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Impairments in the Visual Processing of Global Biological Motion Cues in Down Syndrome

Hugh Riddell, J. Walter Tolentino-Castro, Heiko Wagner and Markus Lappe
University of Münster, Germany

Abstract
Down syndrome (DS) is one of the most common chromosomal disorders and is often associated with a number of motor and cognitive impairments. Little research has been dedicated to investigating the perceptual abilities of individuals with DS. The visual processing of biological motion has been shown to be impaired in DS. It has been proposed that these impairments may stem from an inability to process the global patterns of full-body motion produced by a moving actor; however, this has not been explicitly investigated. We tested groups of participants with and without DS on a task requiring the visual discrimination of point-light walkers from spatially scrambled versions of point-light walkers. Participants with DS demonstrated poorer performance and slower reaction times on the task than healthy controls. From these results, we conclude that biological motion processing is impaired in DS and that this deficit is related to an inability to integrate global configural cues. In a second experiment, individuals with DS were able to discriminate the direction in which laterally translating walkers moved, suggesting that the global motion processing deficit observed in Experiment 1 is specific to biological motion recognition and does not generalise to other types of global motion.

Keywords
biological motion, disorders, Down syndrome, global motion, motion

Introduction

Down Syndrome (DS) is one the most common chromosomal disorders, with 1 in 691 children in the USA born with the condition (Parker et al., 2010). In approximately 90% of cases, DS develops due to an extra chromosome 21 (Lauteslager, 2004). DS is characterised by a number of corporeal and cognitive deficits. Common physical traits seen in DS include craniofacial abnormalities, short stature, musculoskeletal abnormalities and hypermobility of the joints (Hickey, Hickey, & Summar, 2012). Cognitive impairments

Corresponding author:
Hugh Riddell, Westfalische Wilhelms-Universitat Munster Fliednerstr, 21 Muenster, NRW 48149, Germany.
Email: h_ridd02@uni-muenster.de

are also observed in the majority of individuals with DS (Frith & Frith, 1974; Rowe, Lavender, & Turk, 2006; Shumway-Cook & Woollacott, 1985). Due to both physical and cognitive impairments, the acquisition of basic motor skills such as walking, reaching and grasping are commonly delayed (Block, 1991; Palisano et al., 2001).

While an extensive body of literature has focused on the individual cognitive and motor impairments in DS, less research has been dedicated to studying how neuronal and motor systems interact. Delays in the development of the motor system in DS are often attributed to physical factors, such as low muscle tone (hypotonia; Lauteslager, Vermeer, & Helders, 1998) or hypermobility of the joints (Galli, Rigoldi, Brunner, Virji-Babul, & Giorgio, 2008). Such explanations, however, tend to de-emphasise the importance of cognitive factors in motor competence.

During action execution, movements must be planned, initiated and controlled, necessitating input from multiple higher level cognitive and perceptual systems. Conversely, during the observation of other's actions, neurons are activated in the cerebellum, premotor and motor cortices, leading to the argument that mirrors neurons in these motor areas are, in part, responsible of the recognition and interpretation of perceived actions (Prinz, 1997; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). How people with DS adapt their motor output to account for their sensory input, and whether their perception of actions is affected by their physical abnormalities remains a relatively overlooked area.

Despite the fact that people with DS rely heavily on visual input for motor control (Hodges, Cunningham, Lyons, Kerr, & Elliott, 1995; Webber, Virji-Babul, Edwards, & Lesperance, 2004), some perceptual deficits have been reported in domains such as face recognition (Annaz, Karmiloff-Smith, Johnson, & Thomas, 2009) and local feature processing (Bellugi, Lichtenberger, Mills, Galaburda, & Korenberg, 1999; Wang, Doherty, Rourke, & Bellugi, 1995). Virji-Babul and Brown (2004) investigated the process of visual-motor integration in children with DS by measuring how typically developing children and children with DS approached and stepped over obstacles. They found that although children with DS could extract information about the size of the object, they tended to stop in front of the obstacles before stepping over them. It was suggested that unlike typically developing children, children with DS are unable to use visual information about obstacles to modulate their movements and consequently cannot make effective anticipatory adjustments. Other studies have shown similar deficits in hand-eye coordination tasks (Henderson, Morris, & Frith, 1981; Spanò et al., 1999). Such research demonstrates clear evidence for disordered perceptual-motor integration in DS.

