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The effect of motion acceleration on displacement of continuous and staircase motion in the frontoparallel plane[#]

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Abstract: If a moving target suddenly disappears, memorised image for the final location of the target is displaced forward in the direction of motion. This displacement depends on higher order motion regularities (e.g., velocity, acceleration), and so a consideration of displacement might reveal which other motion regularities observers are sensitive to. Perceptually continuous or staircase motions exhibiting either negative, zero, or positive acceleration were presented to subjects. Displacement magnitude was smallest for negative acceleration and largest for positive acceleration, and these differences were larger with continuous motion than with staircase motion. The effect of acceleration is consistent with effects of velocity and an incorporation of effects of momentum into the representation. The weaker effect of acceleration condition with staircase motion is consistent with previous findings that motion signals are more impoverished with staircase motion than with continuous motion. Implications for theories of representational momentum and for perception of motion are considered.

Key words: representational momentum, motion perception, memory, acceleration, staircase motion

Vpliv pospešenosti gibanja na reprezentacijski premik pri zveznem in stopničastem gibanju v čelni ravnini

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Povzetek: Če gibajoča se tarča nenadoma izgine, mesto izginotja v spominu premaknemo naprej v smeri gibanja. Velikost premika je odvisna od nespremenljivih značilnosti gibanja (npr. hitrosti in pospešenosti), zato bi lahko premik kazal, kako občutljivi so opazovalci tudi na nekatere druge značilnosti gibanja. Udeleženci so opazovali različno pospešena zvezna gibanja in stopničasta, nezvezna gibanja dolgega obsega. Premik je bil največji pri pozitivni in najmanjši pri negativni pospešenosti gibanja. Učinek pospešenosti gibanja na velikost premika je bil večji pri zveznem kot pri nezveznem gibanju, kar je v

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skladu s predhodnimi ugotovitvami, da so signali gibanja pri zveznem gibanju močnejši kot pri nezveznem gibanju. Rezultati nakazujejo možnosti povezave raziskovanja premika in občutljivosti za kompleksne značilnosti gibanja pri posamezni vrsti gibanja.

Ključne besede: reprezentacijski premik, zaznavanje gibanja, spomin, pospešenost, stopničasto gibanje

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We live in dynamic environment. Moving objects frequently provide stimuli for our visual system. Besides that our own motion is an impetus for an almost constantly changing optic array. Processing of motion and other optic changes is perpetual and extremely important. Accurate detection of those changes is fundamental for a proper action.

A phenomenon, called representational momentum, shows that the visual system responds to stimulus change with forming dynamic visual representations (Freyd, 1987). Mental representations incorporate the dynamic properties of their external carriers (the stimuli). Representational momentum occurs when a 2-D motion of a target is observed and the target suddenly disappears. The remembered position of the vanishing point is displaced forward. It is as though the representation of a moving target would itself get into motion and could not stop instantly when the target disappeared, but would instead still be moving forward for some time. As a consequence, the memories for the final position of the target are distorted forward.

Freyd and Finke (1984) showed observers a static rectangle at three different orientations. The different orientations were each presented for 250 ms, and there was an interstimulus interval of 250 ms between each presentation. This elicited a clear impression of motion (rectangle rotation). Observers did not correctly remember the final orientation of the rectangle, but rather, they thought the rotation of the rectangle covered a slightly larger angle than it really did. It was as though the representation of the rectangle's rotation obtained the momentum and continued its motion after the stimulation had stopped. Because the displacement of remembered position occurred in visual short-term memory, after the target had disappeared, the authors concluded, that the displacement is a memory distortion. It occurs at a cognitive level (at the level of representations), and not at the perceptual level.

Finke and Freyd (1985) used dot patterns in which each dot implied motion in a different direction. They obtained a similar forward displacement in memory for the final position of dots. Hubbard and Bharucha (1988) presented a single target circle moving horizontally and vertically in the frontoparallel plane, and again the judged vanishing point was displaced forward in the direction of motion. The magnitude of displacement depended on motion velocity: the faster was the motion, the larger was the displacement.

