Incidental and Non-Incidental Processing of Biological Motion: Orientation, Attention and Life Detection

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Abstract

Based on the unique traits of biological motion perception, the existence of a "life detector", a special sensitivity to perceiving motion patterns typical for animals, seems to be plausible (Johnson, 2006). Showing motion displays upside-down or with changes in global structure is known to disturb processing in different ways, but not much is known yet about how inversion affects attention and incidental processing. To examine the perception of upright and inverted point-light walkers regarding incidental processing, we used a flanker paradigm (Eriksen & Eriksen, 1974) adapted for biological motion (Thornton & Vuong, 2004), and extended it to include inverted and scrambled figures. Results show that inverted walkers do not evoke incidental processing and they allow high accuracy in performance only when attentional capacities are not diminished. An asymmetrical interaction between upright and inverted figures is found which alludes to qualitatively different pathways of processing.

Keywords: biological motion perception; point-light walker; incidental processing; inversion effect; life detector

Introduction

An important feature of the visual processing of the dynamic human gestalt in point-light displays is the "automatic" nature of the perceptions. As Johansson (1973) points out, "… we have found that it seems to be a highly mechanical, automatic type of visual data treatment that is most important." While Johansson's use of the term "automatic" points more to the early processes involved in establishing hierarchies of locally rigid perceptual units, there is a case to be made for the automatic processing of biological motion at a higher cognitive level under favorable circumstances, i.e., given an appropriate task. Phenomenally, Johansson's own demonstrations point to the immediateness and vividness of viewing point-light displays of biological motion. Observers are fast and accurate in their identifications when not disrupted by dynamic masking. They appear to have direct access to a level of meaning that facilitates the identification and recognition of actions depicted in the point-light displays. In contrast to upright displays, inverted point-light displays lead to impaired recognition, identification, detection and priming (e.g., Bertenthal & Pinto, 1994; Daems & Verfaillie, 1999; Hemeren, 2008; Shiffrar & Pinto, 2002; Troje, 2003).

Previous results have also shown that point-light walkers (PLWs) trigger attention mechanisms (Thornton & Vuong, 2004). Using a flanker paradigm, Thornton and Vuong (2004) demonstrated incidental processing of upright oriented PLW flankers during judgments of the walking direction of the displays. Upright point-light walkers can elicit incidental processing while static, scrambled or chimeric ones cannot, but in these studies they did not address the question of inversion. Incidental processing was indicated by an increase in the time it took to make direction judgments when the direction of the flankers was incongruent with the direction of the target. The task irrelevant flankers interfered with the visual processing of the target.

Recently, Shi et al. (2010) reported effects of upright PLWs on the accuracy of reporting the perceived direction of a Gabor patch. Accuracy was significantly lower when the walking direction of an upright PLW was incongruent with the orientation of the Gabor patch. Importantly, no such effect was found for inverted PLWs. This suggests the existence of a perceptual cue that triggers reflexive attentional orienting for upright, but not for inverted, PLWs. This is consistent with previous results regarding a general inversion effect and evidence for a "life detector" (see e.g., Johnson, 2006; Troje & Westhoff, 2006).

In our study, we investigate the differential effects of the orientation of PLWs within the framework of Hochstein and Ahissar's Reverse Hierarchy Theory (2002). The idea here is that the visual quality of biological motion perception for upright displays is indicative of global processing as well as quick access to semantic level representations. Consistent with Hochstein and Ahissar (2002), the perception of inverted displays could be characterized as an example of illusory conjunctions. The perception of inverted displays could be said to demonstrate the effects of top-down processing in the sense that the default value is an upright orientation and this creates false conjunctions in the perception of inverted displays.

This line of reasoning is consistent with the reasoning in Shiffrar, Lichtey & Heptulla Chatterjee (1997) where they show that global processes are involved in the perception of upright biological motion displays across apertures but that this global processing is impaired when inverted biological motion displays are viewed across apertures. Their findings show that global processing is associated with viewing upright displays and that local processing is associated with viewing inverted displays.