Point-light walkers (PLWs) are a class of biological motion stimuli that have previously been used to study the relationship between perception and action in DS (Virji-Babul, Kerns, Zhou, Kapur, & Shiffrar, 2006). Originally developed by Johansson (1973), PLWs are depictions of animate humans produced by attaching points of light to the major joints of an actor while they perform an action such as walking. Despite the highly degraded nature of PLWs, humans can readily detect actions (Dittrich, 1993), emotions (Atkinson, Dittrich, Gemmell, & Young, 2004), gender (Kozlowski & Cutting, 1977) and identity (Cutting & Kozlowski, 1977; Loula, Prasad, Harber, & Shiffrar, 2005) from the pattern of biological motion produced by these displays. Furthermore, observers can actively anticipate actions and infer intentions from PLW movements (Blakemore & Decety, 2001; Diaz, Fajen, & Phillips, 2012).

Although biological motion tasks are predominantly visually driven, part of the neural network enabling the perception of biological motion recruits the premotor cortex (Saygin, Wilson, Hagler, Bates, & Sereno, 2004) and the cerebellum (Grossman et al., 2000), areas known to be involved when making judgements about motor activity (Fiez, 1996). Premotor cortex in humans and primates is active during both action recognition and action

production, suggesting that premotor neurons may play a role in mirroring actions in order to understand motor events (Rizzolatti et al., 1996; Rizzolatti, Fogassi, & Gallese, 2001). Thus, biological motion perception represents a powerful tool for studying how motor and perceptual systems interact.

Several studies have shown that the motor system informs biological motion perception in the healthy population. For example, Casile and Giese (2006) found that nonvisual motor training improved performance on a PLW discrimination task. Additionally, it was found that subjects who were able to execute motor patterns with higher accuracy were more sensitive to biological motion. Similarly, Aglioti, Cesari, Romani, and Urgesi (2008) showed that professional basketball players were able to predict the fate of a basketball free throw based on body kinematics alone. Athletes performed with a higher degree of accuracy than other individuals who had a similar amount of visual-only experience, such as coaches or sports journalists. Based on such evidence it can be concluded that motor production, practice and experience all play an important role in the perception of biological motion. It follows that populations exhibiting motor deficits and delays in the acquisition of motor milestones, such as DS, may also exhibit deficits in biological motion perception.

While individuals with DS are able to perceive biological motion from PLW displays, they appear to have some difficulties in processing the patterns of full-body motion required to discriminate between walkers with different kinematic profiles. Virji-Babul et al. (2006) found that though children with DS could identify PLWs, they were unable to discriminate between PLWs with typical and atypical gait patterns. In addition, subjects with DS performed worse than healthy controls in tasks requiring subjects to discriminate between PLWs and rotating points, and between PLWs portraying different emotions. It was concluded that impaired biological motion processing in DS must stem from an inability to identify the complex, dynamic cues required to discriminate between PLWs with different gaits, specifically those associated with the global, whole-body patterns of motion. This conclusion is, however, somewhat limited due to the fact that in all tasks used by Virji-Babul et al. (2006), the reference stimuli differed from target PLWs both in terms of the global motion of the entire stimulus, as well as the local motion of the individual points that made up the reference stimuli. Given that aspects of biological motion can be perceived using either local or global motion cues, it is unclear whether the observed impairments are related to an inability to process the complex full-body patterns of biological motion, or an inability to differentiate the local dot trajectories of individual points.

Biological motion perception is supported by different sources of information in the PLW stimulus (Chang & Troje, 2008, 2009; Giese & Poggio, 2003; Hirai, Chang, Saunders, & Troje, 2011; Lange & Lappe, 2006; Thirkettle, Benton, & Scott-Samuel, 2009; Thompson & Baccus, 2012; Troje & Westhoff, 2006). One source of information is the local trajectories, velocities and accelerations of the individual points that constitute the walker. The motion of the foot points in particular play an important role in conveying this local information (Troje & Westhoff, 2006). The second source of information is the changes in the overall configuration of the walker over time, which produces a pattern of global, full-body motion (Lange & Lappe, 2006). The visual system uses the invariants inherent to the structure of the human body, such as the constant distances between points on the same limb, the relationship of the limbs to one another and the typical form of a human body, to construct templates of static body postures. Patterns of full-body motion are obtained by combining these body posture templates over time, allowing observers to perceive complex movements and actions (Lange, Georg, & Lappe, 2006).

