear contrast: $F(1, 48) = 6.681$, $p = 0.013$, again in general accordance with a signaled fan tendency. No further interactions of any order were found.

The statistical signature of a multiplicative/divisive integration model is a significant linear × linear interaction component which leaves null residuals behind (Anderson, 1982). This was tested with the FM program of CALSTAT (Weiss, 2006), which revealed no significant residuals left by the bilinear components in all cases ($F < 1$).

Taken all together, outcomes point to different integration rules dependent on the rated dimensions (Effort and Time), which agrees well with Anderson's (1981) axiom of purposiveness. In particular, when estimating the effort to bring a halt to the object's motion, participants appear to conform to the following rule:

$$(Velocity + Size) \times Texture$$

In contrast, when estimating the time required for the object to naturally come to a rest, they seem to comply with the different rule:

$$\frac{Velocity}{Size} + Texture$$

Forward Displacement (RepMo). Both preliminary results and analysis performed over the current data have revealed no differences between the mouse and the keyboard as response devices. These two response modalities will thus be aggregated on most of the remainder of the text under the heading indirect responses, and contrasted with the pointer condition as representative of a direct localization response. Figure 2 presents the factorial diagrams of Velocity × Size (panels A and B), Velocity × Texture (panels C and D) and Size × Texture (panels E and F) for both indirect (left column) and direct (right column) responses.

