THE DIRECTION OF THE PERCEPTUAL DISPLACEMENT OF A MOVING TARGET'S STARTING POINT: THE FRÖHLICH EFFECT, THE BACKWARD MISLOCATION AND THE VELOCITY OF MOTION.

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Abstract

The aim of the research presented here was to test the role of velocity on the perceptual displacement of the starting point of target moving on horizontal and vertical trajectories. In this work we summarize the results collected in our previous work together with a new experiment. The results of four experiments are presented, in which the velocity of a moving target was modulated (experiment 1 and 2) and two different absolute velocities were tested (experiment 3 and 4). Pooling together all the results helps to understand the nature of the effect, which has a direction opposite to the direction of motion (i.e. backward mislocation) with slow velocity whereas with higher velocities the first part of the trajectory is deleted (i.e. Fröhlich effect). Results are discussed in light of the motion extrapolation theory, suggesting a possible mechanism for dislocations of starting point.

In 1923 Fröhlich observed that the first perceived position (starting point, SP) of a moving target is mislocated. This illusion, known as the Fröhlich effect, is described as a dislocation error in the direction of motion. This effect originally led to discussion on the processing limits for conscious awareness, the so-called 'sensation time' (Fröhlich, 1923). More recently, Actis-Grosso, Stucchi and Vicario (1996) reported the reverse error, that is an error opposite to the direction of motion (i.e., a backward mislocation). Different interpretations have been proposed to account for these two opposite errors (Kerzel and Gegenfurtner, 2004; Müsseler and Kerzel, 2004). Target velocity seems to play a crucial role. In fact, using a very fast moving target (i.e. 44°/s) Müsseler and Aschersleben (1998) found a *Fröhlich effect*, whereas a backward mislocation was typically observed with slower target's velocity (i.e.< 20°/s) both Thorton (2002). Actis-Grosso and Stucchi (2003) proposed a model based on an early visual extrapolating mechanism (Nijhawan, 1994) that compensates the ~100 ms neural delay by transforming it into a spatial distance. According to this model there are two crucial factors that could account for these opposite errors: i) the target's absolute velocity at the beginning of motion and ii) the presence of a threshold for target absolute velocity, above which the mechanism does not extrapolate the motion of SP, simply cutting the first 100 ms of motion (thus shifting the direction of the error from backward to forward).

The aim of the current research is to test the role of velocity on the magnitude and direction of perceptual displacement of SP. In particular, experiment 1 investigates whether the modulation of velocity in the central part of a motion has an influence on SP; experiment 2 tests the role of target's absolute velocity at the beginning of a motion; and experiment 3 and 4 investigate the presence of a threshold for target absolute velocity.

Experiment 1

Participants. Ten participants (six females and four males, average age 27.6 years) volunteered for the experiment. All had normal or corrected-to-normal vision.
Apparatus and stimuli. The stimuli were presented on a PC Pentium 4- based computer equipment connected to a 17 in. monitor with a resolution of 1024 x768 pixels (where a pixel can be considered as a square of 0.1 mm) and a refresh rate of 100 Hz. A red dot (2 pixels in diameter) travelled on a black background in a straight line covering a path of 18.6 cm in 3.1s. The directions were right-to-left (RL), left-to-right (LR), top-to-bottom (TB) and bottom-to-top (BT). For 1/5 of the stimuli the velocity of the dot was kept constant at 6 cm/s, whereas for the remaining stimuli it was varied following one of four different modulations. Each modulation was divided in three phases (i.e. *a*, *b*, and *c*). In *a* and *c* the velocity was kept constant at 6 cm/s, whereas the middle phase (*b*) could varied as listed below:

1) *Acceleration-Deceleration (AD1)*: the velocity raised to 8 cm/s, decreased to 4cm/s and went back to 6 cm/s following a linear function.
2) *Acceleration-Deceleration (AD2)*: the velocity raised to 10 cm/s, decreased to 2 cm/s and went back to 6 cm/s.
3) *Deceleration-Acceleration (DA1)*: the velocity decreased to 4 cm/s, increased to 8 cm/s and went back to 6 cm/s.
4) *Deceleration-Acceleration (DA2)*: velocity decreased to 2 cm/s, increased to 10 cm/s and went back to 6 cm/s.

