# DERIVING A PSYCHOPHYSICAL LAW FOR VELOCITY FROM THE MOTOR LOCALIZATION OF A MOVING TARGET

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## Abstract

*Asking someone to locate by pointing where a moving target suddenly vanishes reveals an ordered dividing relation between target's velocity and target's traveled distance. This psychological law entails a metric of the "perception-for-action" of velocity, and therefore allows deriving a proper psychophysical function for velocity. Assuming the mislocalisation error known as Representational Momentum (forward displacement of the vanishing point) is aimed at compensating for the neural transmission delay, this psychophysical function provides useful constraints to the operation of any purported extrapolation mechanism.*

The fact that the neural transmission of signals takes a not negligible time is at odds with ordinary experience, wherein humans perform reasonably well in their interaction with the world, even while acting upon fast moving targets, as exemplified by most, if not all, physical sports. Recently, Nijwahan (2008) argued strongly that neural compensations were an integrated feature of the whole nervous system, acting on the processed information even since its very first stages.

Much of the psychophysical empirical work on the subject was made around the *flash-lag* phenomena, wherein a brief visual flash, presented in spatial synchrony with a moving target, is perceptually seen as lagging behind the moving stimulus. Much controversy still exists around the theoretical interpretation of these results (e.g., Eagleman & Sejnowski, 2000; Khurana et al., 2000), particularly in the so called flash terminated conditions, where the flash is synchronous with the disappearance of the moving target. In such conditions, no *flash-lag* is observed. However, other empirical lines of inquiry show instances of motion extrapolation in movement termination conditions. One such line concerns the *forward displacement* phenomenon (Freyd & Finke, 1984). Briefly, when a moving target that suddenly disappears is presented to subjects instructed to locate its vanishing point, an error in the direction of motion is typically found. Kerzel (2000, 2006) has argued for the necessity of a motor engagement for the phenomenon to emerge. Particularly, it was shown that no *forward displacement* is found with suppressed eye movements unless the response modality is itself of a motor nature, such as displacing a mouse cursor or directly touching the screen. Moreover, it was suggested that the compensation is being held in the egocentric space used for motor behaviour and not within the retinotopic space.

Accepting the motor extrapolation as a working hypothesis, Kerzel and Gegenfurtner (2003) raised the question of its variable or constant nature. An index of the temporal error was thus readily suggested (equation 1), with the implication that a constant ratio would mean a temporal extrapolation constant, and a variable ratio would indicate otherwise.

$$t = \frac{forward\ displacement}{Velocity} \quad (1)$$

This index is formally valid, and can be derived easily. However, it depends on the fundamental assumption that physical velocity is the same as perceived velocity; from there follow, as secondary assumptions, that *forward displacement* and *velocity* relate in a linear fashion and share a common known zero (i.e., that direct proportionality holds between them).

The fundamental assumption begs a critical psychophysical issue. Recognizing this is the key to recasting the problem in terms suited to the extrapolation hypothesis, which is actually meant to bridge between the physical realm and the psychological realm of "perception-for-action". From this perspective, (1) *forward displacement* reflects a subjective representation of velocity with the peculiarity that it lies in the straight path to a motor localisation response (rather than to a perceptual judgement); (2) the mechanism underlying this psychophysical relation embodies the extrapolation process, aimed at making action efficient (e.g., ensuring successful intercepting, grasping, or collision avoidance).

Recasting the proposed ratio as a psychophysical function thus sets a proper test bed for the alternative hypotheses on how the compensatory mechanism works: if it is trough an extrapolation constant, then a linear psychophysical function should be the case, with the temporal constant given by the slope of the function or, equivalently, the function's first derivative (by differentiating for velocity). Any other, non-linear functional shape will entail a variable compensation mechanism that will be, nonetheless, similarly characterized by the first derivative of the psychophysical function (2).

$$f'(velocity) = \frac{d(forward\ displacement)}{d(velocity)} \qquad (2)$$

Despite the formal analogy with Kerzel and Gegenfurtner's index, one fundamental difference is that all parameters are empirical, and not presupposed. This allows overcoming what would otherwise be interpreted as mixed results. For instance, Kerzel & Gegenfurtner (2003) reported decreases in their temporal estimates with increases in the physical velocity, whereas the spatial error was shown to increase linearly. This ceases being an inconsistency if one abandons the a priori assumption that the intercept of the function is 0 (as would be true with physical velocity, but needn't be the case in a psychophysical function).