There are different explanations of representational momentum (for a review see Hubbard & Motes, 2002). One of the explanations follows Shepard's (1984) theory of ecological constraints. This explanation claims that representational momentum reflects an adaptive internalization of physical principles in environmental change. The organism resonates with environment, and as a consequence the properties of mental representations (percepts) resemble those of stimuli. According to this view, the representation of a moving target conforms to the physical properties of real motion. Real targets obtain some momentum during motion, and so do their representations. There are some empirical findings that support this view. For example, Freyd and Johnson (1987) presented a sequence of three different orientations of a rectangle. After a short retention interval the probe was presented. Its orientation was either the same or different from the last orientation of the target. They found that the magnitude of representational momentum depends on the length of retention interval: Longer retention intervals produce greater distortion because there is more time for the representation to change. Finke, Freyd and Shyi (1986) and Freyd and Johnson (1987) found that the magnitude of displacement depends on motion velocity: The fastest the velocity, the greater the momentum and the afterward displacement.

However, another explanation can also account for the representational momentum effect. Some researchers (e.g., Hubbard, 1994; Hubbard & Bharucha, 1988; Verfaillie & d'Ydewalle, 1991) claimed that displacement is a consequence of informed anticipation. According to this view, the effect of representational momentum is cognitively penetrable (i.e., affected by higher level cognitive processes). Dynamic representation of motion often includes cognitive inferences about motion event and predictions for future motion, which help an organism to act appropriately to constant dynamic changes in environment. Because the transmission of signals along the visual pathways takes approximately 100 ms for the information to arrive from the retina to the cortex and get interpreted, and in this time an object already travels some distance, the timing of reaction could be inappropriate. In order for the organism to react properly to a new position of a target, this position has to be mentally extrapolated (predicted) in advance. The anticipation of target position includes the knowledge about higher order regularities in motion (Verfaillie & d'Ydewalle, 1991), feasible future motion path (Hubbard, 1994), friction, gravity, other environmental invariants, and the surrounding frame context (Hubbard, 1995a, 1995b).

In the study of Verfaillie and d'Ydewalle (1991), the magnitude of representational momentum changed if motion was periodical (e.g., a target was rotating clockwise, then counter-clockwise, and after that clockwise again). The representational momentum effect vanished if the target disappeared at the moment when direction change was anticipated. The authors reasoned that predictable properties of motion (e.g., periodicity and the points of direction change) were extracted. After the target had disappeared, future event course was anticipated according to the previously perceived structure of events. This anticipation influenced the magnitude of the representational momentum effect. They concluded that "… the momentum effect presents itself as a potentially fruitful vehicle for studying event perception. If the visual system is automatically prompted to anticipate the future event course, then characteristics of distortions in position memory may reveal aspects of the perceived structure of events." (p. 313).

Other complex motion characteristics, e.g. acceleration, could also be depicted in motion representation. The history of perceived change in velocity of a target could be used in the anticipation of future target motion. Although several studies (e.g., Snowden & Braddick, 1991; Werkhoven, Snippe & Toet, 1992) showed that motion acceleration is not perceived accurately, Finke et al. (1986) found, for configurations of pattern elements in apparent motion, that the magnitude of displacement changed with implied velocity and motion acceleration. When the pattern motion accelerated, its final velocity was high and the displacement was larger than in the case of motion with constant velocity. In the case of decelerated motion the displacement was smaller than in the case of constant velocity. It seems that extreme motion acceleration is depicted in motion representation and incorporated in anticipation of event course and future position of a moving object. As a consequence, different accelerations produce different displacements.

If characteristics of displacement may actually reveal aspects of the perceived structure of events, as Verfaillie and d'Ydewalle (1991) reasoned, properties of representational momentum could also show how well motion characteristics, such as velocity change, are extracted and internalized at different types of motion, for instance at apparent motion as opposed to real motion.