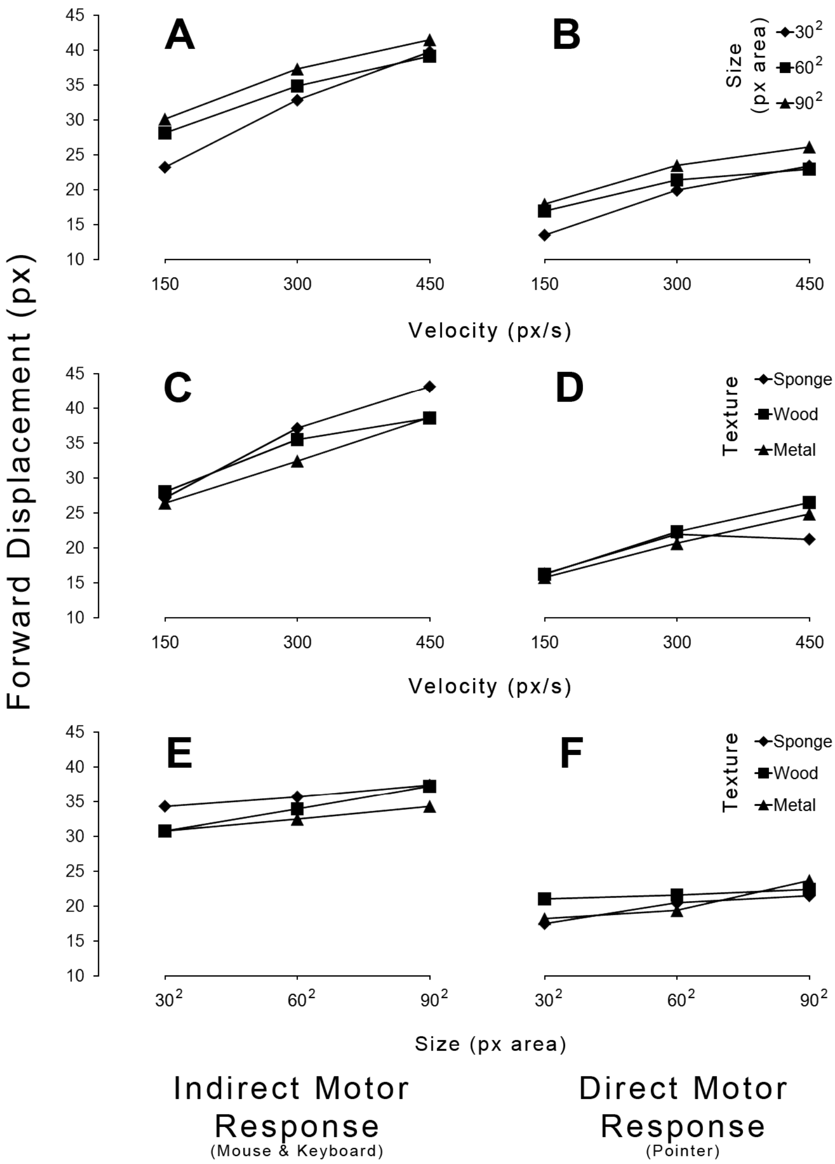

Figure 2. Factorial plots for the two localization tasks. Left column: Indirect localization responses (mouse and keyboard). Right column: Direct localization response (pointer). Top row: Velocity (abscissa) × Size (curve parameter); Middle row: Velocity (abscissa) × Texture (curve parameter); Bottom row: Size (abscissa) × Texture (curve parameter). Mean forward displacement (in pixels) on the ordinate.

Visual inspection mainly discloses gross parallelism in all patterns. Reduced vertical spread of the lines when Texture is the curve parameter (Panels D and F) suggests small or null effects of Texture in the direct response condition. With indirect localization responses, Texture has a decreased effect on forward displacement (RepMo) as the typical density of the materials increase (i.e., $\text{RepMo}_{\text{sponge}} > \text{RepMo}_{\text{wood}} > \text{RepMo}_{\text{metal}}$).

Statistical analyses are again consistent with the results from the visual inspection. A general ANOVA including Response Modality (direct and indirect responses) as a between-subjects factor revealed a single significant interaction, between Texture and Response Modality, $F(2,250) = 6.453$, $p = 0.002$. A separate ANOVA for the indirect response condition found significant main effects of all factors – Velocity, $F(2,168) = 28.063$, $p = 0.000$, $\eta^2 = 0.09$; Size, $F(2,168) = 11.914$, $p = 0.000$, $\eta^2 = 0.02$; Texture, $F(2,168) = 13.627$, $p = 0.000$, $\eta^2 = 0.01$ – along with two significant interactions: Velocity × Size, $F(4, 336) = 2.621$, $p = 0.035$, $\eta^2 = 0.003$, and Velocity × Texture, $F(4, 336) = 2.866$, $p = 0.023$, $\eta^2 = 0.003$. However, given the value of the η^2 along with the fact that no such interactions were significant for mouse and keyboard analyzed separately, we dismissed them as a Type I error. The ANOVA for the direct response condition revealed no significant interactions, together with significant main effects of Velocity: $F(2,82) = 13.034$, $p = 0.000$, $\eta^2 = 0.06$, and Size: $F(2,82) = 6.616$, $p = 0.002$, $\eta^2 = 0.01$, but not of Texture.

These outcomes suggest similar rules for the integration of factors across direct and indirect response modalities, the main difference being the absence of an effect of Texture, a highly symbolic variable, with direct responses. The following rule seems to capture well the findings concerning the indirect response condition:

$$Velocity + Size - Texture$$

Although the additive-subtractive model, unlike the averaging model, does not allow in general assessing the relative importance (weights) of the factors, an index of importance can be obtained, given strict conditions, from the ratio of the response ranges of the factors: the relative range index (RRI) (Anderson, 1982). The conditions to be met are that the response scale be linear, that the integration model be additive, and that the variation of the stimuli matches their entire, or at least their natural, dynamic range of variation (Anderson, 1982). The two first requirements hold in the present case, the third does not. This means that the RRI cannot be used to determine the relative importance of the factors. However, given that the same stimuli were used across response modalities, it can still be used to assess whether the relative importance of the factors (whatever it may be) changes as a function of response modality. Hence, the RRI between velocity and size was calculated on an individual subject basis in each response condition, and its corresponding distributions were compared across response modalities. Figure 3 plots the mean RRI as a function of response modality (now distinguishing between responses with a mouse and with a keyboard in the indirect condition). A One-Way ANOVA revealed a significant trend for more direct responses (pointing) to have a higher RRI, $F(2,124) = 5.091$, $p = 0.007$; linear contrast: $F(1,124) = 9.063$, $p = 0.002$, signaling a corresponding increase in importance of Velocity relative to Size.

