

Visual information from observing grasping movement in allocentric and egocentric perspectives: development in typical children

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Abstract Development of the motor system lags behind that of the visual system and might delay some visual properties more closely linked to action. We measured the developmental trajectory of the discrimination of object size from observation of the biological motion of a grasping action in egocentric and allocentric viewpoints (observing action of others or self), in children and adolescents from 5 to 18 years of age. Children of 5–7 years of age performed the task at chance, indicating a delayed ability to understand the goal of the action. We found a progressive improvement in the ability of discrimination from 9 to 18 years, which parallels the development of fine motor control. Only after 9 years of age did we observe an advantage for the egocentric view, as previously reported for adults. Given that visual and haptic sensitivity of size discrimination, as well as biological motion, are mature in early adolescence, we interpret our results as reflecting immaturity of the influence of the motor system on visual perception.

Keywords Biological motion · Children · Allocentric perspective · Egocentric perspective · Grasping · Size perception

Introduction

The visual system has developed a selective pathway to dialog optimally with action, and the dichotomy between vision-for-action and vision for perception pathways is gaining strong experimental support (Goodale 2014; Goodale and Milner 1992). Milner and Goodale proposed this idea more than 20 years ago, suggesting that the ventral stream plays the major role in constructing the perceptual representation of the visual world and the objects within it, whereas the dorsal stream mediates the visual control of actions directed to those objects. How well can the vision-for-action system develop its visual abilities if the motor system cannot integrate well the relayed visual information because, for example, it is still immature?

Traditional models of action-understanding emphasize the idea that long-term experience in seeing a wide array of actions allows for effective action anticipation or prediction (Mulligan and Hodges 2014). Besides the idea that the visual system plays an important role for the programming and execution of action, more recently it has been suggested that also motor experience and learning can promote improvement in perceptual skills (Aglioti et al. 2008; Arrighi et al. 2011; Calvo-Merino et al. 2006; Casile and Giese 2006) and even programming of a simple action can modulate visual thresholds (Tomassini et al. 2015), closing in an elegant way the visuo-motor control loop.

Knoblich and colleagues (Knoblich and Flach 2001; Knoblich et al. 2002) have suggested that during observation of action, the motor system of the observer activates

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action codes associated with the observed motor commands. As a consequence of these mechanisms (often termed the ‘mirror system’ Rizzolatti et al. 2001; Rizzolatti and Sinigaglia 2010), an enrichment of the observer’s motor repertoire would induce an increase in the ability to understand the consequence of the actions of others. The closer the match between the observer’s motor repertoire and the observed action, the better the understanding of the action of others and the anticipation of the sensory consequences of the unfolding action (Knoblich and Flach 2001).

This view has received support from neuroimaging investigations who have repeatedly associated activity in the human parieto-frontal “mirror neuron system (MNS)”, or more neutrally named “action observation network” (AON), with processing of own and other’s observed movements (Van Overwalle and Baetens 2009). Similar activity has also been observed in 7-year-old children, although AON is clearly immature at this age, with a greater recruitment of cortical processing during observation of complex actions (Biagi et al. 2015). The motor influence on visual motion perception can be revealed also in patients with peripheral motor injury at spinal level, showing an impaired perception of biological motion due to the reduced motor repertoire (Arrighi et al. 2011).

The influence of the motor system on perception can also be revealed by studying the influence of point of view on action understanding given that the performed action, and hence the motor repertoire, in first person are more frequently observed (Bach et al. 2014). Campanella et al. (2011) investigated the ability of young adults to discriminate object size by observing a point-light movie (Johansson 1973) of an actor grasping the object, either from an allocentric or egocentric viewpoint (observing action of others or self). They demonstrated that the discrimination was greater when the action was observed from a viewpoint consistent with the observer performing the action (egocentric view) with respect to when the action was observed from a viewpoint consistent with others performing the action (allocentric view). In addition, when the subjects observed their own previously filmed actions the performance was even better. Several controls demonstrated that the effect was not driven by spatial cues, such as the distance of the fingers at contact time or the maximum grip aperture or the grasping trajectory that could be performed from above or from the side of the object. Interestingly, while size between large and small objects could always be well discriminated, the difference in shape of the objects with the same size was never discriminable, suggesting that shape discrimination requires more fine spatial information than that present in the movies, which is related only to the joint movement. Similar results have been obtained with synthetic hands (Ansuini et al. 2015) showing that it is a general mechanism also operating in

real life. The dynamics of sensorimotor EEG rhythms during the observation of action are different, with a stronger desynchronization in the mu frequency range and a greater desynchronization in the lower alpha band, when the action is observed in the egocentric viewpoint (observing right-handed actions) respect to the allocentric viewpoint (Drew et al. 2015).