Motion can be perceived in situations where a target does not occupy every position along the pathway. When a stationary target is presented at different non-adjacent positions for a short interval, the impression of motion is formed, but this impression is less compelling than at real motion. In one type of such apparent motion, the staircase motion, a target is visible all the time (there is no empty interval between the successive positions). Staircase motion contains successive jumps and rests of the target. Whereas in real motion target velocity is processed directly by different motion detectors that respond preferentially to a certain velocity (Hubel, 1995), in staircase motion velocity cannot be extracted directly by motion detectors, because target jumps are usually much bigger than the receptive fields of motion detectors. In staircase motion, the velocity assessed by low-level motion detectors would either be zero during target rest or infinite during target jump. Motion velocity has to be determined differently. The visual system most probably first estimates the magnitude of target jump and the temporal difference between the onset of the first and the second position of a target. It then calculates velocity as a ratio of these two values. This calculation is a higher-level process, which can be influenced by different cognitive factors, such as attention (see e.g. Mattes & Ulrich, 1998; Suzuki & Cavanagh, 1997) and the interaction of spatial and temporal processing, resulting in tau and kappa effects (Huang & Jones, 1982). So, there is a possibility that in certain conditions the estimated velocity of apparent motion is different from the perceived velocity of equivalently fast real motion.

Poljanšek (2001) found that real and apparent motion differ in perceived acceleration. Detection of velocity change (detection of target acceleration and deceleration) was poorer in staircase motion than in continuous motion. This might be a consequence of different processing of velocity and acceleration in the two types of motion. Suppose that the staircase-motion velocity is calculated as a ratio of the travelled distance (the magnitude of target jump) and the time interval between the onsets of two successive positions of a target. The calculated velocity in each temporal interval (jump) equals the average velocity in that interval. When motion function is linear (motion velocity is constant), the calculated average staircase-motion velocity equals the velocity of the continuous motion. However, in the case of decelerated or accelerated motion, where the velocity changes, the calculated average velocity in the first and the last interval of the staircase motion is different from the starting and the final velocity of the continuously moving target. In accelerated motion, the calculated staircase-motion velocity in the first interval is higher than the average velocity of the continuous motion in the same time interval, and it is also higher than the starting velocity of the continuous motion. The calculated velocity in the last interval of accelerated staircase motion is lower than the final velocity of accelerated continuous motion. As a result of this, the overall difference between the calculated starting and final velocity of staircase motion is smaller than in continuous motion and acceleration is harder to detect.

If representational momentum indeed shows how the structure of events is perceived, a difference in acceleration perception should also be reflected in different displacements of continuous and discontinuous (staircase) motion. Previous studies on representational momentum used both perceptually discontinuous or implied motion (e.g. Finke & Freyd, 1985; Finke et al., 1986; Freyd & Finke, 1984; Freyd & Johnson, 1987; Hubbard, 1996) and perceptually continuous motion (e.g. Hubbard & Bharucha, 1988). Representational momentum occurred with both types of motion. Faust (1990) compared the magnitude of the representational momentum effect in the two types of motion. In his Experiment I, he used a plus sign that moved in a subjectively continuous or discrete manner from one side of the screen to the center at a constant velocity of 4.3ş/s. The discrete condition contained a sequence of three plus signs, which were presented for a short (200 ms) interval. After a short retention interval (which varied between 100 ms and 700 ms) the probe appeared at a certain position which was the same or different from the final position of a moving target. The results showed a larger forward displacement for continuous motion than for discrete motion, and this was found for all retention intervals. Faust argued that continuous motion provides more compelling depiction of motion than the subjectively discrete motion, which is reflected in different magnitudes of the representational momentum effect in the two types of motion.

If velocity of staircase motion is calculated as we have suggested above, constant velocity conditions should not indicate any differences in processing the two types of motion. However, the results of Faust (1990) imply that even with motion having constant velocity we might find differences in the perceived characteristics of continuous and discontinuous motion.