Given this, we suggest that upright PLWs are incidentally processed on the basis of initial explicit perception as 'vision at a glance,' and it also reflects the activity of large receptive fields of high cortical areas and spread attention of initial perception (Hochstein & Ahissar, 2002). At the other (low-level) end of the processing continuum, inverted PLWs constitute 'vision with scrutiny' which involves focused attention and the activation of small receptive fields in lower cortical areas.

By extending the flanker paradigm in Thornton and Vuong (2004) to include inverted walkers, we can further address the issue of incidental processing of flankers while performing a direct visual task on a central target. It may be the case that inverted walkers can be incidentally processed when the target is also an inverted walker. This condition can be directly contrasted with upright flankers and an upright target, for which there is already evidence of incidental processing (Thornton & Vuong, 2004). This study will therefore include a replication of those results. Directional congruence will also be included in this study in order to assess the potential interference or facilitation effects of similar or different walking directions of the targets and flankers.

Here we can investigate the orthogonal pattern of interaction between upright and inverted displays under conditions of orientation congruence and direction congruence. This allows us to potentially see asymmetrical interactions in the way upright and inverted flankers modulate the visual processing of upright and inverted targets.

One obvious prediction from previous findings of the inversion effect is that inverted flankers will have no effect on reaction time or accuracy in detecting the walking direction of an upright target. This is due to the relatively fast and automatic processing of an upright and biologically relevant moving human. The structure of the information in the inverted flankers is not sufficient to modulate the processing of an upright target.

The potential effect of inverted flankers on inverted targets is less obvious to predict. Previous evidence (Hemeren, 2008) shows that inverted PLWs can prime (repetition priming) themselves as well as other inverted point-light actions. Given this evidence, inverted flankers may be incidentally processed because the visual system is active in scanning the available information for clues to resolve the conflicts (false conjunctions) in the inverted targets. This, however, entails that the information in the inverted flankers is relevant. If there is no relevant information, then there will be no incidental processing of inverted displays.

Since upright flankers convey biologically relevant information and are visually processed relatively automatically, we expect them to be incidentally processed when presented with an inverted target. This incidental processing will likely lead to significant interference when judging the walking direction of an inverted target.

The effect of upright flankers on upright targets will likely depend on the congruence of walking direction for the target. Based on results from Thornton and Vuong (2004) we expect the incidental processing of upright flankers to interfere with upright targets when they are walking in different directions (directional incongruence). When they are walking in the same direction (directional congruence), the question is whether the incidental processing of upright flankers will speed up (facilitate) the ability to correctly detect the walking direction of the target in relation to inverted flankers or whether there will be no difference between the effects of upright and inverted flanker on detection time for upright targets.

Methods

Participants

Ten right-handed subjects (5 male and 5 female, aged 20 to 49 years, M = 28.9, with normal or corrected-to-normal vision) participated in the experiment. Participants were selected from colleagues and the student population of the University of Skövde. All participants were naive to the purpose of the experiment and only the students received monetary compensation (approximately $15). Participants provided written informed consent. Experiment protocol conformed to Swedish law and the World Medical Association Declaration of Helsinki.

Stimuli

The stimuli consisted of the target walker (1.26° x 0.74°) displayed in the center surrounded by five distractors evenly placed at a fixed distance from the target (1.89°) with a randomly defined angular offset for the five flankers together. To compensate for the smaller cortical representation of peripheral stimuli, flankers were scaled by a cortical magnification factor (Goolkasian, 1997), thus having the size of 2° x 1.17°. The total size for the whole display was 5.78°. Figures were depicted in profile by 13 dots based on the 3-dimensional coordinates of the action ”Walk” from a stimulus set of human point-light actions created by Vanrie & Verfaillie (2004). For presentation of the stimuli and recording of the answers MatLab R2010a was used on an HP EliteBook 8440p laptop computer. An HP L2245wg monitor (1440 x 900 pixels, 60 Hz) displayed the stimuli at 100 cm viewing distance.