The present study uses functional measurement to establish the psychophysical function of velocity with *forward displacement* as the dependent variable. It rests on the previous finding of a dividing model for the combined effect of target's *Velocity* and *Offset position* on *forward displacement* values (De Sá Teixeira & Oliveira, 2008). This integration model can be used as a base and frame for the measurement of subjective values of velocity, expressed through *forward displacement*. These values are an appropriate measure of "perception-for-action" and, taken as a function of physical velocity, allow setting the sought psychophysical function. A test of the two alternative hypotheses of a constant or variable temporal compensatory mechanism thus follows, along the indicated lines.

## Method

### *Participants*

Twenty under-graduate (19 female and 1 male) students at the University of Coimbra volunteered for the experiment. They all had normal or corrected to normal vision and were unaware of the purposes of the experiment.

*Stimuli*

A set of avi animations (40 fps) that depict a 30 pixels$^2$ black square travelling horizontally across a white background, at constant speeds of 180, 240, 300, 360, 420, 480 or 540 pixels per second (px/s). The target emerged from either the left or the right edge of the screen and suddenly vanished after covering 536, 593 or 650 pixels. All animations were created with *Interactive Physics 2000* and edited with *VirtualDub*.

*Apparatus*

The experiment was implemented with *Super Lab 4.0*. Animations were presented on a PC equipped with a flat touchscreen LCD monitor, at a refreshing rate of 120 HZ and with screen resolution of 1024 x 768 pixels. Participant's responses consisted either in displacing a "plus sign" cursor controlled by an optical wireless mouse (mouse condition), or in directly touching the screen with a Softpoint Pen (pointer condition).

*Design and Procedure*

The experiment obeyed a full factorial 7 (*velocity*) x 3 (*offset location*) x 2 (*direction of movement*) repeated measures design, with six replications. Half the subjects used the mouse for responding and the other half the pointer. Subjects sat at around 60 cm from the screen, and were requested to hold a steady attitude. Compliance to this instruction was monitored by the researcher, and corrective feedback was provided whenever necessary. Subjects were asked to attentively observe the randomly presented videos and, the moment these were over, to locate the target's geometrical centre at the last seen position. Subjects responding with the "mouse" displaced the cursor from the centre of the screen, where it appeared, to the desired position. Those responding with the pointer simply touched the screen at the last perceived location of the target. Practice trials were given beforehand to ensure good understanding of the instructions and familiarity with the task.

## Results

Left column of Figure 1 illustrates the factorial diagrams of *velocity* × *offset* for both the *Mouse* (first row) and the *Pointer* (second row) conditions. A clear trend for higher *forward displacement* with greater velocity is denoted by the line's positive slopes, while the vertical separations among them illustrate a reversed effect of travelled distance, which decreases *forward displacement*. The fan-like pattern observed overall suggests a strong statistical interaction between factors, with larger (and decreasing) effects of *offset location* for higher levels of *velocity*. Concurring with the visual inspection, statistically significant main effects were found for *offset location* ($F(1.636, 29.44) = 92.697$, $p < 0.01$) *and velocity* ($F(2.921, 52.576) = 26.394$, $p < 0.01$), together with a significant *velocity * offset* interaction ($F(12, 216) = 9.86$, $p < 0.01$). No other interactions were observed involving these factors.