The present study was done to compare the representational momentum effect at differently accelerated continuous and discontinuous motions. Three variations of motion acceleration were used: the decelerated motion, the accelerated motion, and motion having constant velocity. If implied velocity and acceleration were similar in both kinds of motion, we would expect that displacement for both would be similar, too. If, on the other hand, less information about velocity and acceleration is available with staircase motion, then observers might be less willing to assign a more extreme acceleration or deceleration to the target, and so relative to continuous motion we would expect with staircase motion to see a smaller increase in displacement for accelerating targets and a smaller decrease for decelerating targets. In other words, the effect of motion acceleration on the displacement of staircase motion would be smaller than the effect on displacement of continuous motion.

Method

Participants

Fifty-one undergraduate psychology students (42 women and 9 men) participated in the experiment to fulfil the psychometrics course requirements. They were 20 to 42 years old ($M = 26$ years), reported of normal or corrected-to-normal vision, and were naive to the purpose of experiment. All of them completed the first part of the experiment, and 45 of them completed the second part[1].

Apparatus and stimuli

The stimuli were generated with Dell Optiplex GX100 computer and presented on 17'' CRT screen (with resolution 1024´768, 85 Hz refresh rate, non-interlaced, and a P22 phosphor). A black square was presented on a uniform grey surround (approx. 25.8°´19.5°; 83 cd/m^2). The target subtended 100 pixels (which was approx. 2.5° of visual angle). It appeared suddenly, vertically centered, at a random horizontal posi-

[1] *The first 6 observers did not go through the second part of the experiment. They participated in the first part only. During their participation the author has noted that displacement could be attributed both to the dynamic properties of motion representation and to the changes in the representation of static-target location. In order to examine how the latter contributes to the magnitude of displacement, the second part of the experiment was added later, and so only 45 observers completed both parts of the experiment.*

tion between 2.5° and 7.5° from the screen edge. It appeared either on the right side of the screen and then moved to the left, or on the left side of the screen and then moved to the right. It traversed 410 pixels (approx. 10.25° of visual angle) in 3 s. The travelling distance changed as a power function of time, with a power 0.5 (decelerated motion), 1.0 (motion with constant velocity) or 2.0 (accelerated motion). Such motion functions are usually categorized as decelerated, linear, and accelerated motion (Poljanšek, 2001). The average velocity of motion was the same for all motion functions (it was approx. 3.4°/s), but the final velocities differed. The final velocity was approx. 3.4°/s for motion with constant velocity, 1.7°/s for decelerated motion, and 6.8°/s for accelerated motion.

Two types of motion were used. With rapid change of position, motion appeared continuous enough. In staircase motion only seven points from power functions were presented: the first and the last point were always the same, and the five points in between were chosen according to the power function. In decelerated motion, the distances between the successive positions of the target were: 167, 70, 53, 45, 39, and 36 pixels. In accelerated motion, the distances between the successive positions were: 11, 34, 57, 80, 103, and 125 pixels. The target was presented for approx. 430 ms at each position. There was no interstimulus interval. The staircase motion was perceptually discrete and it was a clear version of the long-range motion (as defined in Braddick, 1980).

The end of motion period was signalled by a short computer beep and at the same time the target disappeared. After a retention interval of 500 ms the probe reappeared on the screen. It reappeared at a random horizontal position, not more than 20 pixels (0.5°) away from the vanishing point[2]. The vertical position of the probe was the same as that of the preceding target.

Distractor stimuli were presented to prevent potential learning of trajectory length. Distractor stimuli were black squares whose area increased as a power function of time (with powers 2, 4, or 8). The overall duration of each distractor stimulus was 4 s. In this time the stimulus area increased from 0° to either 3.8° or 5° of visual angle. Distractor stimuli were screen-centered. With symmetrical increase in area, motion in depth was simulated (as if the target directly approached observers).