In every condition the same figure was mirrored so that there were two possible directions of translation (left and right) and two possible orientations (right-side-up and upside-down). In addition to these four variations, scrambled flankers were created for control by mixing dots randomly chosen from the four conditions and displaying them with random starting positions, while the total size of the figure was kept equal to the regular flankers. This way, scrambled flankers as a whole did not contain directional or orientation information, while the local motion patterns of the dots remained the same as in the globally intact figures. The four variations of the target and five variations of the flankers resulted in twenty conditions in total (see examples in Figure 1).

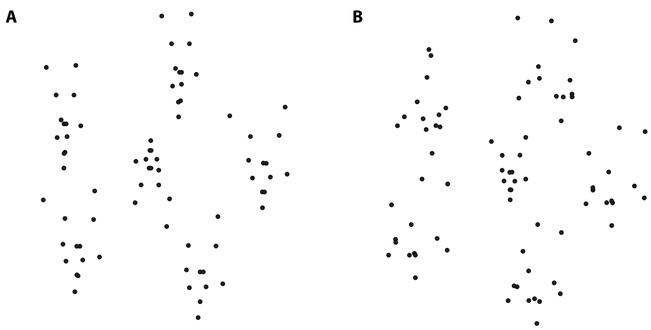

Figure 1: Upright target with translation to left and inverted flankers with translation to right (panel A); Inverted target with translation to right and scrambled flankers (panel B).

Procedure

Participants were informed about that they would see a centrally located PLW (target) either upright or inverted and that flankers would surround the target. They were instructed to just focus on the target and to indicate the walking direction of the target by pressing one of two keys.

Left or right responses were given by key presses with the corresponding index fingers, indicating the direction of translation of the target regardless of its orientation. Participants were instructed as to the importance of the speed and accuracy of their responses. Stimuli were played from a randomly chosen starting frame (randomized between figures as well) in a continuous loop at 30 FPS (stride frequency: 2/s) until the participant responded. Every trial was preceded by an ISI of 500-800 ms, during which a fixation cross (0.23°) marked the center of the display.

Each participant started with a training session of 32 trials. After that, 1440 trials were recorded, divided by arbitrary breaks into three sessions of 480 trials. In one session out of the three, 50 % of the trials contained the scrambled conditions, while the other two sessions were made up of only non-scrambled trials. The order of the sessions varied between participants. This design was necessary to avoid a possible novelty effect of scrambled trials, since their total number was less than the total number of non-scrambled trials. Altogether, 1200 non-scrambled and 240 scrambled trials were completed by each subject, which means 75 trials per each non-scrambled condition and 60 trials per each scrambled condition.

The design of this experiment consisted of four independent variables; Target orientation (upright vs. inverted), Flanker orientation (upright vs. inverted), Target direction (left vs. right) and Flanker direction (left vs. right). In addition, four conditions of scrambled flankers were created by pairing scrambled flankers with levels of target orientation and direction. Dependent variables are reaction time and accuracy.

Results

Reaction Times

Reaction time (RT) data were analyzed only for correct responses, with all outliers exceeding 2 SDs above and below the mean eliminated. Errors (accounting for 2.42 % of all answers) were analyzed separately. Means generated for each condition and subject were used in a repeated-measures ANOVA analysis. Individual conditions in relevant cases were compared with t-tests.

Since the task of the participants was to respond to targets and to ignore the flankers, the amount of influence of the flankers on RTs and accuracy can be accounted for incidental processing of these figures. This is expressed in the walker congruency effect (WCE, Thornton & Vuong, 2004) which in our case is positive for upright flankers but missing when flankers are inverted, i.e., responses to all targets are faster ($t(9)$ = 5.46, p = 0.000) when upright flankers have congruent direction of translation (M = 644.2 ms, SD = 79.10) compared to responses on incongruent trials with upright flankers (M = 683.75 ms, SD = 76.61), while this difference cannot be found ($M_{Congruent}$= 650.05, SD = 78.98; $M_{Incongruent}$= 650.55, SD = 78.38; $t(9)$ = 0.15, p = 0.886) when flankers are inverted (Figure 2).