It has been proposed that these two systems provide different information about PLWs and may be acquired at different stages over the lifetime. The local point motion conveys

information about the facing direction of the PLW and also provides an important cue about the animacy of the stimulus (Chang & Troje, 2009; Hirai et al., 2011; Thurman & Lu, 2013). Human infants are sensitive to local biological motion cues (Bardi, Regolin, & Simion, 2011; Fox & McDaniel, 1982; Simion, Regolin, & Bulf, 2008), as are pigeons (Troje & Aust, 2013), suggesting that local biological motion processing is an evolutionary old, innate ability that is present from birth. Global processing, on the other hand, accounts for abilities such as the discrimination between actions and individuals, the identification of walkers in noise and the discrimination of walking direction (Beintema & Lappe, 2002; Lange et al., 2006; Lange & Lappe, 2006). Biological motion tasks requiring global processing are susceptible to learning (Casile & Giese, 2006; Chang & Troje, 2009; Grossman, Blake, & Kim, 2004), suggesting that global cue sensitivity is developed over the lifetime and is experience dependent.

Individuals with DS experience both motor development delays (Meegan, Maraj, Weeks, & Chua, 2006; Pereira, Basso, Lindquist, da Silva, & Tudella, 2013), as well as significant motor impairments in day-to-day life. In addition, populations with DS are generally less physically active than healthy populations (González-Agüero et al., 2010; Shields, Dodd, & Abblitt, 2009; Whitt-Glover, O'Neill, & Stettler, 2006). Considering that the acquisition of global biological motion processing mechanisms is dependent on experience, we might expect that, due to these impairments and delays in DS, tasks requiring the discrimination of biological motion based on global cues alone should be affected.

Experiment 1

The aim of our first experiment was to test how individuals with DS perform in comparison to healthy controls on a visual perceptual task requiring the discrimination of point-light biological motion based on global cues alone. In the current task, DS and healthy control participants were required to indicate whether they thought a visually presented target was a PLW or a spatially scrambled PLW (SPLW). SPLWs were generated by spatially randomising the starting location of each PLW dot while retaining its original trajectory. The resulting point-light display contained no recognisable form, but retained an equivalent amount of local motion to a regular PLW; thus, discriminating between these two stimuli can only be achieved using global, full-body cues. It was hypothesised that DS participants would perform worse than healthy controls on the perceptual task.

Methods

Participants. Both the DS and control group consisted of 16 participants, each with 10 males and 6 females. The DS group had a mean age of $M = 19.19$, $SD = 9.98$, while the control group had a mean age of $M = 13.81$, $SD = 3.04$. Control participants had no history of mental or physical disability. All subjects were in either primary or high school at the time of testing and were naïve to the aims of the study. All participants had normal or corrected to normal visual acuity. Written informed consent was obtained from both participants and a parent or guardian. Ethical approval for the testing of these subjects was obtained from the ethics board of the Westfälische-Wilhelms University of Münster prior to testing.

Materials. Stimuli for the task were generated and presented using a 15.4″ Apple MacBook Pro laptop (2.4 Ghz, 2 Gb RAM) equipped with an Nvidia GeForce 9400M graphics card

(256 Mb). The laptop display operated at a resolution of 1440 × 900 pixels with a refresh rate of 60 Hz. Stimuli were produced using MATLAB (Mathworks) with the PsychophysicsToolbox (version 3) add-on (Brainard, 1997; Kleiner et al., 2007).

PLW Generation. Kinematic data for PLW generation was obtained using a MotionStar Wireless motion capture system (Ascension Technology Corp., Burlington, USA). Data were gathered from 11 healthy adults (4 female, 7 male) who were instructed to walk at a natural pace during recording. PLWs were produced by placing single white points at the left and right ankle, knee hip, shoulder, elbow and wrist joints. An example PLW can be seen in the left panel of Figure 1. SPLWs were produced by randomising the starting locations of each individual regular PLW point. The resulting figures had no recognisable biological form; however, the dot trajectories and speeds matched those of their regular PLW counterparts. An example SPLW can be observed in the right panel of Figure 1. Individual PLW and SPLW points subtended 0.1° of visual angle. Walkers were scaled to fit on the computer monitor. The largest walker in the set subtended a maximum of 4.30 × 9.05°, while the smallest subtended a maximum of 1.91 × 5.25°. Participants did not report that any walker appeared to be more difficult to detect. Walkers were always presented centrally against a black background.

