Distance perception in autism and typical development[†]

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Abstract. Children with autism and typically developing children walked blindfolded to a previously seen target (blindwalking task) and matched the frontal to the sagittal extent of a pattern formed by ropes on the ground (L-matching task). All participants were accurate in the blindwalking task. Children with autism were also very accurate in the matching task. By contrast, in the matching task typically developing children made substantial underestimations that were inversely correlated with age. These findings support models that posit independent representations for the egocentric distance to a target location and for the spatial extent to a target object relative to the other spatial extents. These latter representations involve a form of large-scale pattern perception that may mature more slowly than representations of egocentric distance and develop atypically in autism.

1 Introduction

Healthy individuals can walk without using vision to previously seen targets with remarkable accuracy. For instance, blindfolded participants can reach targets up to 15 – 20 m away with no systematic errors (Thompson 1983; Ellard and Shaughnessy 2003). Yet, when the same participants are asked to compare distances to targets, their phenomenal reports show systematic distortions. For instance, when comparing distances along the line of sight (sagittal) to frontal extents, participants report that the two appear equal only if the frontal extent is considerably shorter than the line of sight (Loomis et al 1992). Such different outcomes in tasks involving the same distances suggest that spatial perception is not unitary, but is based on different processes and internal representations for specific visual functions. However, the nature of such processes and how they might generate accurate locomotion in the face of distorted perception remains controversial (Loomis et al 2002). Two critical issues, with this regard, are whether the apparent dissociation actually supports separate spatial representations, and whether these are necessarily tied to specific response modes (eg locomotion compared to verbal reports of one's phenomenal experience).

In previous studies, children's ability to walk without vision to near targets was examined without including data on their ability to estimate distances to the targets (Mauerberg-deCastro and Moraes 2002). Since no data are currently available about the developmental trajectory of locomotor and phenomenal responses to depth extents, we report new developmental evidence that bears on these issues. In the current study, we compared the development of vision-for-locomotion and vision-for-perception by collecting data on tasks specifically devised to compare these visual functions in typically developing first-graders and third-graders, normal adults, and children with autism.

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Autism is typically associated with 'locally oriented' perception. Compared to their typically developing counterparts, children with autism often show superiority in processing visual details and may neglect configurational and contextual information (Plaisted et al 1999). This aspect of their information processing has been revealed by tasks employing both short-exposure stimuli, as in the Navon-type attention tasks, and long-exposure stimuli, as in the block-design test (see Dakin and Frith 2005; Mottron et al 2006, for excellent reviews). Explanations for the local bias in autism have posited a deficit in the ability to integrate contextual elements and details into coherent wholes (Frith 1989), an atypical cognitive style (Happé 1999), insufficient top–down processes influenced by prior knowledge (Ropar and Mitchell 2002), and default setting of perception more locally oriented in autism than in typical development with intact processing of global aspects of information (Wang et al 2007). Several hypotheses have also been proposed on the neural basis of processing deficits or enhancements in autism (Caron et al 2006). Most relevant for the present study is the proposal that children with autism may show abnormalities in the magnocellular pathway (Milne et al 2002). In line with this hypothesis, a recent study found that infants at risk of autism had contrast sensitivities to a magnocellular-pathway stimulus that were nearly twice those reported in controls (McCleery et al 2007). However, research on adolescents and adults with autism has found normal functioning of the magnocellular pathway (Bertone et al 2005; Caron et al 2006). To assess and understand the role of the magnocellular abnormalities in autism, we probably need to consider that, while such abnormalities may be overcome in older children and adults, they are present early in life and may have lasting effects on cortical areas that depend on magnocellular input to mature.

Perceptual processes in typical and atypical development are an additional, important source of evidence for investigating the functional independence of different spatial processes. If vision-for-locomotion and vision-for-perception indeed involve distinct processes, we might observe characteristic dissociations in the developmental patterns of tasks tapping different processes. More specifically, we hypothesise that dissociations will be found in typical development and will be revealed by slower developmental rates of vision-for-perception than vision-for-locomotion. Investigation of these perceptual processes also in children with autism contributes to the current debate on the origin of their peculiar responses on several perceptual and cognitive tasks. Moreover, the performance of children with autism provides relevant evidence allowing us to assess explanations of task dissociations based on task difficulty and resource demands.