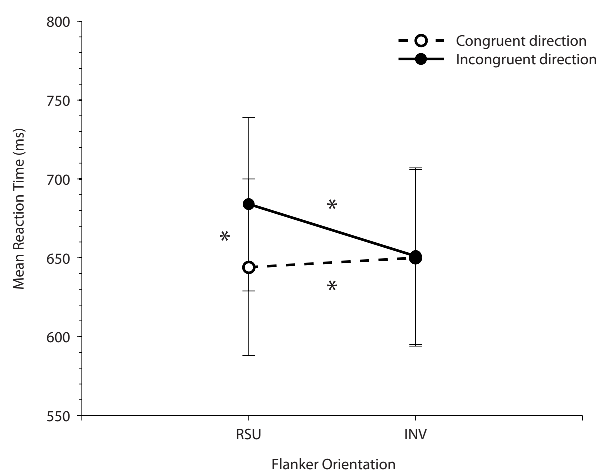

Figure 2: Walker congruency effect. (RSU = right-side-up, INV = inverted. Asterisks indicate significant differences at p<0.05, error bars show 95% confidence intervals.)

Regarding the interaction between the processing of upright and inverted biological motion, the RT means for direction judgments as a function of direction congruence and orientation congruence between flankers and targets are presented in Figure 3.

The pattern of results shows that inverted flankers have no effect on reaction times to the target and that these responses are also similar to conditions where the target was surrounded by scrambled flankers (Figure 3).

A 2x2x2x2 repeated measures ANOVA was carried out on the means. The relevant differences here are between right-side-up and inverted targets, where the inversion effect leads to a significant increase in RTs. The main effect for target inversion was significant, $F(1,9) = 40.90$, *partial* $\eta 2 = 0.82$, $p < 0.001$. In relation to the error rates displayed in Figure 4, this main effect was not accompanied by a difference in accuracy. Upright flankers had no effect on the accuracy of judging the direction of upright or inverted targets. The difference of flanker influence in this case is restricted to reaction time, not accuracy.

The effect of flanker orientation on reaction time is limited to upright flankers. These distractors show a highly significant interference on inverted targets when their directions are incongruent ($M = 728.30$, $SD = 86.82$; $t(9) = 6.51$, $p < 0.001$) compared to the effect of inverted flankers in the respective condition ($M = 669.45$, $SD = 81.10$). This effect is smaller but still significant when comparing the same conditions ($M_{RSU\ flankers} = 682.90$, $SD = 88.41$; $M_{INV\ flankers} = 670.25$, $SD = 82.10$) with congruent direction ($t(9) = 2.42$, $p = 0.039$).

The effect of upright flankers is different when targets are also upright. In this case we do not see any increase in reaction times even with incongruent directions ($M_{RSU\ flankers} = 639.20$, $SD = 69.60$; $M_{INV\ flankers} = 631.65$, $SD = 78.00$; $t(9) = 1.55$, $p = 0.156$), although the higher error rates show that flankers are processed and they affect the accuracy of responses ($M_{RSU\ flankers} = 3.71$, $SD = 3.49$; $M_{INV\ flankers} = 1.89$, $SD = 2.87$; $t(9) = 2.29$, $p = 0.047$). When directions are congruent however, the effect of upright flankers on upright targets becomes facilitative: RTs are significantly lowered compared to the corresponding condition with inverted flankers ($M_{RSU\ flankers} = 605.50$, $SD = 72.92$; $M_{INV\ flankers} = 629.85$, $SD = 79.21$; $t(9) = 7.90$, $p = 0.000$). This relative facilitation however does not appear when compared to the effect of scrambled flankers ($M_{Scrambled\ flankers} = 624.45$, $SD = 76.14$; $t(9) = 1.45$, $p = 0.182$). This shows that upright flankers are processed to an extent that seems to occur in parallel to the upright targets. This is only the case when the direction of upright flankers and targets is congruent.