Procedure. The task required participants to judge whether a centrally presented walker was human or not. If the participant perceived the walker as human, they responded by pressing the right shift key of the laptop keyboard. If they perceived a nonhuman walker, they were instructed to press the left shift key. A correct response was registered when participants identified either a regular PLW as human or an SPLW as nonhuman. Reaction times for key

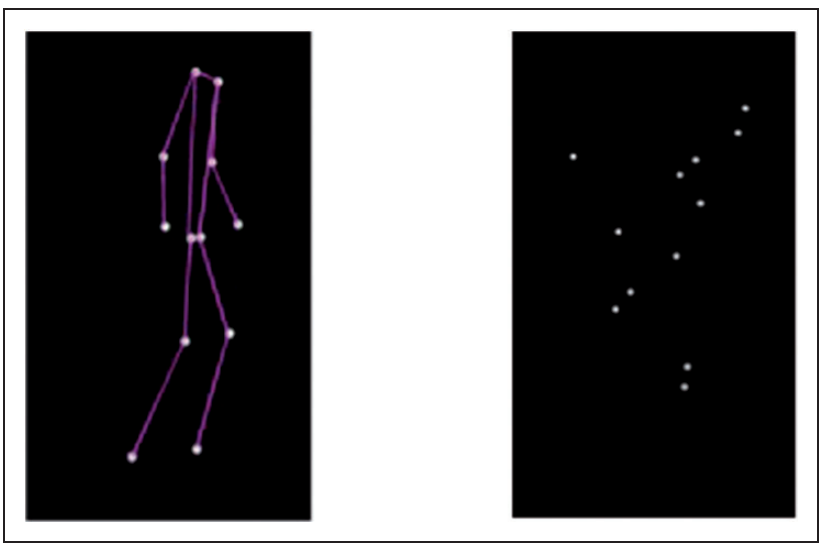

Figure 1. Example of regular (left) and scrambled (right) PLWs. In the sample regular PLW, limbs are highlighted in purple. These purple lines have been added to assist the reader in recognising the underlying form of the static walker and were not present during the experiment.

presses were also recorded. Prior to beginning the task, participants were given several practice trials as a screening procedure to ensure that they (a) spontaneously perceived PLWs as walking humans on at least some trials, and (b) understood the task. The inability to meet either of these two criteria was established as a grounds for exclusion from the experiment; however, none of the participants failed at this stage of the experiment and thus no participants were excluded based on these grounds.

Participants completed 40 experimental trials: for half of the trials, a regular PLW was presented and on the other half of the trials, an SPLW was presented. PLW and SPLW trials were presented in a random order. Each walker trial was displayed for 1600 ms, no time limit was placed on responses and there was a 50 ms interval between the participant's response and the onset of the next trial. Participants were seated 60 cm from the laptop and instructed to keep their left and right fingers on the left and right shift keys during the entire experiment.

Statistics. Prior to statistical analysis, the data were checked for outliers, normality and any assumption violations. No participants were excluded from the analyses. The task performance data were not found to violate any relevant statistical assumptions. Reaction time data violated the assumption of normality and were converted to reaction speeds using an inverse transformation. This transformation is commonly used for reaction time data, and is achieved by simply taking the inverse of the reaction time (1/RT; Whelan, 2008). Because of this transformation, higher reaction speeds denote shorter reaction times.

Task performance, as measured by the number of correct responses, was compared between the DS and control groups using a binomial generalised linear mixed model with participant as a random effect and group as a predictor. An independent samples *t*-test was used to compare the reaction speeds of the two groups.

Results and Discussion

Behavioural Task Performance. A significant difference in performance was found between DS and control groups ($\hat{\beta} = -2.40$, SE = 0.21, $Z = -11.21$, $p < .01$). The DS group produced fewer correct responses than controls; however, it should be noted that both groups performed above chance (percentage of correct responses >50%, see Figure 2). These results suggest that biological motion perception is impaired but not absent in DS. Because regular and SPLWs contain the same local motion, it is argued that this impairment must originate from a deficiency in the processing of global biological motion cues.