Procedure. Participants sat at a comfortable distance from the screen (about 64 cm) in a dark room. A blue cross-hair (2 x 2 pixels) signalled the point at which the stimulus was going to appear. The blue cross-hair remained on the screen for 1.5 s, followed by a blank interval of 50 ms, and then the dot appeared, and the motion started at once. At the end of motion the participants had to localize by using the mouse where the moving dot had appeared. As soon as the mouse was moved, a green cross-hair (2 x 2 pixels) was displayed on the screen in a random position. The task of participants consisted of placing the cross exactly where he/she had seen the disk to appear and pressing the mouse button. The response marked the start of the next trial. The completely within-subjects experimental design included two factors: Directions (four levels) x Modulations (5 levels) for a total of 20 stimuli. The set of stimuli presented comprised four replications, for a total of 80 trials per sessions. The whole experimental session lasted approximately 8 minutes.
Results. The difference between judged starting point and actual starting point is referred to as displacement. For horizontal motion we analysed only the *x* displacement and for vertical motion only the *y* displacement. The mean constant error (CE) was obtained by subtracting the coordinate of the response from the actual coordinate, thus obtaining a negative value for backward displacement and a positive value for forward displacement. In figure 1 mean error for SP is reported for the four directions of motion.
Consistently with previous results, a backward SP displacement was obtained. The average error in pixels computed over participants were 28.96 (SD= 43.27) for SP [$t(9) = 4.76$ $p < .001$]. A mirror reflection for the Ces of SP was needed to perform the ANOVA on CE. Because ANOVA is aimed at detecting systematic effects in the magnitude of CE, the sign of Ces of SP should be changed so as to obtain positive values for backward displacements of the SP. A two-way ANOVA on CE showed an effect of Directions for SP [$F(9) = 3.67$ $p < .02$]. This effect is mainly due to the difference in magnitude between the error in the direction LR and the error in the vertical direction [e.g. AD2 in the direction LR (CE=25.95, SD=37.09) vs. AD1 in the direction BT (CE=4.025, SD=38.92) $t(9)=-2.475$, $p<.05$].

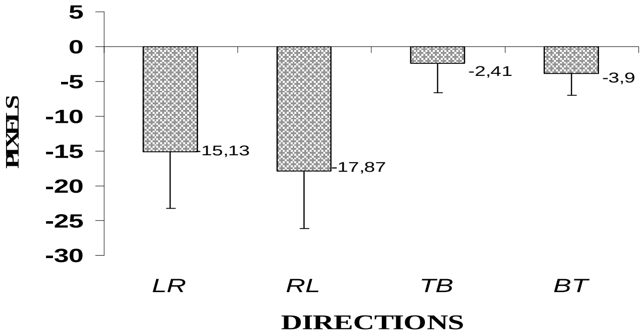

FIGURE 1. Mean errors for the four directions of motion for SP. Standard errors on top.

Experiment 2

Participants. Ten naïve participants (seven females and three males, average age 23.6 years) volunteered for the experiment. All had normal or corrected-to-normal vision.
Apparatus and stimuli. Apparatus was the same as in the experiment 1. For 1/5 of the stimuli, the velocity of the dot was kept constant at 6.37 cm/s, whereas for the remaining stimuli the dot could have four different instantaneous velocities at SP (2.12 cm/s, 4.25 cm/s, 8.50 cm/s and 10.62 cm/s). In these cases the dot reached the velocity of 6.37 cm/s in the first 482 ms of motion. In this way, we obtained two linearly accelerated (8.82 cm/s^2 and 4.41 cm/s^2) and two linearly decelerated motions (-4.41 cm/s^2 and -8.82 cm/s^2)
The actual SP could be in a random position varied between 5 and 7.5 cm from the centre of the screen. Stimuli were randomized between subjects.
Procedure. Procedure was the same as in the experiment 1.
*Results***.** The displacement of SP and the mean constant error were obtained as described in the experiment 1. In figure 2 mean errors are reported for the four directions of motion. Consistently with previous results, a backward SP displacement was obtained. The average error in pixels computed over participants (-7.27) proved not significant. As it is clear from Figure 2, this is mainly due to vertical direction. Both horizontal directions proved significant [CE=-17.04, SE=5.29 t(9)=7.28, p<.000, for LR, and CE=-13.67, SE=5.98 t(9)=2.75, p<.01 for RL respectively] when the mouse coordinates were confronted with the actual coordinates. A two-way ANOVA on CE was performed. The results showed only an effect of Direction [F(1,9)=3.9 p< .02]. This effect is due to the difference between horizontal (CE=-15.35 SE=3.80) and vertical directions [CE=0.79, SE=5.22 t(9)=-4.607, p<.001]. In fact, for constant velocity profile, the error was statistically significant for both horizontal directions [(CE=-16.56, SE=4.18) t(9)=2.43, p<.01 for LR and CE=-13.23, SE=5.60 t(9)=-3.12, p<.003 for RL respectively]. This substantiates previous results. Furthermore, for LR direction, both positive accelerations proved significant [(CE = -14.62, SE=3.52) t(9)=3.64, p<.001 for +2 and CE=-10.67, SE=6.54 t(9)=2.79, p<.01 for +1 respectively], while for RL direction both negative accelerations proved significant [(CE=-14.4, SE=6.49) t(9)=-2.54, p<.02 for -2 and CE=-8.25, SE=7.15 t(9)=3.29, p<.002 for -1 respectively]. The absence of a significant error in the vertical direction, albeit consistent with our previous results, is not consistently reported in the literature and needs further investigation.