In contrast to the reaction times, the error rates in the case of relative facilitation stayed unchanged ($M_{RSU\ flankers} = 1.24$, $SD = 1.79$), compared to conditions either with inverted ($M = 1.29$, $SD = 2.52$; $t(9) = 0.14$, $p = 0.89$) or scrambled flankers ($M = 1.58$, $SD = 2.31$; $t(9) = 0.65$, $p = 0.533$). Accuracy is therefore not affected by flankers when directions are congruent, only in incongruent conditions and with upright flankers.

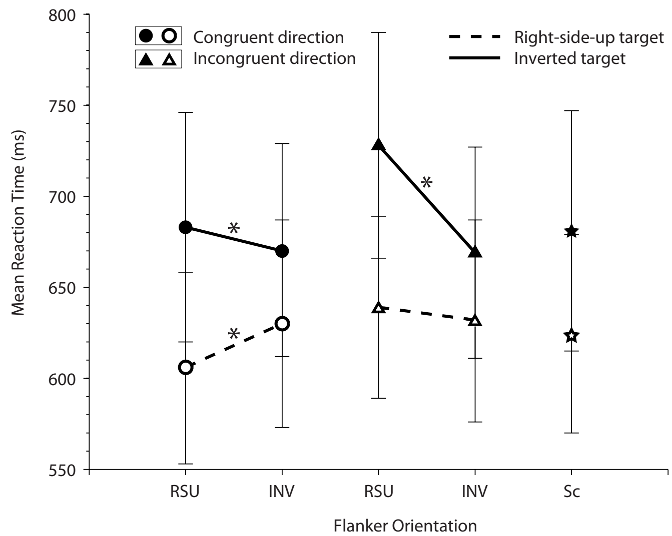

Figure 3: Conditions across orientation and direction of translation. (RSU = right-side-up, INV = inverted, Sc = scrambled. Asterisks indicate significant differences at p<0.05, error bars show 95% confidence intervals.)

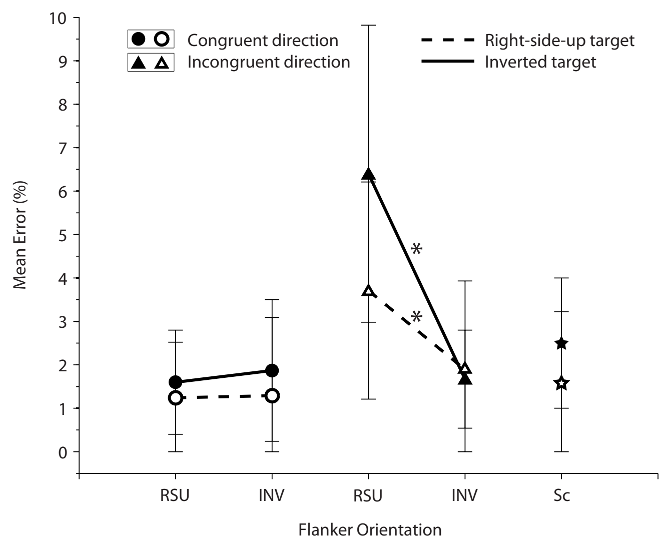

Figure 4: Errors. (RSU = right-side-up, INV = inverted, Sc = scrambled. Asterisks indicate significant differences at p<0.05, error bars show 95% confidence intervals.)

Discussion

Our results show that inverted biological motion does not elicit incidental processing and even more importantly, upright and inverted point-light walkers have substantially different attention demands. Subjects are only required to respond to targets, and thus the processing of flankers happens without active top-down control. Nevertheless, upright flankers have significant effects on the responses to targets, the effect of which is different depending on the orientation of the target. When both the target and the flankers are upright, reflexive attention seems to be drawn to both, thus resulting in either a relative facilitation in RTs (seen in the case of congruent directions) or in interference leading to higher error rates (incongruent directions). This interference shows the processing of both the target and flankers reach the level of subtracting directional information by the starting of the response. However, this does not lead to higher RTs – which may be due to the reflexive manner of the response to the target as well, allowing the two processes to run in a parallel manner.

When targets are inverted, they require more top-down control, and there is no incidental processing which indicates that attention is directed to them in a reflexive manner. The amount of attention incidentally drawn by the upright flankers leads to faster processing of the distractors, thus always interfering with the processing of inverted targets and leading to higher RTs. Furthermore when the two processes involve handling incongruent direction between flankers and targets, error rates become higher as well.