2 Experiment 1
2.1 *Method*
2.1.1 *Participants.* In the first experiment we compared three groups of typically developing participants. There were two groups of children: twenty-six first-graders (eleven males and fifteen females; mean age [SD] = 7 years and 1 month [4 months]), and thirty-three third-graders (twenty males and thirteen females; mean age [SD] = 9 years and 1 month [4 months]). The third group consisted of thirty-two adults (seven males and twenty-five females; mean age [SD] = 24 years and 4 months [7 years]; mean schooling [SD] = 14 years and 1 month [2 years]) recruited within the University of Trieste community. To screen for verbal and nonverbal cognitive abilities, we pretested all children with the Peabody picture vocabulary test – revised (PPVT—Dunn and Dunn 1981; Stella et al 2000) and with Raven's coloured progressive matrices (RCPM—Raven 1956/1991; Pruneti et al 1996). Six children were not included because of their poor performance in the prescreening tests. To identify possible neurological impairments, we also screened adults by means of a questionnaire. No adult was excluded from the analysis.

2.1.2 *Materials and procedure.* Testing was performed in two large rooms, with no furniture, high ceilings, and a relatively irregular texture on the floor. The first (used for fifteen children of the first group and seventeen of the second group), was an auditorium measuring 13 m × 16 m. The second (used for all the other children) was a gymnasium measuring 9 m × 14 m. Adults were tested in a quiet outdoor area behind the departmental building. This area was also roughly rectangular (approximately 10 m × 14 m) and was bounded on one long side by the building walls, on the other two sides by large pots with plants and flowers, and opened to a narrower walkway on the remaining short side. Maximum care was taken to ensure that the test locations were comparable in terms of available depth cues. In all locations, the testing area was free of furniture or other objects. Area floors were covered with grids of medium-sized rectangular elements (in the indoor locations, these consisted of parquet wooden blocks; in the outdoor location, of comparably sized stone tiles) laid down such that the long sides of the rectangles were all parallel, whereas the short sides of near rectangles never were. Finally, in all areas measured distances were along directions roughly parallel to one diagonal of the flooring elements to discourage a counting strategy. Target locations were selected to maximise distances from the room's walls in all directions.

Testing materials consisted of a bright orange cardboard disk (40 cm diameter) used as target, a metre tape in a plastic wind-up case, and one additional rope used in the L-matching task (see figure 1).
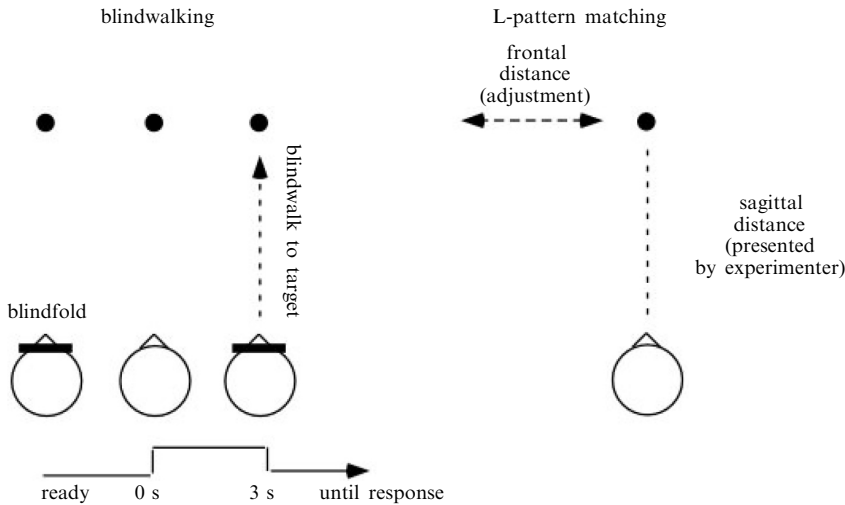

Figure 1. Schematic illustrations of the two spatial tasks employed in experiments 1 and 2.

In the blindwalking task, participants were blindfolded and positioned at a fixed starting point. A target was placed in front of them at a randomly chosen distance between 3 m and 6 m. The blindfold was removed for 3 s and then applied again. Participants immediately walked to the previously viewed target until they felt to be where the target had been. To prevent participants from obtaining acoustic or haptic cues when stepping on the disk, a collaborator silently removed the cardboard disk from its location as soon as the walk began. At this point, one of the experimenters measured and recorded the walked distance. No participants reported having practiced blindwalking before.

In the L-pattern matching task, participants sat on a chair and were instructed to look at the target disk, also previously placed at a randomly chosen distance bet-ween 3 m and 6 m, with a rope laid down on the ground from the chair to the target.