Visual perception of motion and the motor system develop at different rates, with motor system development occurring much later. It is possible that the delayed maturation of the motor system might interfere with the ability to understand the action of others in children. Recently Geangu et al. (2015) showed that 6- but not 4-month-old infants were able to discriminate between biomechanically possible and impossible grasps of a hand movement, with a good correlation of anticipatory shifts toward the goal of the possible action. This demonstrates that infants discriminate the goal structure of reaching and grasping action by 6 months. At the same age, high precision and efficient goal-directed reach movements start to develop (Rochat 1989; von Hofsten 1991; Woodward 1998). From birth, infants spend a large amount of time exploring their own and other people’s hands (Vandermeer and Vanderweel 1995), and by toddlerhood the hands are the main focus of attention in exploring self and other’s object-related actions. Despite this early development, the fine-tuning of grasping movements does not reach full maturity before 8–10 years of age (Forssberg 1999; Heineman et al. 2010; Kuhtz-Buschbeck et al. 1998). This partly reflects the immature connections from the motor cortex to the corticospinal projections that increase in density up to 10 years, and partly the fact that the mechanisms integrating grip and load forces do not fully mature until around 10 years of age (Forssberg 1999). On the other hand, biological motion perception develops very quickly, being present in newborns and reaching adult-like sensitivities by 5 years of age (Blake et al. 2003; Hadad et al. 2015; Pavlova et al. 2001). This opens the possibility of posing the question of how strong is the contribution of the immature motor system to the perception of the biological motion.

We aim to study the developmental trajectory for understanding the goal of an action in egocentric and allocentric view, in children from 5 to 16 years of age, the age in which the motor system development lags behind those of the visual system. Following Campanella et al. (2011), we measured the discrimination of the size of the grasped object by observing a biological motion movies, a property that may not follow the development of other biological motion sensitivities. If the motor system provides an important contribution to the discrimination of this task we should observe a progressive improvement in discrimination ability from 5 to 18 years, and a facilitation for the allocentric views, given that internal neural

representation of the object's weight and size (Forssberg 1999) is immature before 10 years of age.

Materials and methods

Subjects

A total of 115 typically developing children and adolescents between the ages of 5 and 18 years were recruited from local nursery, elementary, junior and senior high schools. The sample comprised five age groups: 27 children aged 5–7 years, 20 aged 7–9 years, 23 aged 9–11 years, 27 from 11 to 14 years and 18 from 16–18 years. The sex and age distributions of the sample are shown in Table 1. All subjects showed right-handed dominance and had normal or corrected-to-normal vision. All subjects were native Italian speakers and were naive to the purpose of the experiment. They and their parents gave informed consent to participate in the study. All subjects were attending regular classes for their age, and none was included into programs for students with special needs.

Table 1 Distribution of males and females by age groups

Age groups (years)	Total number	Males	Females
5–7	27	13	14
7–9	20	8	12
9–11	23	10	13
11–14	27	13	14
16–18	18	13	5
Total number	115	57	58

Stimuli

The visual stimuli were made up of point-light biological motion movies representing a hand grasping two different objects that were invisible to the observer. The reach action was performed both from the side and from above the objects. The same movement was presented in the egocentric (observing self-action) and in an allocentric point of view (observing others' actions), as shown in Fig. 1, by rotating the 2D movie by 180°. The biological motion stimuli were imported from our previous experiment (Campanella et al. 2011), where actors were recorded grasping two objects (a cube of side 6.5 cm or a cylinder of 4 cm diameter, 6.5 cm high), with an array of cameras positioned to capture the action in the three-dimensional space, using 23 markers placed on the center of the nails, joints of all digits, the dorsal aspect of the hand and the radial and ulnar styloid process. To change the perspective of the grasping movement, the three-dimensional motion was rotated around the azimuth by 180°. The movie showed both a lateral view and a top view of the hand grasp of the objects.