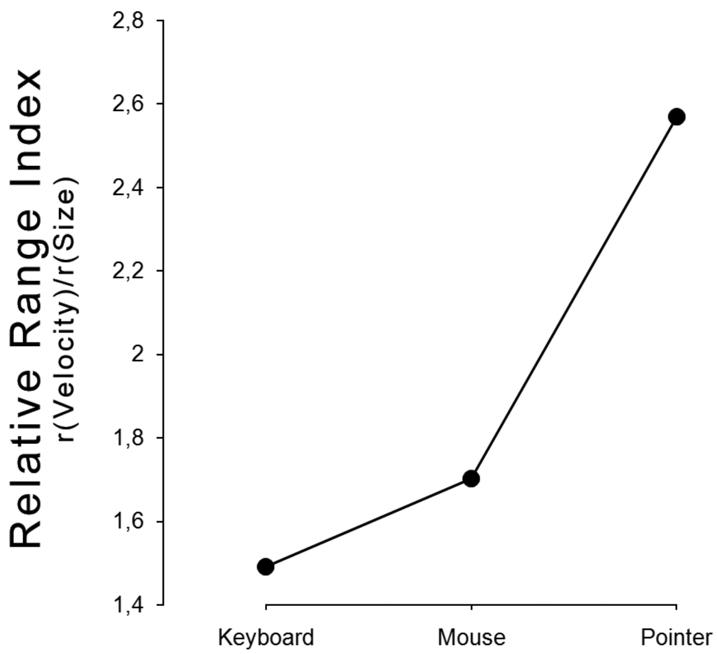

Figure 3. Relative Range Index, given by the ratio of the response range of Velocity and the response range of Size, plotted as a function of response modalities. Higher RRI values signal and increase in the relative weight of Velocity regarding Size.

DISCUSSION

Overall comparisons among the patterns found with phenomenological ratings and with localization responses suggest a trend for simpler integration rules in the latter. Both the multiplicative operation of Texture found with effort ratings and the divisive relation Velocity/Size observed with time estimates gave way to simple summative-subtractive rules in the motor localization tasks. Considering the incertitudes surrounding a possible role of high-level cognitive processes in RepMo (vis-à-vis perceptual and low level sensorimotor processes), these results might suggest at least the partial impenetrability of forward mislocalisation to higher-level representations, as those typically addressed by naïve physics (Hayes, 1978; McCloskey, 1983).

Given that none of the integration patterns is isomorphic to physical momentum, results disagree with what might be generally expected from a straightforward internalization mechanism (Freyd & Finke, 1984). They also question the hypothesis of a second-order isomorphism, involving a correspondence between the subjective consequences of physical principles (rather than the principles per se), and mental representations (Hubbard, 1999, 2006), as similar rules for the localization responses and for the phenomenological ratings would then be expected in general.

As for the variables considered, Size displayed significant effects not just on the ratings as on the magnitude of RepMo across all response modalities (direct and indirect). Contrary to the *null effect* of mass reported in the RepMo literature (Cooper & Munger, 1993; Hubbard, 1997), increases in mass as implied by Size bear an increasing impact on forward displacement in memory (at least for smooth motion stimuli). The direction of this effect rules out the possibility of a simple perceptual explanation by *velocity transposition* (Snowden, 1999), the phenomenon whereby increases in size of a moving object within a frame results in decrements of its perceived velocity. Because target Velocity contributes positively to RepMo, a decrease in perceived velocity would thus reduce forward displacement, instead of augmenting it.