Participants adjusted the length of a second 'rope' (this was in fact the wind-up metre tape), presented frontally, orthogonally to the first rope, to form an L-pattern on the ground, until it matched the apparent length of the first rope (see figure 1). The adjustments of the rope length were performed by giving verbal instructions to a collaborator. They started always with the tape at zero length, and proceeded as follows. At the beginning of the trial, indicating the collaborator, the experimenter told the participant: "She will now slowly lengthen her rope, please tell her to stop when you think the length matches that of the other rope". As soon as the participant asked the collaborator to stop, the experimenter told the participant: "Now consider the two lengths, are they really the same? Or would you like her to change the length of her rope? Less or more?". These three questions were then repeated after each successive adjustment until the participant answered affirmatively to the first. One or two changes after the initial unwinding of the tape were typical. The task was presented to all children as a game they could play with the collaborator.

Both the blindwalking and the L-pattern matching tasks were performed only once by each participant, after instructions and familiarisation with the task materials. We chose to collect only one response in each condition from each participant to avoid stereotyped responses or learning effects and reduce the effects of boredom or fatigue in children with typical and atypical development. Task order was randomised across participants. All experimental protocols complied with the guidelines of the Italian Board of Psychologists and were approved by the appropriate committee of the University of Trieste.

2.2 Results and discussion

For each measure in the two tasks, we computed the proportional signed error using the formula:

$$(\text{response measure} - \text{actual distance})/\text{actual distance},$$

where the response measure is a walked or a matched distance, depending on the task. Negative values represented underestimations and positive values represented overestimations. The distribution of these errors is presented in the box-plots of figure 2, top panel, as a function of age group and task.

As can be seen in figure 2, proportional errors were close to zero for all groups in the blindwalking task, whereas they were substantial, negative, and dependent on age in the matching task. When comparing between tasks, but within participants, mean errors were -0.005 and -0.35 in the blindwalking and matching tasks, respectively ($F_{1,88} = 232.36$, $p_{\text{rep}} > 0.99$, partial $\eta^2 = 0.73$). Separating the data by both age group and task yielded the six distributions in the plot, where average errors for adults, third-graders, and first-graders were -0.003, -0.035, 0.023 in blindwalking and -0.23, -0.37, -0.47 in matching. This pattern yielded a reliable interaction ($F_{2,88} = 10.4$, $p_{\text{rep}} > 0.99$, Cohen's $f = 0.59$). Scheffé a posteriori tests demonstrated that all pairwise comparisons between age groups were statistically significant in the L-pattern task ($0.000001 < p < 0.05$), but not in the blindwalking task (all $ps > 0.36$).

Correlations between proportional errors in the two tasks provided little evidence of a relationship in the adults ($r_{31} = -0.098$, $p_{\text{rep}} = 0.434$) and third-graders ($r_{32} = 0.049$, $p_{\text{rep}} = 0.289$). In the first-grade group, the correlation was larger, but negative ($r_{25} = -0.386$, $p_{\text{rep}} = 0.876$). Inspecting the corresponding scatterplot in fact suggested that small blindwalking errors tended to be associated with large matching errors. However, the size of the correlation was critically dependent on one child that overestimated in the blindwalking trial, but produced a large underestimation in the matching trial. Finally, correlations between children's blindwalking errors with their PPVT and RCPM scores were negative ($r_{57} = -0.17$ and -0.211, $p_{\text{rep}} = 0.731$ and 0.808).
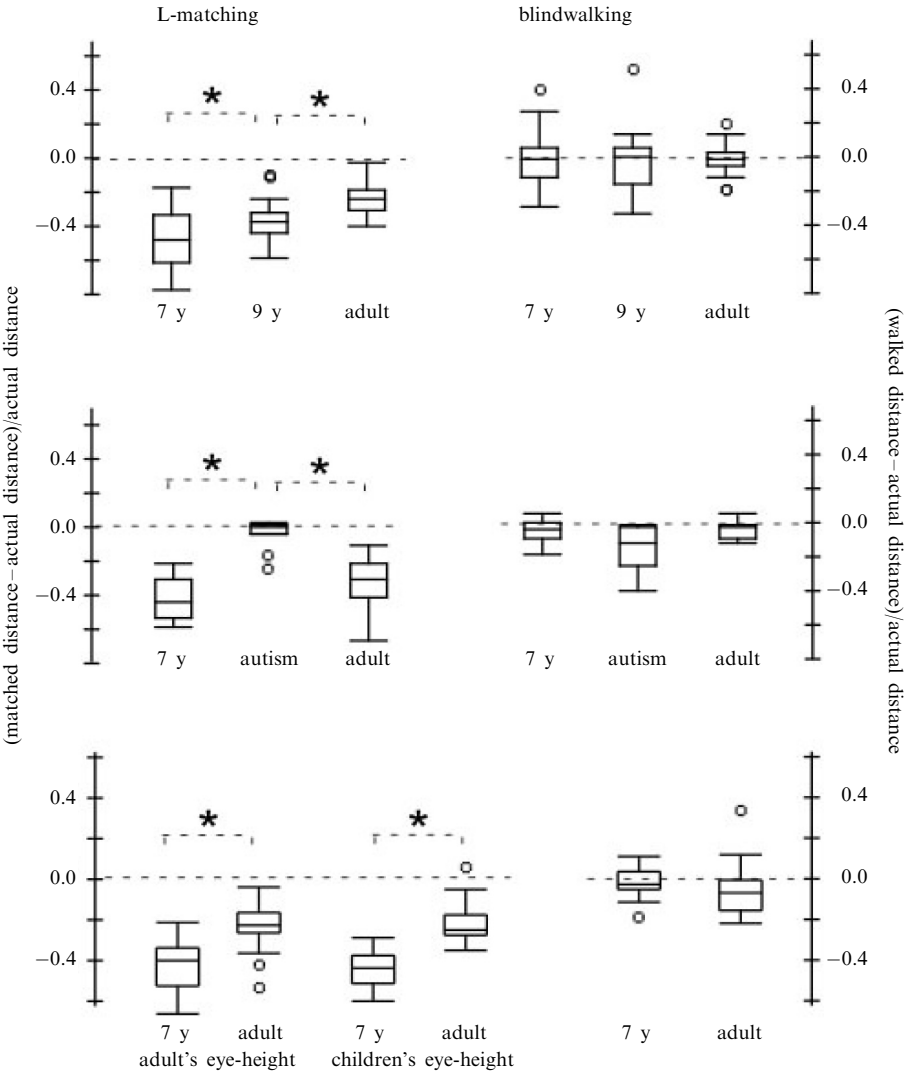
Figure 2. Results of experiments 1 (top row), 2 (central row), and 3 (bottom row). Left column: results for the matching task. Right column: results for the blindwalking task. In each box plot, the central line is the median, the box identifies the central 50% of the distribution, and the bars mark the minimum and the maximum values. Open circles are the outliers. Asterisks identify statistically significant differences in the critical Scheffé a posteriori pairwise comparisons ($p < 0.05$).