Procedure

The experiment was performed individually in an illuminated room. Participants sat approx. 70 cm from the screen. Their head and body movements were not restrained, and they could adjust their position in order to achieve maximum comfort. Viewing was binocular. There was no fixation point. When ready, the participants started a

[2] The probe appeared close to the disappearing position. We have assumed that had it appeared further away, the time to adjust the target would be longer and there would be greater possibility for observers to look away from the place of target disappearance, and as a result memory trace could fade or distort.

new trial by pressing a spacebar.

The experiment had two parts. In the first part we measured the magnitude of displacement. After the target moving in the frontoparallel plane disappeared and the probe appeared on the screen, the observers adjusted the position of the probe to the point of target disappearance. They used four numerical keys for adjustments: *4* and *6* for gross position changes to the left or to the right, and *1* and *3* for detailed settings. With distractor stimuli, participants used the same numerical keys to adjust the size of the probe to the final size the target achieved before it disappeared. Before starting the experiment participants read the instructions on the screen and the experimenter showed them how adjustments could be done. During a short training they learned how to use the four keys. They were instructed to follow the target as a whole (not only its borders) and not to look away from the screen during responding.

Twelve experimental conditions were used in the first part of the experiment: type of motion (2) ´ acceleration (3) ´ direction of motion (2). The conditions were randomly mixed within a block. Eight blocks of trials were presented, and therefore each condition was repeated 8 times. Ninety-six distractor stimuli were intermixed randomly with stimuli moving in the frontoparallel plane. Observers were not told which stimulus will follow. Altogether 192 trials were presented. The first part of experimental session was usually completed in 30 min.

Only data for motion in the frontoparallel plane will be presented here. Average errors in adjustment of the position of target disappearance for each observer were entered into a 3-way repeated-measures ANOVA.

After observers completed the first part of the experiment, the second part followed. This part was added to determine the importance of displacements. A change in the representation of target location could also occur because of other factors (e.g., nystagmus), not only the representational momentum effect. In order to see what change in target position can be left unnoticed if the target disappears from the screen for 500 ms, the localization threshold (i.e., the measure of discrimination of target positions) was determined. If the magnitude of displacement was larger than the localization threshold, displacement would be important, and would lie outside the range of the usual distortions that occur in the representation of target location when the target is not visible for 500 ms.

To measure the localization threshold, the method of limits (Guilford, 1954) with 5 ascending and 5 descending series was used. Stimulus was similar as above. It was presented for 1 s at a horizontal position that randomly varied within the range of 20 pixels around the screen center in order to prevent the comparison with the position in the previous trial. The target then disappeared from the screen for 500 ms and reappeared at a certain position. The reappearance position varied from 12 pixels to the left of the previously presented position to 12 pixels to the right of the previously presented position. (The values were chosen according to preliminary measurements of the author’s threshold.) Twelve different reappearance positions could be presented in a single series (12, 10, 8, 6, 4, 2 pixels to the left or right of the previously presented position, and the accurate position). Observers had to assess whether the position of target reappearance was accurate, or left or right of the previously presented position. The "left" localization threshold was calculated as the limit between responses "left" and "accurate", and the "right" localization threshold was calculated as the limit between responses "accurate" and "right".

For each observer, the observer's average displacement in a certain condition in the first part of the experiment was then compared to the relevant localization threshold. Displacement of motion to the left was compared to the "left" localization threshold, and displacement of motion to the right was compared to the "right" localization threshold (the *t* test for correlated samples was used). Observers whose forward displacement was smaller than their localization threshold and observers with backward displacement were counted. This was done for all experimental conditions.

Results and discussion

In the second part of the experiment, the average "left" localization threshold was 1.7 pixels ($SD = 2.6$), and the average "right" localization threshold was 3.4 pixels ($SD = 2.2$). The point of subjective equality of target and probe location was therefore 0.9 pixels to the right of the accurate target position. A small shift in the representation of target location to the right was also found by Faust (1990, Exp. 6), but the explanation for such results is not yet known.