Reduced performance by participants with DS could result from incorrectly identifying either SPLWs as regular walkers or regular PLWs as scrambled. To further investigate the source of errors in the behavioural task, we calculated the average number of correct responses and false identifications (i.e. a normal PLW identified as an SPLW or vice versa) in both the normal and scrambled PLW conditions. These results are shown in Table 1.

As can be seen in Table 1, correct response and false identification rates hardly differed between normal and scrambled PLWs. This was true for both control and DS groups. This suggests that reduced biological motion detection performance in the DS group was not due to a systematic perception of one walker as the other, or to difficulties with perceiving one PLW in particular. Instead, the impairment appears to manifest as an inability to reliably identify the walker type.

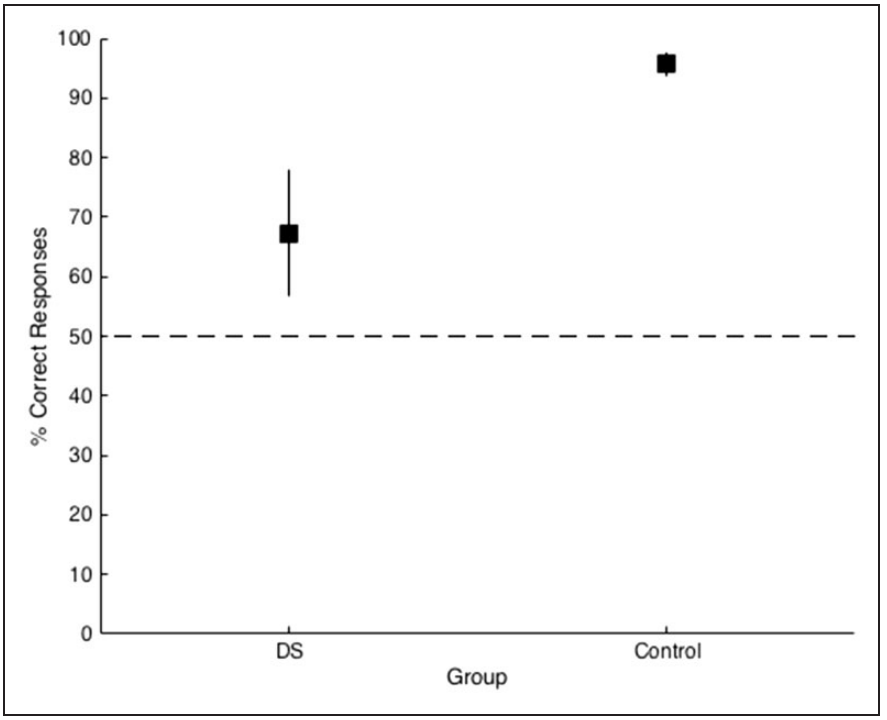

Figure 2. Percentage of correct responses made by subjects in the DS and control groups on the biological motion discrimination task. Vertical bars represent 95% confidence intervals. The dashed horizontal line denotes chance performance.

Table 1. Average Number of Correct and False Identification Responses (±Standard Deviation) Given in the Regular PLW and SPLW Conditions.

	PLW		SPLW	
	Correct response	False identification	Correct response	False identification
DS	13.24 ± 6.45	6.65 ± 6.45	13.24 ± 4.34	6.76 ± 4.34
Control	18.63 ± 3.72	1.38 ± 3.72	18.63 ± 1.67	1.36 ± 1.67

PLW = point-light walkers; SPLW = scrambled PLW; DS = Down syndrome.

Reaction Speeds. The difference in reaction speeds for the two groups was also significant, $t(30) = -4.65$, $p < .01$, with control participants responding faster than DS participants. Mean untransformed reaction times for the two groups can be seen in Figure 3.