In terms of Hochstein and Ahissar's RHT (2002), these results suggest that the visual processing of upright human point-light walkers is consistent with *vision at a glance* since upright flankers not only interfere with the visual processing of inverted displays but that they can also modulate the visual processing of upright centrally displayed targets. In addition to the results for the speed of visual processing (RT-results), this interpretation is strengthened by the increase in the error rate for upright targets when the direction of upright flankers is in conflict with the target.

It is important to emphasize that RHT is not restricted to perceptual learning as such but applies to perception in general (Ahissar & Hochstein, 2004). PLWs are salient examples of dynamic gestalt figures, which also include other action categories (e.g., Hemeren, 2008). The original findings from Johansson (1973) demonstrate that when presented with a static form, people have difficulty in identifying the figure and action. However, once the figure starts to move, people see the action that the person is performing. Much previous research (see e.g., Shiffrar & Pinto, 2002) demonstrates the holistic/global processing involved in the visual perception of point-light displays of biological motion. From a perceptual learning perspective, biological motion perception is an example of the Eureka effect (Ahissar & Hochstein, 2004), in which learning is governed by top-down control and single exposures and has long-lasting effects.

In contrast to upright targets and flankers, the results for inverted flankers in relation to inverted and upright targets indicate visual processing consistent with *vision with scrutiny*. There appears to be no access to high-level perceptual meaning that would trigger reflexive attention and lead to incidental processing. Although there is evidence of perceptual learning for inverted displays of biological motion (Grossman, Blake & Kim, 2004), learning is relatively difficult in terms of time taken and the ability to discriminate between different action categories depicted in the point-light displays (Hemeren, 2008). Inverted displays are perceptually difficult to resolve, i.e., they have no perceptually obvious ecological relevance. When confronted with this situation, visual processing is guided down the processing hierarchy where more local processing of the stimulus is carried out in order to find a solution to the perceptual problem. This requires the activation of small receptive fields in lower cortical areas. This takes additional time and is also prone to an increase in perceptual errors. If incidental processing of upright PLWs is evidence of a life detector (Johnson, 2006; Troje & Westhoff, 2006), then it also shows that it also occurs at a high cortical level.

Recently, Ikeda, Watanabe and Cavanagh (2013) used a horizontal flanking paradigm to investigate the effect of the distance of upright PLWs and scrambled PLWs to upright PLW targets. Consistent with our results, they found that direction discrimination became more difficult with smaller distances between the flankers and the target. It is important to note that the conditions in their experiment were all directionally incongruent between flankers and targets. Ikeda et al. (2013) assert that their results show that the "crowding" effect occurs at a high-level of motion perception since the effect was absent when scrambled flankers were used.

An additional perspective on our results can be seen in the work of Vicario and Kiritani (1999) where the issue can be described as a matter of a vertical organization of visual events, i.e., determining what rules apply if simultaneous stimuli are perceived as one object (integration) or as different objects (segregation). In our case the relevant traits of the point-lights influencing this judgment seem to be: the amount and direction of displacement, speed and acceleration patterns and the variability in distance from neighboring dots. These traits are comparable with the Gestalt principles; however, it is not clear how they can unequivocally explain the inversion effect. One possibility is through the congruency or incongruency between acceleration patterns of the dots presented and acceleration patterns normally determined by gravity (this approach is discussed in detail by Chang and Troje, 2009). Another possibility is that an additional Gestalt principle is playing a role here, which leads to an effortless and fast form-from-motion perception of human figures, when the emerging form matches the usual human body configuration (i.e. it is walking with the right side up). Presumably both mechanisms are important in the inversion effect with point-light walkers (Hirai, Chang, Saunders & Troje, 2011).

Our results suggest that people have implicit access to initial high-level meaning for upright PLWs and that this access can be reflexively triggered when a visual target is difficult to perceptually resolve or when simultaneously presented PLWs are incongruent with regard to a relevant visual task.

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