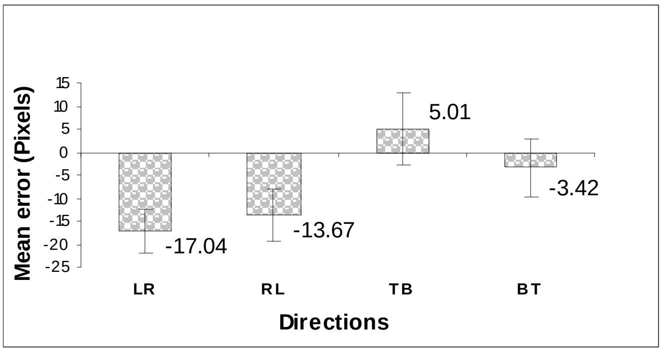

FIGURE 2. Mean errors for the four directions of motion for SP. Standard errors on top.

Experiment 3

Participants. Six naïve participants (4 females and 2 males, average age 26.6 years) volunteered for the experiment. All had normal or corrected-to-normal vision.

Apparatus and stimuli. The stimuli were presented on a PC Pentium 4- based computer equipment connected to a 19 in. monitor with a resolution of 1280 x 1024 pixels and a refresh rate of 100 Hz. A red dot (5 pixels in diameter) travelled in a straight line on a black background, covering a horizontal path of 3 cm (either in the direction right-to-left or in the direction left-to-right). The velocity of the target could be 2.23 cm/s or 11.13 cm/s. At the beginning of each trial two vertical lines were presented (reference system) in a position randomly located within a 80 pixels viewing square, centred on the middle of the screen. The two white lines were aligned one below the other with an empty space between them of 3.5 cm. After an interval between 500 and 1000 ms the dot appeared on the monitor and the motion started at once. Motion SP could be in one of seven possible positions. One of these positions was in the empty space between the lines, aligned with them (Position 0, P0). The two lines served thus as a reference system; the other six SPs were located away from P0 (three at its left and three at its right) with steps of 2 mm.

Procedure. Procedure was the same as in the experiment 1 and 2. The method of constant stimuli was used. The task of participants was to judge, after the end of motion, whether target SP was **in** the direction of motion (by pressing the left key) or opposite to it (by pressing the right key). Each trial was separated by a random interval between 500 and 1000 ms. The completely within-subjects experimental design included three factors: Direction (2 levels) x Velocity (2 levels) x Position (7 levels) for a total of 28 stimuli. Each stimulus had 10 replications, for a total of 280 trials. The duration of the whole experimental session was approximately 15 minutes. The order of presentation was randomized for all the participants.

Results. For each subject the proportion of responses "opposite to the direction of motion" was calculated. In figure 3 the proportion of responses averaged over subjects are reported for each position as a function of velocity. Proportions were then transformed into z scores. Linear regression was used to calculate the line that fit the data. The point of subjective equality (PSE) for each velocity was then calculated by determining the value on the stimulus scale that corresponds to a null z. PSE for the slower velocity (2.23 cm/s) was -1.87 mm, whereas PSE for the faster velocity (11.13 cm/s) was – 0.62 mm. The difference between the two thresholds was significant ($t = -3.49$ $p < .01$) when the *jnd* was used as an estimate of $\tilde{\sigma}$. JND was calculated with the linear regression coefficient b, where JND = $\frac{1}{b}$.