The correlation of their matching errors with PPVT scores was positive but small ($r_{57} = 0.11$, $p_{rep} = 0.579$), but the corresponding correlation with RCPM scores was positive and substantial ($r_{57} = 0.36$, $p_{rep} = 0.966$). Positive correlations between cognitive ability and proportional errors in the L-task are to be expected, given that proportional errors in this task were different in different age groups, and such scores in turn correlated with age. Multiple regressions of L-task errors as a function of either cognitive ability score, controlling for chronological age, suggested that both PPVT and RCPM were poor predictors of errors (regression $b = -0.001$, $t_{57} < 1$, and -0.007, $t_{57} < 1$).

The outcomes of the above analyses converge in suggesting that children's matching errors did not depend on differences related to verbal and non-verbal intelligence. However, one possibility is that the task dissociation reported in experiment 1 was due

to a difference in cognitive demands. This possibility will be considered in section 5, after our examination of atypical development. In experiment 2 we compared the performance of children with autism with that of controls matched for mental age.

3 Experiment 2
3.1 Method
3.1.1 *Participants.* In experiment 2, we compared a group of fifteen children with autism, a group of typically developing (TD) children, and a group of adults. Children in the first group were all male (mean age [SD] = 10 years [3.3 years]) and attended a centre in Northern Italy specialised in the diagnosis and treatment of children and adolescents with autism spectrum disorders (ASD). The diagnosis of autistic disorder was made by a clinical psychologist or a child neuropsychiatrist on the basis of the autism diagnostic interview – revised (ADI-R—Lord et al 1994) and by an explicit assessment of the *Diagnostic and Statistical Manual for Mental Disorders (DSM) IV* criteria. Moreover, the children were all described as high-functioning, given their good comprehension abilities and reasoning abilities demonstrated on the RCPM (mean score [SD] = 22.8 [3.8]). Also, they did not present significant clumsiness, as reported by teachers and clinicians. More precise clinical details and information about the severity of autism symptoms were not made available. In the TD children, there were eighteen first-graders recruited at a primary school in the Trieste area (thirteen males and five females, mean age [SD] = 7 years [3 months]). These children were matched to the autism group for non-verbal mental age by their RCPM score (mean score [SD] = 22.9 [3.9]). The adult group without autism was recruited among the teachers at the special education institution that hosted the children with autism (three males and nine females, mean age [SD] = 29 years [4 years]).