On the whole, results are compatible with a dividing model, whereby *velocity* is divided by *offset location*. As established in *Information Integration Theory* (IIT), the statistical signature of a multiplying model is a significant bi-linear interaction component which leaves null residuals behind (Anderson, 1981; 1982). This was tested with the CALSTAT program (Weiss, 2006): a significant *linear* × *linear* component of *velocity * offset* was found in both response modalities [Mouse: ($F(1, 9) = 23.01$, $p < 0.01$); Pointer ($F(1, 9) = 65.3$, $p < 0.01$)], and no significant residuals were left in both cases ($F < 1$).

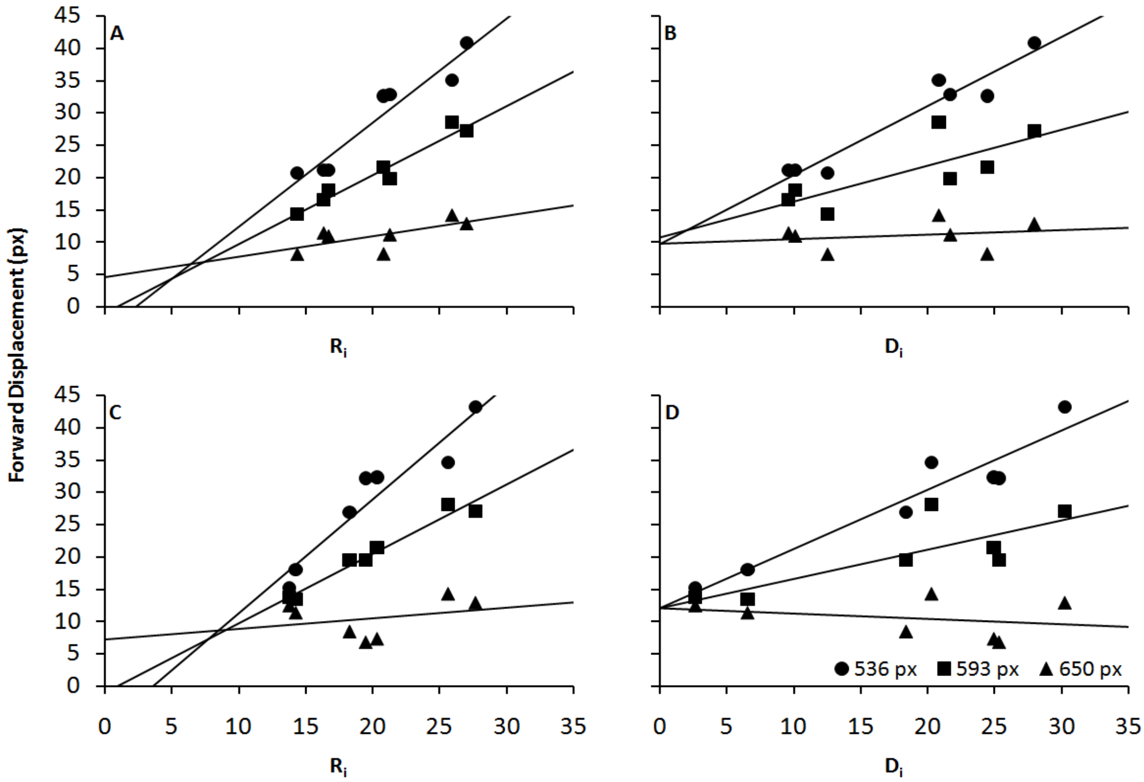


**Figure 1 –** Average *forward displacement* magnitude plotted, respectively, as a function of the marginal means of velocity (panel A: *Mouse*; panel C: *Pointer*) and of "differences with minimum relative error" taken from the velocity factor (panel B: Mouse; panel D: Pointer). Curve's parameters are the levels of travelled distance.