Experiment 2

The results of Experiment 1 show that individuals with DS are less sensitive to differences in global biological motion than healthy controls. While this result may indicate a specific

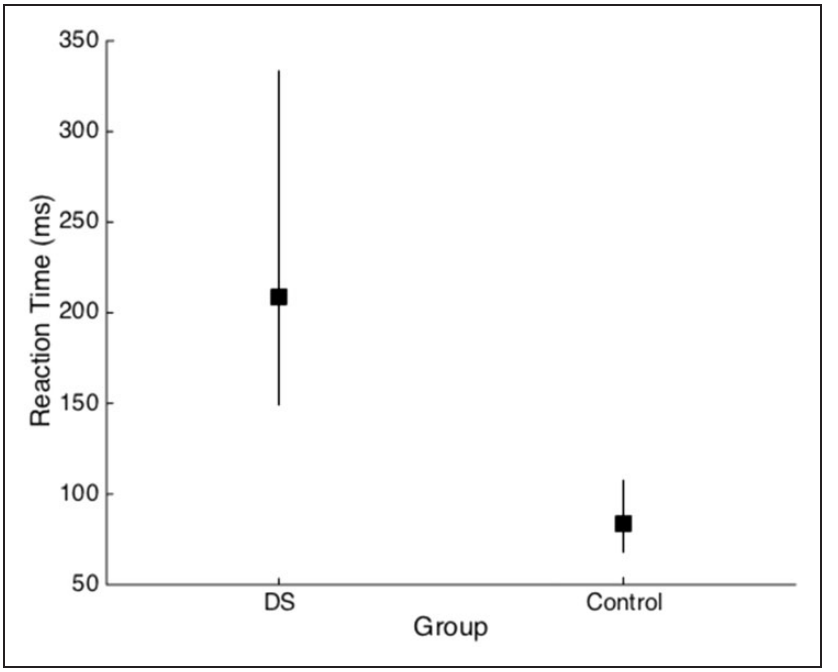

Figure 3. Average reaction times (untransformed) of DS and control participants in the biological motion discrimination task. Vertical bars represent 95% confidence intervals.

deficit in the perception of biological motion, it could potentially stem from a more generalised impairment in motion processing. Although individuals with DS tend to be biased toward global features in spatial tasks (Wang et al., 1995), we know little about their ability to perceive visual motion.

The purpose of Experiment 2 was to examine generalised global motion processing in DS. In Experiment 2, participants with DS viewed scrambled and normal PLWs that translated laterally (left or right) across the screen. The participants' task was to judge the direction of lateral motion. If individuals with DS were unable to perform this task above chance level, one would be led to conclude that a more generalised motion processing deficit produced the reduced performance for discriminating biological motion observed in Experiment 1. If, on the other hand, participants were able to perform the task, an explanation based on a generalised motion deficit can be ruled out.

Methods

Participants. Nine individuals (three female, six male) with DS participated in the current experiment. Participants were recruited from a local school specialising in the education of children with mental disabilities. The participant group had a mean age of $M = 17.22$, $SD = 3.11$. All participants had normal or corrected to normal visual acuity. Written informed consent was obtained from both participants and a parent or guardian. Ethical approval for the testing of these subjects was obtained from the ethics board of the

Westfälische-Wilhelms University of Münster, Germany, prior to testing. One of the participants also participated in Experiment 1.

Materials. Materials and PLW generation were identical to Experiment 1 (see earlier subsections for full details).

Procedure. Participants were presented with either a regular PLW or SPLW that moved in a randomly selected rightwards or leftwards direction at a speed of 2.39° of visual angle per second. Walkers faced in the same direction as they translated. Walkers also ambulated while translating so that they appeared to walk across the screen. Participants were asked to judge the direction of object motion. Responses were signalled by pressing the left or right shift key on the keyboard of the laptop corresponding to the direction of motion. Participants were not told that some of the objects were depictions of biological motion and were simply asked to judge the direction of global positional change while ignoring the motion of individual points as much as possible.

Participants completed 40 trials in total. Half of these trials contained a regular PLW while the other half of the trials contained an SPLW. Trials containing regular and SPLWs were randomly intermixed. Trials were displayed for 1600 ms with a 50 ms interval between trials. Participants were seated 60 cm from the display. The experiment was completed in a quiet room with the experimenter present.

Statistics. Prior to analysis, the data were scanned for outliers and relevant statistical violations. One participant scored more than three standard deviations lower than the mean of the group was thus classified as an outlier and excluded from further analysis. The data failed to meet the assumption of normality. Comparisons were therefore carried out using binomial tests.

A binomial test was used to compare participant performance against chance level, which was defined as 50% correct responses. A binomial generalised linear mixed model with participant included as a random factor and walker type as a predictor was used to compare performance in the regular and scrambled PLW conditions in order to determine whether the two walker types affected the discrimination of motion differently.