3.1.2 *Materials and procedure.* All materials and testing procedures were identical to those of experiment 1. Participants with autism and in the adult group were tested individually in a suitable room at this institution, whereas the first-graders were tested in a gymnasium at their school. The characteristics of these testing rooms were similar to those in the first experiment. Special care was taken to ensure that children with autism understood the 'rules' of the rope game correctly.

3.2 Results
The distributions of mean proportional errors by children with autism, typically developing children, and adults are presented in figure 2, central panel. Errors in the blindwalking task were close to zero for all age groups. By contrast, the errors of the typically developing children and adults were negative and dependent on age for the L-pattern task, but closely clustered around zero in the group with autism. More precisely, when comparing between tasks but within participants, average errors were -0.07 in blindwalking and -0.26 in matching ($F_{1,42} = 43.66$, $p_{rep} > 0.99$, partial $\eta^2 = 0.226$). Separating the data by both age group and task yielded the six distributions in the plot. Mean errors for the adults, typically developing children, and children with autism were, -0.036, -0.041, -0.14, respectively, in blindwalking and -0.31, -0.40, -0.04, respectively, in matching. This pattern yielded a substantial interaction ($F_{2,42} = 29.7$, $p_{rep} > 0.99$, partial $\eta^2 = 0.217$). Scheffé a posteriori tests demonstrated that pairwise comparisons between adults and the autism group and between typically developing children and the autism group were statistically significant in the matching task (all ps < 0.00001). Conversely, no pairwise comparison was significant in the blindwalking task (all ps > 0.08). Finally, pairwise comparisons between the two tasks within the same age group were significant for adults and children ($p < 0.0001$), but not for children with autism ($p > 0.09$). Noting that the variance of the autism group in the matching task was markedly smaller than that in the other groups, suggesting potential

violations of the parametric assumption for ANOVA we also performed pairwise Mann–Whitney non-parametric tests to re-evaluate the critical comparisons between the autism group to the adults and first-graders in the L-task. These tests showed the same pattern of statistical significance as the Scheffé tests, $U = 14$ and 11, $p < 0.0001$ and 0.002, for the comparisons with adults and normally developing children, respectively.

As in experiment 1, proportional errors in the two tasks were not positively correlated ($r_{89} = -0.179$, $p_{rep} = 0.829$). In contrast, however, correlations of RCPM scores with L-pattern errors were negative in both typically developing children ($t_{17} = -0.073$, $p_{rep} = 0.297$), and children with autism ($r_{14} = -0.071$, $p_{rep} = 0.275$). Correlations of RCPM scores with blindwalking errors were, instead, positive. These were $r_{17} = 0.159$, $p_{rep} = 0.48$ for the typically developing group, and $r_{14} = 0.513$, $p_{rep} = 0.877$ for the autism group. The larger size of this latter correlation was explained again by the effect of chronological age, which ranged from 9 to 16 years in the autism group. When the errors were multiple-regressed against the RCPM while controlling for age, again the effect of the RCPM disappeared (regression $b = 0.009$, $t_{13} < 1$).

4 Experiment 3

In several spatial tasks, eye-height plays a role in judgments of object size and distance (Sedgwick 1983; Bertamini et al 1998; Dixon et al 2000). This suggests a potential confound for our results. Recall that, in our L-matching task, participants sat on a chair when they compared the frontal extent to the sagittal extent. In the blindwalking task, conversely, they stood when they viewed the target before starting to walk. Thus, there was a difference in the height from the ground of the participants' viewpoint in the two conditions. Eye-height modulates the angular declination of the target below the horizon (often also called the 'height in the visual field' cue), an optical variable which has been shown to determine perceived egocentric distance in conjunction with texture-based ground information (see for instance Ooi et al 2001). Thus, this difference may have played a role in producing changes in perceived distance in the matching task in comparison with the blindwalking task. Additionally, it may also be argued that differences in eye-height could have a role in causing our observed developmental gradient. Given that children are shorter than adults, the height of their typical viewpoint is bound to be less than that of adults. Therefore, one could argue that the visual input received by children differed from that of adults, and that this is precisely the reason for the larger compression of their L-matches. However, our results do not fit this account well. Consider first the overall pattern. If all distance responses were simply controlled by variations in eye-height, we should see equivalent amounts of compression in the matching and the blindwalking tasks. Instead, the difference between the two conditions indicates that optical information about distance is processed in different ways for the purpose of matching as opposed to guiding locomotion (see discussion below). Second, because children with autism were typically taller than their mental age-matched controls, but shorter than adults, they should have shown an intermediate level of compression between these two groups, but they did not. Finally, because the optical horizon coincides with one's eye-height, lowering height produces a decrease, not an increase, in angular declination, an optical change that is consistent with larger, not smaller, egocentric distance. Therefore, it is not clear why reducing eye-height should produce compression. Again, that it did in our L-task as well as in other published results might be taken as evidence that observers do not use angular declination when matching depth extents. Still, to be completely sure that our results were not affected in significant ways by differences in eye-height, we performed an additional control experiment.