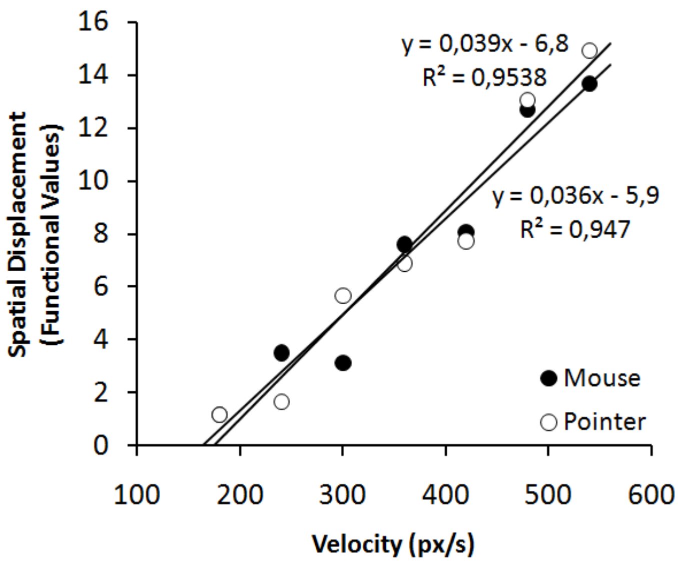


**Figure 2.** Psychophysical Functions relating physical *Velocity* (in abscissa) with the functional (subjective) values derived from *forward displacement* (vertical axis), for both the *Mouse* (black dots) and *Pointer* (white dots) modalities.

Following on earlier work by N. Anderson, Masin (2004) has derived two additional predictions from the multiplicative model, concerning the orderly relations of the intercept $c_0$ to interval (marginal means of the responses: $\overline{R}_j, \overline{R}_i$ ) and ratio-scale (differences with minimum relative error: $D_j = \left|R_{1j} - R_{Ij}\right|, D_i = \left|R_{i1} - R_{iJ}\right|$) measures of the stimuli (for details of the algebraic derivation see Masin, 2004). Of special significance to our purposes is the prediction of invariance of the curve's intercepts with ratio-scale measures in the abscissa, which provides an estimate of $c_0$. This can be seen to verify on the right column of Fig 1 (panels B and D), which illustrates an almost perfect convergence of the fans on a single point of the ordinate. Because estimation of $c_0$ was done on an individual subject basis, statistical comparisons could be done between the intercepts of different lines, which disclosed no significant differences, in accordance with the prediction of $c_0$ invariance.

The multiplying model of IIT conjoins a linear response function $R_{ij} = c_0 + c_1 r_{ij}$ with the multiplicative operation $r_{ij} = s_{Ai} s_{Bi}$ ($s_{Ai}$ and $s_{Bi}$ standing for subjective values). Subtracting $c_0$ from $R_{ij}$ thus makes possible to go beyond linear (interval-scale) measures to obtain ratio measures of the functional values of the stimuli. By virtue of the Linear Fan Theorem (Anderson, 1981; 1982), linearity of the response function is validated simultaneously with the multiplying operation. Because in the present case the integration operation is divisive, marginal means of *velocity* do not actually correspond to linear measures of *velocity* but instead of 1/*velocity*. Sheer inversion of the marginal estimates would not be a solution unless $c_0 = 0$ or is subtracted to *Rij*. By doing just that, and taking the inverse of the obtained values, proper subjective values for all the levels of velocity on a ratio-scale were eventually obtained.

Since these values, expressed in terms of *forward displacement*, are the subjective counterpart of physical velocity, this allows building true psychophysical functions, reflecting the "perception-for-action" of velocity. Figure 2 plots those functions. Clear linear trends were observed in both response modalities, confirmed through linear regressions. [*Mouse*: ($F(1, 5) = 89.346$, $p < 0.01$); *Pointer* ($F(1, 5) = 103.216$, $p < 0.01$)]. Slopes and intercepts differed significantly from zero in both cases ($p < 0.01$) and no significant differences in slope were found between response modalities (independent samples *t*-test over the distributions of individual slopes: $p > 0.7$). Outcomes concur with a linear psychophysical function for *velocity*, and thus with a compensation mechanism resting on a temporal constant of extrapolation.