Results and Discussion

Participants produced almost perfect performance, with a median of 39.50 out of 40 (range = 38–40) correct responses. Performance was significantly higher than chance level ($Z = 69.87$, $p < .01$). No difference was found between the number of correct responses for normal (median number of correct responses = 20.00, range = 19–20) and scrambled walkers (median number of correct responses = 20, range = 19–20; $\hat{\beta} = -0.41$, SE = .92, $Z = 0.45$, $p = .65$).

These results suggest that individuals with DS are able to perceive global translational motion. Additionally, we found that biological motion does not impair the perception of translational motion, implying global translational motion and biological motion are two separately processed domains in DS.

General Discussion

The aim of the current study was to test whether individuals with DS differed from healthy controls in a task that required the discrimination of biological from nonbiological motion based on global features alone. It was hypothesised that individuals with DS would perform

worse than controls on the discrimination task. In support of this hypothesis, we found that participants with DS were less accurate and slower than controls when discriminating PLWs from SPLWs. Experiment 2 extended this finding, showing that this difference cannot be accounted for by a generalised motion processing deficit.

Previous studies investigating biological motion perception in DS have only examined performance in situations in which test stimuli differed based on both local and global cues (Virji-Babul et al., 2006). In a task that excludes the possibility of using local motion cues, we show that PLW perception remains impaired. This implies that global cue processing is deficient in DS. In addition, we found that correct and false identification rates did not differ between walker types in the DS group, suggesting that this impairment stems from an inability to reliably identify the presented stimuli. Again, this suggests that participants with DS were unable to use the configuration of the points to discriminate the PLWs, and that performance was not due to a response bias toward one particular walker type.

Biological motion is a unique category of visual input with a specialised neural network dedicated to its processing (Giese & Poggio, 2003; Grezes et al., 2001; Grossman et al., 2000). Thus, deficits in the global processing of biological motion observed in the current experiment may not generalise to global processing deficits in other visual domains or under other task conditions. For instance, individuals with DS are generally found to be biased toward global stimulus properties in spatial copying tasks (Bihrle, Bellugi, Delis, & Marks, 1989; Wang et al., 1995).

Indeed, Experiment 2 showed that individuals with DS do not exhibit deficits in the processing of global translational motion, suggesting that it is unlikely that differences in the ability to perceive biological motion between DS and healthy populations are the result of a more generalised motion processing deficit. Additionally, no difference was found between PLWs and SPLWs for the direction discrimination task, indicating that biological motion is a specialised domain that does not interfere with motion processing in DS. A similar dissociation between biological and directional motion processing has been reported for healthy subjects (De La Rosa, Ekramnia, & Bülthoff, 2016); however, this may be limited to cases when the direction of motion is not a characteristic feature of the portrayed action. In situations where the overall motion of the body and the action direction are inherently linked (e.g. walking), these two sources of information can influence one another (e.g. Masselink & Lappe, 2015). Although a direction-dependent action was presented in Experiment 2, the action direction was always congruent with the overall motion direction. In this case, biological motion did not appear to influence the perception of global motion in subjects with DS. It is possible, however, that when action and motion direction are incongruent, an interaction may occur.

It should be noted that participants in Experiment 2 reached ceiling-level performance. This may have had the effect of masking more subtle deficits in global motion processing in our subjects. We argue, however, that this does not necessarily detract from our results. The decision to use a simple global motion detection task in Experiment 2 was made in order to attempt to approximate the level of difficulty of the task in Experiment 1. The task used in Experiment 1 was also extremely simple, as evidenced by the fact that control participants produced over 90% correct responses. Despite this simplicity, DS participants in Experiment 1 exhibited reduced performance. Thus, we reasoned that if a general motion processing deficit were to account for the results in Experiment 1, it must be a fairly severe deficit. In this case, even basic global motion detection tasks should be impaired in individuals with DS. The motivation behind Experiment 2 was to show that individuals with DS are unimpaired in global motion tasks that have a similar level of complexity to the biological motion task used in Experiment 1, thereby demonstrating that any deficits in biological

motion processing are unlikely to be caused by difficulties with the basic discrimination of visual motion. More difficult tasks, such as the detection of global motion in noise, require additional levels of processing and could potentially reveal more subtle deficits in global motion perception in DS, but may also employ different mechanisms than those used by global biological motion detection (e.g. Lange & Lappe, 2006; Theusner, de Lussanet, & Lappe, 2014). As such, they represent an interesting avenue for future investigation but are outside the scope of the current study.