Displacements, obtained in the first part of the experiment, are shown in Table 1. Positive values denote representational momentum, or forward displacement of the remembered final position of the target. The column $N_{\text{small forward}}$ shows the number of observers whose displacements were forward, but smaller than their individual localization threshold, and the column N_{backward} shows the number of observers that had backward displacements. In all the conditions both numbers ($N_{\text{small forward}}$ and N_{backward}) were small, and for more than half of the observers displacement was bigger than the localization threshold. This means that the majority of observers would notice that they had made an error in adjustment if they were shown their adjustment and the accurate final position of the target. For those observers, displacement fell outside the range of the usual distortions that occur in the representation of target location when the target is not visible for 500 ms. Displacement was significantly different from the localization threshold in almost all experimental conditions (see the last two columns in Table 1), which again illustrates that the change in the representation of target position was an outcome of a dynamic event and not merely a distortion related to eye movements or to decay of memory for target position.

The average displacement of the remembered final position of the moving

Table 1: Mean and standard deviation of displacements, and the results of comparing displacements to localization thresholds

Motion function	*M*	*SD*	$N_{\text{small forward}}$	N_{backward}	*t*	*p*
Continuous						
Decelerated						
to the right	7.9	8.8	7	7	3.79	.000
to the left	3.1	5.1	8	12	1.52	.135
Linear						
to the right	11.0	10.9	2	3	4.93	.000
to the left	6.0	7.2	7	10	347	.001
Accelerated						
to the right	14.9	11.4	3	3	7.34	.000
to the left	9.0	10.5	4	7	4.58	.000
Staircase						
Decelerated						
to the right	8.9	9.2	5	5	3.92	.000
to the left	6.0	8.1	6	13	2.58	.013
Linear						
to the right	10.7	9.7	5	3	5.06	.000
to the left	6.7	8.7	8	10	3.23	.002
Accelerated						
to the right	12.0	12.4	6	5	4.42	.000
to the left	7.3	11.4	3	15	2.88	.006

Note. The first two columns (M and SD) show the results (in screen pixels) of 51 observers. The results shown in other columns were obtained with 45 observers. $N_{small\ forward}$ stands for the number of observers (out of 45) whose average displacement in a certain experimental condition did not exceed the localization threshold, but was still positive, i.e. indicating forward displacement. $N_{backward}$ stands for the number of observers (out of 45) whose average displacement was negative (the remembered final position of the target was displaced in the direction opposite to the direction of motion). The last two columns show the results of the *t* test for correlated samples (df was 44 in all conditions), which tested the difference between displacement and localization threshold.

target was in the direction of motion in all the experimental conditions. For example, when the target was moving from left to right, the remembered position of target disappearance was to the right of the accurate disappearance position, and the opposite, when the target was moving from right to left, its remembered final position was to the left of the real final position. The representational momentum effect was obtained even though we have used a slightly different method of data gathering, i.e. the method of adjustment, instead of the "same-different" method that is commonly used in studies on representational momentum.

The overall average magnitude of displacement was around 8.5 pixels, which was approximately 13' of visual angle. This value was smaller than in the experiment of Hubbard and Bharucha (1988), who found displacements as big as 2.5ş. We can attribute slightly smaller displacements in our experiment to the use of lower average velocity. Our results were close to the ones obtained by Hubbard (1996, Exp. 3) and by Hubbard and Motes (2002) in conditions where size and velocity of the target were similar to ours.