While the original study used four objects (a sphere and a cube of the same size; a cylinder and a clipped pyramid of the same size), we chose for our test only two objects of different size (cube versus cylinder) to optimized collection of number of trials in children, given that adults were never able to discriminate the shape of size-matched objects by observing the point-light biological motion movies. We used objects that differed mostly in shape (cube versus cylinder), helping implicitly children to classify the objects and minimizing error in verbal reports. However, the instructions were clearly stated: we asked the children to report the size of the objects (small or large). Campanella et al. (2011) performed many controls to demonstrate that the information contained in the maximum grip aperture,

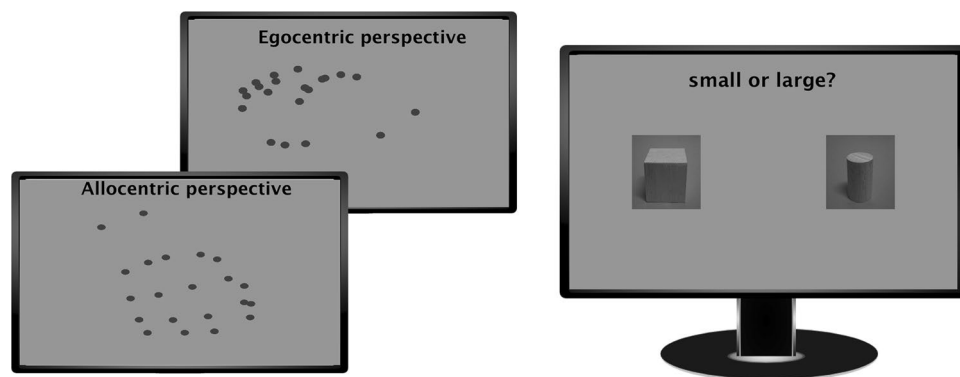


Fig. 1 Examples of stimuli and procedures used in the experiments. Size identification task: biological motion movies representing a hand grasping non-visible objects displayed either from an egocentric (observing self-action, *top* example) or from an allocentric point of

view (observing others' action, *bottom* example). Subjects were asked to indicate whether the goal of the reach-and-grasp movement was towards a small or large object

peak velocity of finger aperture and percentage of time to maximal finger aperture were not used by the observer to discriminate the two large objects (sphere and cube) from the two small objects (clipped pyramid and cylinder).

The motion was always presented in the center of the screen, starting from either the bottom or the top of the display for the egocentric and allocentric perspectives, respectively. The biological motion movie of the schematic hand marked with black dots only were displayed with the MATLAB Psychophysics toolbox (Brainard 1997). The hand subtended about $13 \times 15^\circ$ of visual angle [for other details see the electronic supplementary materials of Campanella et al. (2011)].

General procedures

All visual stimuli were presented in a dimly lit room on a 15.4-inch Acer monitor with 1024×768 resolution at refresh rate of 60 Hz, viewed binocularly from 57 cm. Visual stimuli were displayed for 0.90 ± 0.15 s. After the movie presentation, a response page with the images of the cube and of the cylinder appeared and the subjects were required to indicate by pointing the object that was the goal of the reach-and-grasp movement; the operator inserted the response by clicking with the mouse on the image, in order to minimize finger errors. Each subject performed five training trials before data acquisition. Children in the 5–7-year-age-group were assessed in separate sessions of 25 trials for the egocentric perspective and for the allocentric perspectives. For all other children, the number of trials was increased to 60 per block. No feedback on the single-trial discrimination was given. No time limit was imposed for the response acquisition. The number of trials associated with each object ($p=0.50$) and two perspectives ($p=0.50$) were counter-balanced. The number of trials with movies showing grasping from the side or above were nearly balanced (difference less than 10%). To make sure that the task was clear to the children during the training trials, the operator first mimicked a reach and grasp movement towards a real cube and a real cylinder, stressing the difference in size of the two objects, then asked the subject to perform the same action. Only when the children understood the task did the operator proceed with the collection of data.