4.1 *Method*

4.1.1 *Participants.* We tested thirty adults (eleven males and nineteen females; mean age [SD] = 27 years and 9 months [6 years]; mean schooling [SD] = 17 years [9 months]) and twenty-six children (nine males and seventeen females; mean age [SD] = 6 years and 8 months [6 months]). Adults were undergraduate or graduate students at the University of Trieste. All had normal or corrected-to-normal vision and were naive. Children were recruited at a dance school and at a primary school in Gorizia, Italy. As in the first experiment, adults were screened for neurological impairments and children were pre-tested with the Peabody picture vocabulary test – revised and with Raven's coloured progressive matrices.

4.1.2 *Materials and procedure.* For each participant, we administered one blindwalking trial and two L-pattern matching trials involving different eye-heights. The logic of the eye-height manipulation was as follows. In the adult's eye-height condition, adults stood on the ground, whereas children stood on a platform that raised them to the approximate average eye-height of an adult participant. In the children's eye-height condition, conversely, children stood on the ground, whereas adults sat on a chair that lowered them to the approximate average eye-height of children. The height from the ground of the platform was 47 cm, whereas the height from the ground of the chair was 45 cm. These values were chosen after considering typical adult and first-grader eye-heights in our participants, which were 155 – 170 cm and 100 – 110 cm, respectively. Testing was performed in three large rooms comparable to those of the first experiment: A room in the dance school (10 m × 20 m), a gymnasium in the primary school (13 m × 18 m), and a third room used to test adults (9 m × 16 m). Materials were the same as those of experiment 1, with the addition of the platform used to raise children. All participants were tested individually. The order of the three tasks was randomised across participants. Training, measuring procedures, and analyses were the same as in the previous experiments.

4.2 *Results and discussion*

The distributions of mean proportional errors are presented in the box-plots of figure 2, bottom panel. Average blindwalking errors were again close to zero (−0.08 and −0.005, respectively, for children and adults). L-task errors were instead substantial and larger for children (−0.41 and −0.44, respectively, at the adults' and children's eye-height) than for adults (−0.24 and −0.22), with little difference as a function of eye-height. There was a substantial effect of group ($F_{5, 162} = 78.9$, $p_{rep} > 0.996$, Cohen's $f = 0.7$). However, Scheffé pairwise a posteriori tests confirmed that this effect was solely due to the differences between age groups in the two L-matching tasks (all $ps < 0.0001$ or smaller), and not to differences between age groups in the blindwalking task or between eye-heights within age groups (all $ps > 0.15$ or larger). Thus, our control provided no evidence for an effect of eye-height on the L-matching responses.

5 General discussion

The present data document a three-fold dissociation between the two spatial tasks. First, as shown previously by Loomis et al (1992), adults were accurate in the blindwalking task, but showed significant underestimation of distance in the L-pattern matching task. Second, typically developing children were as accurate, on average, as adults in the blindwalking task, whereas their responses on the matching task were more compressed than those of adults and their errors were inversely related to age. This second aspect of the dissociation was not known. Mauerberg-deCastro and Moraes (2002) tested children of comparable age to ours in a blindwalking task. As we did, they found that children's accuracy was similar to that of adults. However, they did not compare children's performance to that of adults in a perceptual task.

Third, children with autism were very accurate both in the blindwalking task and in the matching task. Children with autism differed from adults and from controls matched on chronological (experiment 1) or mental age (experiment 2). They showed essentially no underestimations in the matching task.

The developmental dissociations reported here may be interpreted with reference to four broad types of explanation that emphasise the effect of differences in (i) the testing locations, (ii) the cognitive load associated with the two tasks, (iii) the response modes (motor versus verbal), or (iv) the spatial representations used by vision-for-locomotion as opposed to vision-for-perception. Here we will entertain, and argue against, the first three of these. Next, we will argue that the fourth type of explanation accounts best for the present pattern of results.