The analysis of variance showed that both the shape of motion function and the direction of movement affected the magnitude of displacement (see Table 2). Displacement of the final position of the target moving to the right (*M* = 10.9, *SD* = 10.6) was larger than displacement for the final position of the target moving to the left (*M* = 6.2, *SD* = 8.3). Some previous studies (Faust, 1990; Halpern & Kelly, 1993; Hubbard & Bharucha, 1988, Exp. I) also obtained a similar difference in displacements for motions in different directions. However, other studies (e.g., Hubbard, 1994, 1995a, 1996) did not find such a difference, or the difference found was even in reverse direction. Because the results of different studies are inconsistent, we cannot be certain that the difference we have found is reliable. Halpern and Kelly (1993), who found similar left-right effect, suggested that a slightly bigger displacement for motion to the right might be an intrinsic property of the visual system and a consequence of hemispheric specialization. Another possible explanation of the left-right effect is that, due to our everyday reading experience, we might be more used to extrapolating and predicting patterns and content in the right part of our visual field, and so displacement for motion to the right is bigger than displacement for motion to the left. It would be interesting to test this explanation in future. Displacement in observers coming from cultures where reading is from left to right could be compared to displacement in observers coming from cultures where reading is in the opposite direction, or even to displacement in pre-school children.

Displacement of accelerated motion (*M* = 10.8, *SD* = 11.7) was bigger than displacement of linear motion (*M* = 8.6, *SD* = 9.5), and this in turn was bigger than displacement of decelerated motion (*M* = 6.2, *SD* = 8.2). Thus, the results of Finke et al. (1986), who discovered that motion acceleration affects representational momentum, were replied. Our results conform both to the view that environmental invariants are internalized (Freyd, 1987; Shepard, 1984) and to the view that anticipation of future motion affects displacement. In accelerated motion, the kinetic force continually increases, whereas in decelerated motion, the kinetic force continually decreases. In reality, two targets with equal properties will not stop at the same time if different forces are exerted on them. The target with increasing velocity cannot stop as quickly as the target with decreasing velocity. Mental extrapolation shortly after stimulus offset follows the external physical principles, e.g. motion acceleration (Babler & Dannemiller, 1993). If the dynamic representation of motion persists for a while, or if the target future position is anticipated, the displacement will be larger in the case of accelerated motion where final target velocity is higher and it is assumed that the target would travel a larger distance in a certain time interval.

Displacement in continuous (*M* = 8.6, *SD* = 9.9) and staircase (*M* = 8.4, *SD* = 10.2) motion conditions did not differ significantly, but motion type did interact with motion function (see Table 2). As shown in Figure 1, motion acceleration had less effect on displacement of staircase motion than on displacement of continuous mo-

Table 2: Summary of analysis of variance for displacements

Source of variability	*SS*	*df*	*MS*	*F*	*p*
Between subjects	30385.94	50	607.72	73.28	.000
Within subjects					
Type	6.54	1	6.54	0.10	.750
Error (Type)	3172.33	50	63.45		
Function	2158.32	1.54[a]	1401.29	33.75	.000
Error (Function)	3197.13	77.01[a]	41.52		
Direction	3403.55	1	3403.55	16.79	.000
Error (Direction)	10133.47	50	202.67		
Type × Function	382.32	2	191.16	7.23	.001
Error (Type × Function)	2644.07	100	26.44		
Type × Direction	37.38	1	37.38	1.23	.273
Error (Type × Direction)	1523.86	50	30.48		
Function × Direction	27.22	2	13.61	0.57	.570
Error (Function × Direction)	2404.49	100	24.05		
Type × Function × Direction	0.29	1.68[a]	0.17	0.06	.987
Error (Type × Function × Direction)	2387.24	83.93[a]	28.44		

Note. *Type* stands for motion type, the factor with two variations: continuous motion and staircase motion. *Function* stands for the shape of motion function, with three variations: decelerated (target position changed as a power function of time, with power 0.5), linear (function with power 1.0), and accelerated motion (function with power 2.0). *Direction* stands for the direction of motion: the target could either move from left to right or from right to left.
[a] Because the sphericity assumption was not met, the value of *df* was set according to the Greenhouse-Geisser correction.