Data analysis

Discrimination performance was measured in d' defined as the difference between the means of the signal and the signal plus noise distributions, normalized by the standard deviation of the noise distribution (Green and Swets 1966). d' was calculated as the difference between the z-scores of

the hits and the false alarms which, for a two-alternative forced-choice design, equals 1 for 76% correct responses (threshold value) and of 0 for 50% correct responses (chance level). Differences in developmental rate of size identification performance as a function of age groups, as well as mean group differences between perspectives were tested by repeated measures ANOVA and paired t test. Difference in perspective preferences across age groups were tested with linear regression analysis, and the statistical significance of the slope tested with a bootstrap sign-test (Efron and Tibshirani 1993): for each age group, we calculated the mean discrimination performance using a random sample of the data (sampled with replacement), then computed the slope of a linear regression. The process was reiterated 10,000 times and statistical significance was fixed when the proportion of times the slope was smaller or equal to 1 was less than 0.05. A statistical power analysis was performed to estimate the required sample size to reach statistical significance in the difference between sensitivity in egocentric and allocentric perspectives. The effect size (ES) in Campanella study was $d=1.08$ considered to be extremely large using Cohen's (1988) criteria. For a simple paired-sample t -test with an $\alpha=0.05$ and minimum power=0.80, the predicted sample size is approximately $n=8$. Before data collection in children, we set the required sample equal at least $N=15$, considering an increased noise in children data.

Results

Figure 2a shows the discrimination performance expressed in d' and percent correct (data reported in Table 2) for the two perspectives as a function of age group. Before 8 years, all children performed at chance level for both allocentric ($t_{(26)}=1.08$, $p=0.28$) and egocentric viewpoints ($t_{(26)}=-0.88$, $p=0.38$). Thereafter there was an age-related improvement in size discrimination for both perspectives, reaching a plateau by 16 years of age. This pattern was confirmed with a mixed-design ANOVA on d' , with age group (5–7, 7–9, 9–11, 11–14, 16–18 years) as the between-participant factor and type of perspectives (egocentric and allocentric) as the within-participant factor. As expected there was a significant main effect of age group [$F(4,110)=34.682$, $p<0.0001$, $\eta_p^2=0.55$] with mean d' (averaging the two conditions) increasing with age, (5–7-year-olds: $M=0.001$, $SEM=0.07$; 7–9-year-olds: $M=0.53$, $SEM=0.08$ 9–11-year-olds: $M=0.85$, $SEM=0.08$; 11–14-year-olds: $M=1.07$, $SEM=0.07$; 16–18: $M=1.17$, $SEM=0.09$). The ANOVA revealed also a statistically significant main effect of perspective [$F(1,110)=11.99$, $p=0.001$, $\eta_p^2=$

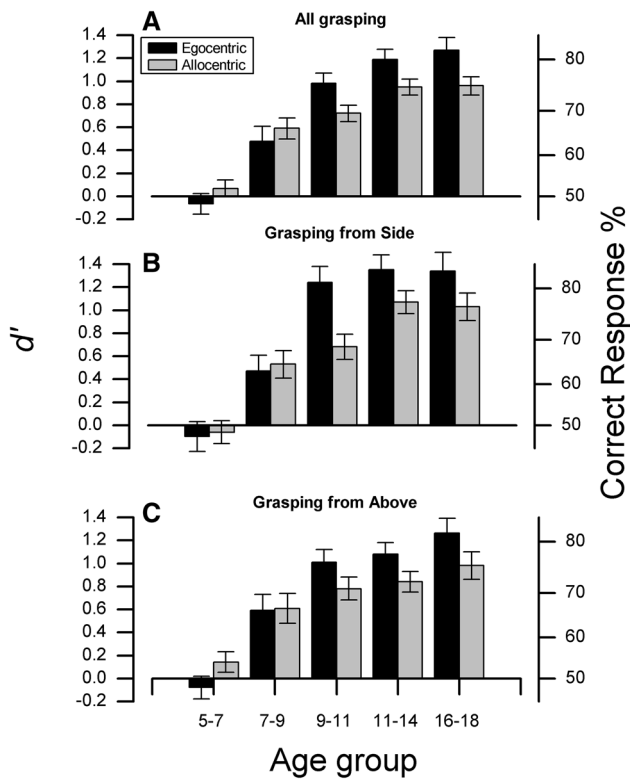


Fig. 2 **a** Mean discrimination performance expressed in d' and percent correct for the egocentric (black) and allocentric (gray) perspectives as function of age group. **b** Mean discrimination performance for the egocentric and allocentric perspectives when the grasping action was performed from the side as function of age group. **c** Mean discrimination performance for the egocentric and allocentric perspectives when the grasping action was performed from the above as function of age group. Error bars represent ± 1 standard error of the mean (SEM)

0.1] and a statistically significant interaction between age group and perspectives [$F(4,110) = 8.69, p < 0.0001, \eta_p^2 = 0.24$]. Interestingly the interaction was not driven by the flooring effect of the youngest age group that had chance performance: it remains significant also when limiting the ANOVA to the subjects groups older than 7 years [$F(3,84) = 6.07, p = 0.001, \eta_p^2 = 0.18$], implying a differential development for the allocentric and egocentric perspective conditions.