The simplest explanation for the dissociations reported here is that our observed differences reflect differences in the testing locations of the three experiments. This is potentially a serious concern: for obvious practical reasons it was not possible to test children with autism outside of the institution that hosted them, nor was it practical to bring all other children and adult participants to that institution. We took great care to ensure that testing locations were comparable in terms of size and spatial layout, but they may have contained subtle differences in depth cues that may have affected the results at least in part. For instance, the adult blindwalking performance appears to be especially accurate in experiment 1 (testing in open space) in comparison to that of the other two experiments. To test this possibility in an explicit way, we performed an additional ANOVA on the adult data using location (three levels, corresponding to the three experiments) and task (two levels) as predictors. Not surprisingly, this analysis yielded a significant effect of task ($F_{1, 172} = 159.3$, $p < 0.001$). However, it also yielded a significant effect of location ($F_{2, 172} = 4.4$, $p < 0.015$). A posteriori Scheffé pairwise comparisons indicated that this was due to overall greater accuracy in experiment 1 than in experiment 2 ($p < 0.04$). Finally, the analysis also revealed a significant interaction ($F_{2, 172} = 6.7$, $p < 0.005$). A posteriori comparisons indicated that this was due to the difference between experiments 1 and 3 in blindwalking ($p < 0.008$) and to the difference between experiment 2 and both experiments 1 and 3 in the matching task ($p < 0.04$ and 0.02, respectively). These results indicate that the testing locations may have improved somewhat the blindwalking accuracy in experiment 1, and provoked somewhat larger underestimations in the matching task in experiment 2. However, these differences of detail cannot explain the overall pattern of our results. In particular, we note that these location effects predict larger, not null underestimations in experiment 2, and therefore cannot be invoked to explain the findings in the autism group. Given the outcome of this comparison, we conclude that our results provide no reason to believe that the overall pattern of our results is due to differences in the testing locations.

A second possible explanation is that the two tasks are not equated for difficulty. If the matching task required greater attentional resources than the blindwalking task, one might expect larger errors in the matching responses than in the locomotor responses. Against this explanation we point to three arguments. First, if the matching task were more cognitively taxing to children than to adults, one would expect that participants with low non-verbal IQ, as revealed by their scores on the RCPM, would perform less well than non-disabled adults and typically developing children. Instead, the performance of the autism group was essentially error-free in both tasks. Second, in both experiments there was no evidence of a relation between proportional errors in the matching task and measures of verbal and nonverbal cognitive ability. If the developmental gradient in that condition was due to greater cognitive difficulty, one would have expected less compression in participants with greater PPVT or RCPM scores, but our data did not show this effect.

Third, and finally, consider the prediction that more difficult tasks should produce larger errors. Although this prediction is reasonable, there is no reason to assume that such errors should be systematic, producing greater underestimation, on the average, in younger children than in older children, and in older children than in adults. Indeed, a typical symptom of difficulty in performing a task would be an increase of within-group variability, which would be caused by errors being both in the direction of underestimation and of overestimation. In our experiments, we did find some evidence for an increase of within-group variability in younger participants (see especially figure 2, top left panel). Thus, it could be the case that children found the matching task harder than adults. Even if they did, however, the fact remains that children, as a group, also showed a systematic increase of response compression relative to adults. Such systematic tendency is independent of the within-group variability, and is consistent with a developmental difference in the involved processes, not with merely larger errors in a harder task. Given these three arguments, we believe that the reported results cannot be explained by task demands.

The other two, theoretically more interesting, explanations are related to the different functions served by visual processes in the two tasks. In a much-debated proposal, the distinction between the ventral and dorsal streams of projection in the primate visual system corresponds to a division of labour between subsystems for visual recognition and the visual guidance of actions (Goodale and Milner 2004; see also Jeannerod and Jacob 2003; Rizzolatti and Matelli 2003; Rossetti et al 2003; Müsseler et al 2004). Broadly conceived, such a two-visual-systems hypothesis predicts dissociations of motor and perceptual responses with equivalent stimulus properties. For instance, two recent studies of grasping and perceptual responses to illusions in children (Rival et al 2003, 2004) reported that visuo-manual pointing was unaffected by illusions, whereas visual matches were. These results echo earlier claims that visual illusions deceive the eye, but not the hand, in adults (Aglioti et al 1995).

Most studies supporting two visual systems for perception and action have been concerned with reaching and grasping (Goodale and Westwood 2004). For this reason, their relevance for locomotion is not completely agreed upon. However, studies of walkable illusion patterns have been taken as evidence for a common visuo-motor system for upper-limb and lower-limb movements (Glover and Dixon 2004). The existence of such a common system would make evolutionary sense, given that quadrupedal locomotion often involves precise positioning of limbs as well as propulsion. If the visual control of hands and legs calls into play shared mechanisms, one might expect dissociations between a walking and a perceptual task. We suggest that such a dissociation could explain the present pattern of results in the two different ways discussed below.