tion. One possible explanation is that in continuous motion the target had a higher velocity at the very end of the trial than in staircase motion in which a static target was presented for the last 430 ms, which could signal the termination of motion. However, if this were the case, then displacement should have been smaller in staircase motion than in continuous motion in all conditions, but inspection of Figure 1 shows that displacements for continuous motion and staircase motion were nearly equal when the target travelled at constant velocity. It appears that constant velocity results in similar motion representations for both continuous and staircase motion (for a related finding, cf. Giaschi & Anstis, 1989). It should also be mentioned here that the results of Faust (1990) were not replicated. According to Faust's results, with the retention interval and the time of target presentation at a single position we have used, we should have found no displacement of staircase motion. This was not the case. The larger displacement of discrete motion in our study could be related to integration of information about motion. In our study more information was present, because in the discrete condition the target was displayed seven times instead of three times only.

A second possible explanation of the Motion type ′ Motion function interaction shown in Figure 1 is that detection of changes in velocity is poorer with staircase motion than with continuous motion. Acceleration had greater impact on displace-

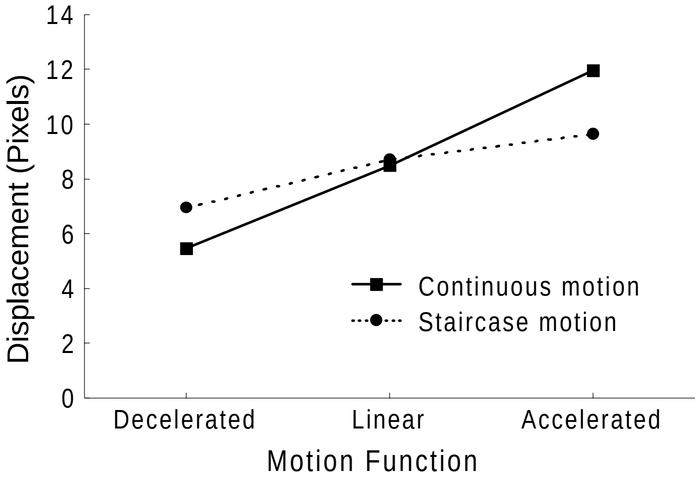

Figure 1: The interaction between Motion type (continuous vs. staircase) and Motion function. The figure shows the average magnitude of displacement in pixels on the computer screen (1 pixel corresponds to approx. 1.5' of visual angle). The average displacement was always in the direction of motion.

ment of continuous motion, and this suggests that it is more difficult to derive information regarding a change in velocity from staircase motion than from continuous motion. When velocity changed with time, estimated velocities at the beginning and the end of motion were presumably different in both cases. As we suggested in the Introduction section, perceived velocity of discontinuous motion changed less from the beginning to the end of movement than did velocity of continuous motion.

The latter explanation would also predict that the final velocity of staircase motion is overestimated in decelerated motions and underestimated in accelerated motions. If the final velocity is indeed crucial for the magnitude of representational momentum, as Finke et al. (1986) claimed, this could explain why in decelerated motions the displacement of staircase motion was larger than the displacement of continuous motion, and why in the accelerated motions the displacement of staircase motion was smaller than the displacement of continuous motion. The explanation, however, assumes that velocity discrimination was quite accurate in the case of the continuous motion. This assumption is often not true (Werkhoven et al., 1992).

Conclusion

Our results support the notion that representational momentum reflects the precision of detecting higher-order regularities in motion, just as Verfaillie and d'Ydewalle (1991) suggested. The process of calculating the velocity in staircase (i.e., a typical long-range) motion gives an output that is similar to the output of a low-level processing of velocity of linear continuous motion (Giaschi & Anstis, 1989), and the displacements are similar in both cases. The threshold for detecting velocity change is higher for staircase motion than for continuous motion (Poljanšek, 2001), and as a result, motion acceleration affects displacement of staircase motion less than it affects displacement of continuous motion.

Future studies that will use representational momentum to determine how discontinuous motion is perceived relative to continuous motion should not use constant-velocity motion exclusively. Our results imply that, for representational momentum to indicate differences in the processing of continuous and discontinuous motion, motions having non-constant velocity should also be used.

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