## Discussion

Outcomes replicate the previously documented dividing rule for the integration of target's *velocity* and *offset location*, and through there the ability of *forward displacement* to provide a valid linear response scale in these integration tasks.

The found psychophysical law for velocity, involving the "perception-for action" of target's physical velocity, was shown to be linear, with positive slope. These results suggest that, accepting the hypothesis of a compensatory mechanism for the neural lag, its operation rest on a temporal extrapolation constant.

Because the slope values were the same with the two sorts of motor responses (direct for pointing, indirect or mediated for locating with the mouse cursor), compensation is suggested to occur primarily at the stages of motor planning, and not so much of motor execution. Analysis of the response times (*RT*) in both modalities strengthens this interpretation. As expected, using the mouse resulted in significantly higher *RT* than using the pointer ($F(1, 18) = 4.936$, $p < 0.05$; Mouse: 1227 ms; Pointer: 1002 ms); however, no relation was uncovered between *RT* and the magnitude of forward displacement, which stayed roughly constant across the span of response times. This supports the notion that compensation occurs at a different stage from actual engagement in motor behaviour.

The linear shape of the psychophysical function for velocity has not been a common finding in studies using judgments (Scialfa et al., 1991). This may reflect a difference between perceiving-for-action and perceiving-for-knowing. Proper measurement of the "perception-for-action" of velocity does appear to usefully constrain the "motion extrapolation" framework as regards some of its hypothesis, even if psychophysical data alone cannot be expected to provide the full picture on the matter of neural compensations.

## References

ANDERSON, N. H. (1981). *Foundations of information integration theory*. New York: Academic Press.

ANDERSON, N. H. (1982). *Methods of information integration theory*. New York: Academic Press.

DE SÁ TEIXEIRA, N., & OLIVEIRA, A. M. (2008). A perceptual-cognitive dividing model for the integration of velocity and travelled distance of a moving target by localization rersponses. In B. A. Schneider & B. M. Ben-David (Eds.). *Fechner Day 2008. Proceedings of the 24th Annual Meeting of the International Society for Psychophysics*. Toronto, Canada: The International Society for Psychophysics (pp. 99-104).

EAGLEMAN, D. M. & SEJNOWSKI, T. J. (2000). Motion integration and postdiction in visual awareness. *Science. 287(5460),* 2036-2038.

FREYD, J. J., & FINKE, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 126-132.

KERZEL, D. (2000). Eye movements and visible persistence explain the mislocalization of the final position of a moving target. *Vision Research, 40(27),* 3703-3715.

KERZEL, D. (2006). Why eye movements and perceptual factors have to be controlled in studies on "Representational Momentum". *Psychonomic Bulletin & Review, 13(1),* 166-173.

KERZEL, D., & GEGENFURTNER, K. R. (2003). Neuronal processing delays are compensated in the sensorimotor branch of the visual system. *Current Biology, 13(22),* 1975-1978.

KHURANA, B., WATANABE, K., & NIJHAWAN, R. (2000). The role of attention in motion extrapolation: Are moving objects 'corrected' or flashed objects attentionally delayed? *Perception, 29,* 675-692.

MASIN, S. C. (2004). Tests of functional measurement theory for multiplicative models. In A. M. Oliveira, M. Teixeira, G. F. Borges, & M. J. Ferro (Eds.). *Fechner Day 2004. Proceedings of the 20th Annual Meeting of the International Society for Psychophysics*. Coimbra, Portugal: The International Society for Psychophysics (pp. 447-452).

NIJWAHAN, R. (2008). Visual prediction: Psychophysics and neurophysiology of compensation for time delays. *Behavioral & Brain Sciences, 31,* 179-239.

SCIALFA, C. T., GUZY, L. Y., LEIBOWITZ, H. W., GARVEY, P. M., & TYRREL, R. A. (1991). Age differences in estimating vehicle velocity. *Psychology and Aging. 6(1),* 60-66.

WEISS, D. J. (2006). *Analysis of variance and functional measurement*. New York: Oxford University Press.

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