One way for a distinction between vision-for-perception and vision-for-locomotion to explain the current results is by means of a dissociation at the level of a response mode, locomotor versus perceptual. Consider the blindwalking task. When viewing the target, a conscious spatial representation of the depth extent from the station point to the target location is produced. This representation would be substantially compressed relative to an equivalent frontal extent. Visuo-motor feedback in previous locomotor experience, however, may have calibrated step parameters such that the conscious compression is compensated. Thus, if a 10 m sagittal extent is presented, the internal representation of this extent is equivalent to a 8.5 m frontal extent, but the visuo-motor transformation is calibrated to correspond to a 10 m walk, yielding accurate blindwalking despite a compressed representation of distance.

An alternative explanation is that the crucial factor is not the response mode, but the type of spatial representation used in the locomotion or matching. Over the last decade, several researchers have proposed that dissociations between perception and various types of action may be explained by the selection of different representations

of spatial features within specific frames of reference (Bruno 2001; Loomis et al 2002). Presumably, when using vision to plan a motor response, such as walking to a target, the natural computation of step parameters appropriate to reach the target is based on a representation of the egocentric distance to the location of the locomotor target. Several results suggest that participants are accurate in perceiving egocentric distance in natural scenes (for discussions of the optical information, including texture gradients, that supports distance perception, see Sedgwick 1983; Ooi et al 2001). Conversely, when vision is used to compare phenomenal extents, the sagittal extent is represented relative to the other, frontal extent. Rather than computing a distance, observers engage in a form of large-scale pattern perception. Thus, representing sagittal extents relative to other extents might be expected to exhibit relative compression due to optical foreshortening on the sagittal direction relative to the frontal direction.

Although the accounts above are both broadly consistent with a division of labour between vision-for-perception and vision-for-locomotion, they differ on a crucial issue. If the dissociation depended on response mode, one would simply predict that the pattern of observed errors depends on whether participants respond by walking or by matching. In the case of our tasks, one would expect that walking is always accurate, whereas matching is always compressed. Conversely, if the dissociation depended on the selection of different spatial representations, it is in principle possible that one could observe different patterns of errors within the same response mode, provided that some factor prevented the use of an appropriate representation. For instance, one study reported that verbal estimations of extents dissociate from matching extents; that is, verbal estimations are accurate, whereas matching responses show an underestimation (Loomis et al 2002; but see Pagano and Bingham 1998; Andre and Rogers 2006 for conflicting results). Such dissociation between perceptual responses may occur if subjects focus on the target to estimate its distance and this tends to underplay its relation to the frontal extent.

The pattern observed here in children with autism shows that perceptual responses, even in the matching task, can be very accurate, possibly because of the perceptual bias favouring local rather than configurational or contextual information (Dakin and Frith 2005; Mottron et al 2006). To investigate the cognitive bases of such superior performance, future studies should assess the relation between children's proportional errors and their responses on tasks assessing their local bias, such as the embedded figure test. The responses in the autism group are coherent with previous findings showing that individuals with autism resist visual illusions more than controls do [Happé 1996; but see Ropar and Mitchell (1999) for conflicting results suggesting a substantial heterogeneity in children with autism]. We suggest that the model positing two spatial representations for the distance to a target accounts best for the observed developmental and task-related dissociations. Further research is needed to establish whether these results are generalisable to the entire population of people with autism and investigate the relationship between the superior performance on the perceptual matching task and the severity of the classic diagnostic symptoms of autism such as poor social and communication skills, repetitive behaviours, and overfocused interests. Another limitation of the present study is that the clinical population and the controls could not be tested in the same rooms. We have discussed this problem already above. Here it is useful to point out that future studies may strengthen the present findings by overcoming such limitation.

The representation of location relative to the observer's standpoint is preferentially used to guide actions, including locomotion. The processes that rely on such representations are fully mature by the age of 7 years, and probably much earlier. The representations of spatial extent to the target relative to other spatial extents are instead used in the matching task by typically developing children. The processes that rely on

such representations are still developing between 7 and 9 years of age. Current theories proposed to explain the local bias in children with autism could also account for the present findings if accuracy in vision-for-perception, as assessed by the matching task used in the present study, benefits from a reduced efficiency in global processing (Dakin and Frith 2005) or from an enhanced low-level perceptual functioning (Mottron et al 2006; Wang et al 2007). Other possible explanations, to pursue in future studies, for the autism group's very accurate performance is that children with autism relied on representations relative to the observer's standpoint in both tasks or they may have developed atypical strategies that rely on information provided by eye movements (Enright 1991).

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PERCEPTION

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