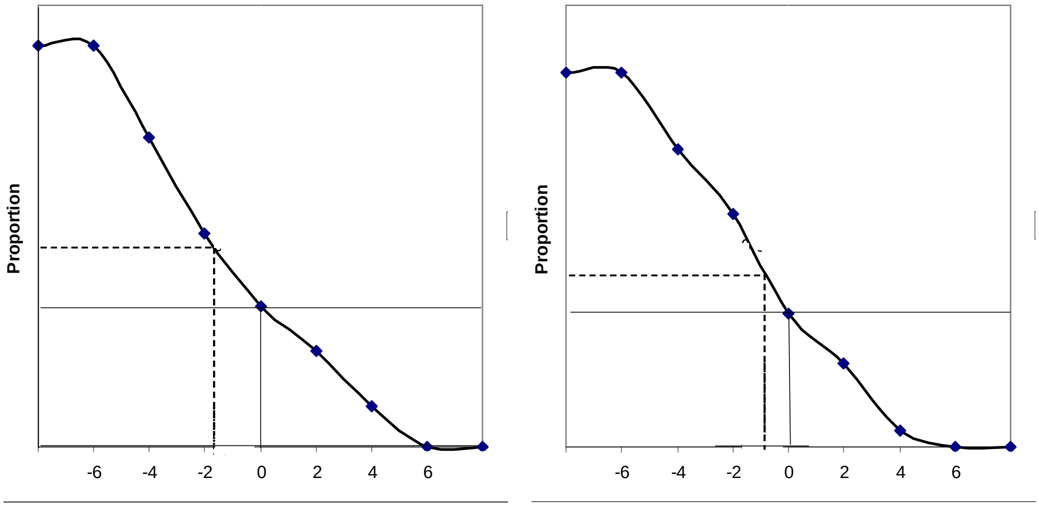

Figure 3 . Proportion of responses averaged over subjects for each position as a function of velocity 2.23 (left) and 11.13 (right).

Experiment 4

Participants. Six naïve participants (3 females and 3 males, average age 28.83 years) volunteered for the experiment. All had normal or corrected-to-normal vision.

Apparatus, stimuli and procedure. Apparatus, stimuli and procedure were the same used for the experiment 3, with the following exceptions: i) The target followed a vertical path (either in the direction top-to-bottom or in the direction bottom-to-top); ii) The task of participants was to judge, after the end of motion, whether target SP was up respect to the two horizontal lines (by pressing the up key with their left hand) or down to them (by pressing the down key with their right hand).

Results. The data were analysed as described in the Experiment 3. In figure 4 the proportion of responses averaged over subjects are reported for each position as a function of velocity. PSE for the slower velocity (2.23 cm/s) was -0.33 mm, whereas PSE for the faster velocity (11.13 cm/s) was 1.5 mm. The difference between the two thresholds was significant ($t = -2.52$ $p < .01$)

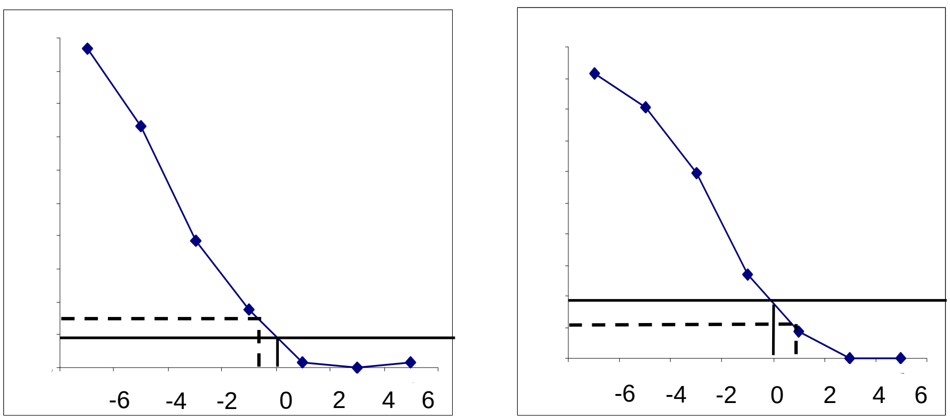

Figure 4 . Proportion of responses averaged over subjects for each position as a function of velocity 2.23 (left) and 11.13 (right).

Discussion: In four experiments, perceptual mislocation for SP was explored. A backward mislocation was not found when the velocity was modulated in the middle part of the trajectory. When the absolute velocity was tested at the beginning of motion (experiment 2) the backward mislocation was found only for horizontal trajectories. Results of experiment 1 and 2 indicated that only what happens before the perception of SP has an influence on its localization. The modulation of velocity in the initial part of the trajectory had no effect on the perception of SP. This is not consistent with previous studies, Hubbard and Motes (2002) in fact have showed an effect of absolute velocity on the magnitude of SP error. In experiment 3 and 4, an effect of velocity was found. With slower velocity both horizontal and vertical motion SP was shifted opposite to direction of motion. For vertical motion the backward mislocation is very near to zero. With faster velocity a backward displacement proved significant only for horizontal motion but not for vertical one, this is consistent with previous results (Bastianelli et al 2005) where no backward mislocation was found. Furthermore, the experiment 4 showed that increasing velocity causes an inversion of the error.

A relevant result (at least for horizontal motion) is that the magnitude of the error decreases as velocity increases. This seems to suggest that the faster velocity used in this experiment is near to the threshold (at least for a dot of 5 pixels in diameter). In fact, although the presence of a reference system should improve accuracy especially for the slowest velocity, in which the target is present for a longer time, accuracy is better for faster velocity.

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