Effects of Size on ratings were heavily influenced by the dimension under judgment, showing a positive (additive) impact on estimated effort to actively put a stop to the object's motion, and a decreasing (divisive) effect on the estimated time for the object to naturally come to a rest (Figure 1, Panel A and Panels B and F). A possible interpretation for this inversion (which disagrees with normative physics) is that larger Sizes bring with them the suggestion of larger friction (see Hubbard, 1995, for a notion of representational friction and associated findings). Effort estimates, on the other end, would involve the phenomenological consequences of opposing the object's motion with one's own body, with an increasing (even if additive, not multiplicative) effect of its Size. In any circumstance, the inversion obtained through instructions argues for a high-level cognitive nature of the Size variable. The fact that this same variable bears a consistent increasing impact on forward displacement (opposite to that on estimated time for the object to come to a rest) adds further to the notion that motor localization responses are at least partly impervious to the contents of high-level representations

Texture offers another opportunity to look at the effects of implied mass. Differently from Size, which suggests mass across perceived volume, Texture conveys a notion of mass through implied, but not perceived, density, acting in this sense as a more symbolic variable. The first point to notice is the absence of effects of Texture with direct localization responses (pointer condition). This accords well with the suggestion that high-level, symbolic variables are strongly limited in their ability to modulate motor responses. With indirect localization responses, on the other hand, a decreasing effect on forward displacement was observed, which goes against normative physical momentum (mass × velocity). In the rating tasks, Texture contributed multiplicatively to effort estimates, and additively to ratings of time. Similarly to Size, thus, Texture was shown a variable susceptible to task instructions (shifting from multiplication to addition). Differently from size, however, it didn't seem to call upon a sense of friction as suggested densities increased (it kept an increasing contribution in both tasks); also, it appeared to reflect more strongly (amplifying it through multiplication) the subjective dynamic consequences of opposing the objects motion with one's own effort. The reason why a decrease in RepMo occurred with increases of implied density in the case of indirect localization responses is unclear. One possible conjecture is that this is being simply caused by random perceptual artifacts introduced by the shaded textures: this hypothesis is not easily allowable given the overall behavior of Texture in all other tasks. A different heuristic conjecture is that, though partially impervious to high-level representations, RepMo is also partially responsive to a mesh of unanalyzed naïve representations, particularly in the more indirect response modalities.

In agreement with the previous literature (Freyd & Finke, 1985; Hubbard & Bharucha, 1988; Munger & Owens, 2004), increased Velocity always increased the magnitude of RepMo, irrespective of the response modality. Also, it kept contributing positively across both rating tasks. This signals an important difference between kinematic variables, such as velocity (and acceleration: see Finke, Freyd & Shyi, 1986), and dynamic variables, such as mass, concerning their effects on RepMo. The former exert a neat and invariant influence on forward displacement, while the later typically provide ambiguous results, exhibiting seemingly strong dependencies from contextual factors.

The primary effects of response modality concerned the canceling out of the effects of Texture in the pointer condition, and the significant reduction of the relative importance of Size regarding Velocity in that same response condition (see Figure 3). Both findings suggest the imperviousness of the direct motor response to dynamic-laden symbolic variables (Size and Texture), and the converse possibility that such variables exert differential effects depending on the more direct or indirect nature of the localization response. One example from the previous literature is the result reported by Daum & Frick (2003) of the disappearance of representational gravity (see Hubbard, 1990) with direct pointing. A framework worth exploring in addressing the nature of RepMo might be the distinction between perception for action and perception for recognition (Milner & Goodale, 1995; 2002), with direct localization responses preferentially tuned to overt kinematic variables, and mediated localization responses more open to the modulation of high-level, symbolic, representations of dynamic processes.

Finally, contrasting the normative multiplicative rule of physical momentum with the simpler additive rules exhibited by forward displacements in memory suggests that a general simplification mechanism, rather than strict internalization or second-order isomorphism, best accounts for the sort of dynamic representations underlying RepMo.

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(Manuscript received: 8 September 2009; accepted: 25 October 2009)