Motion processing impairments are not typically reported in DS, and populations with DS are generally thought to have relatively normally functioning visual systems. We therefore argue that biological motion processing deficits observed in DS are specialised for this type of motion and may stem from an inability to integrate different sources of motion information, rather than an inability to perceive the motion itself.

The global biological motion processing deficit observed in the current experiment supports findings in previous work studying biological motion perception in DS. Virji-Babul et al. (2006) found that individuals with DS have difficulty discriminating between gaits and emotions of PLWs. This could be attributable to an inability to recognise differences in configural changes between walkers. Global form cues play an important role in emotion recognition (Atkinson, Tunstall, & Dittrich, 2007; Roether, Omlor, Christensen, & Giese, 2009) and could explain why subjects with DS perform poorly on biological motion tasks requiring the recognition of emotion from gait patterns, despite the fact that impairments in other social functions are not typically reported (Fidler, 2005). In their work, Virji-Babul et al. (2006) concluded that the inability of individuals with DS to compare gait patterns was likely due to an inability to discriminate complex patterns of body motion. Our research supports this conclusion by showing that people with DS are less accurate when discriminating between biological and nonbiological stimuli that differ only in their global motion, which is driven by changes in configural cues.

Based on behavioural evidence showing that biological motion can be perceived even if local point motion is heavily attenuated (Beintema & Lappe, 2002), Lange and Lappe (Lange et al., 2006; Lange & Lappe, 2006) have proposed a model for the processing of biological motion based on global configural cues alone. In this model, static templates of body postures are integrated over time to form the perception of global biological motion. Considering that people with DS do not exhibit any dysfunctionality for the perception of static global forms (Bihrle et al., 1989; Wang et al., 1995), it is possible that impairments in biological motion processing arise due to an inability to combine form-based templates over time. Future research should focus on attempting to elucidate the specifics of how the integration of global biological motion is impaired in DS, exploring the relationships between biological motion processing and motor functioning in DS and investigating potential neural differences that may underpin the biological motion processing deficit observed in the current work.

One potential limitation of the current study is the fact that control and DS groups were not matched based on some measure of either mental or motor functioning. We argue that this does not necessarily represent a major confound. Cognitive impairments, at least insofar as understanding the task, are unlikely to have affected task performance. Participants were screened before testing to ensure that they understood the task requirements and the ability to understand the task is also reflected by the fact that, though performance was impaired in the DS group, it was above chance level. We thus conclude that any differences in cognitive ability between the two groups did not impede the ability to complete the task. Beyond the level of task understanding, it is counter intuitive to control for differences in cognition, as these impairments are inherent to the condition of DS and may well represent an important factor in biological motion processing in DS. Additionally, it is often undesirable to match

control groups and groups with neurodevelopmental disorders based on common measures of cognition such as IQ, as this can create unrepresentative groups for the respective populations, with either the disordered group having a higher than representative IQ or the control group having a lower than representative IQ (Dennis et al., 2009). Attempting to control for such differences statistically is also an invalid approach, as the two groups would undoubtedly differ on the covariate (for a more detailed discussion on the problems behind this, see Miller & Chapman, 2001).

In previous studies (e.g. Virji-Babul et al., 2006), DS and control groups have been matched on motor function. While the motor system does play an important role in aspects of biological motion processing in healthy populations, the extent to which this relationship influences biological motion processing in DS is unclear. Furthermore, if this relationship does exist in DS, there has been no research dedicated to investigating its nature. Therefore, it is unclear whether controlling for differences in motor function is valid or would lead to unnecessarily restrictive selection criteria for the healthy group. Virji-Babul et al. (2006) observed degraded PLW perception performance in DS, even when DS and control groups were matched on motor functioning. This could be interpreted as weak, correlational evidence that deficits in biological motion processing in DS are not related to deficits in the motor system. However, due to the apparent importance of the motor system in the processing of at least some aspects of biological motion, we would be extremely hesitant to draw such a conclusion. Instead, we suggest that investigating the relationship between biological motion and motor function in DS is a necessary step for future research into biological motion processing in DS.

Availability of Data and Analyses

All data and analyses used in the current experiments will be made available upon request to the corresponding author.

Declaration of Conflicting Interests

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