Only after 9 years of age did the sensitivity for egocentric perspective become greater than for allocentric perspective. Paired t tests confirmed that the differences in size discrimination between the two perspectives for the younger groups (5–7- and 7–9-year-olds $p > 0.05$) were not statistically different, but for the groups older than 9 years, size discrimination became significantly (Holm–Bonferroni corrected) facilitated for the egocentric point of view (9–11-year-olds $t_{(22)} = 5.35, p < 0.001$; 11–14-year-olds

Table 2 Distribution of correct responses and d' for the two experimental conditions (egocentric and allocentric), and for grasping action performed from the side or from above for the five age groups

Age groups (years)	All grasping				Grasping from side				Grasping from above			
	Egocentric view		Allocentric view		Egocentric view		Allocentric view		Egocentric view		Allocentric view	
	% Correct	d'	% Correct	d'	% Correct	d'	% Correct	d'	% Correct	d'	% Correct	d'
5–7	48.14 \pm 2.04	-0.06 \pm 0.09	51.85 \pm 1.72	0.06 \pm 0.06	48.37 \pm 2.68	-0.1 \pm 0.13	48.29 \pm 2.53	-0.06 \pm 0.10	48.00 \pm 2.42	-0.08 \pm 0.10	53.70 \pm 2.47	0.14 \pm 0.09
7–9	62.92 \pm 2.76	0.48 \pm 0.10	66.11 \pm 2.06	0.58 \pm 0.08	59.00 \pm 2.96	0.47 \pm 0.11	62.40 \pm 3.02	0.53 \pm 0.16	65.15 \pm 3.35	0.59 \pm 0.13	66.20 \pm 2.41	0.61 \pm 0.09
9–11	74.80 \pm 1.72	0.98 \pm 0.09	68.82 \pm 1.80	0.72 \pm 0.07	76.13 \pm 2.51	1.24 \pm 0.14	67.82 \pm 2.44	0.68 \pm 0.11	75.26 \pm 2.12	1.01 \pm 0.11	69.60 \pm 2.92	0.78 \pm 0.10
11–14	78.06 \pm 1.85	1.19 \pm 0.09	73.66 \pm 1.86	0.95 \pm 0.08	80.03 \pm 2.09	1.35 \pm 0.13	75.92 \pm 2.24	1.07 \pm 0.10	75.40 \pm 2.28	1.08 \pm 0.10	71.07 \pm 2.62	0.84 \pm 0.09
16–18	80.40 \pm 1.91	1.27 \pm 0.11	74.77 \pm 1.57	0.96 \pm 0.07	82.00 \pm 2.77	1.34 \pm 0.16	75.11 \pm 2.33	1.03 \pm 0.12	79.72 \pm 2.23	1.26 \pm 0.13	74.94 \pm 1.75	0.98 \pm 0.12
Total	68.12 \pm 1.47	0.74 \pm 0.06	66.43 \pm 1.14	0.63 \pm 0.04	68.59 \pm 1.77	0.83 \pm 0.08	65.32 \pm 1.48	0.62 \pm 0.06	67.85 \pm 1.56	0.74 \pm 0.07	66.46 \pm 1.29	0.65 \pm 0.05

$t_{(26)}=3.07$ $p=0.004$; 16–18-year-olds $t_{(17)}=3.48$ $p=0.003$).

Figure 2b, c show the discrimination performance expressed in d' and percent correct (data also in Table 2) for the two perspectives, respectively when the grasping action was performed from the side (B) and from above (C), as a function of age group. For grasping action from the side, ANOVA revealed a significant main effect of age group [$F(4,110)=37.13$, $p<0.0001$, $\eta_p^2=0.53$] and a statistically significant main effect of perspective [$F(1,110)=6.68$, $p=0.01$, $\eta_p^2=0.06$], but no significant interaction between perspectives and age group [$F(1,110)=2.063$ $p=0.09$, $\eta_p^2=0.07$]. Similarly, for the grasping action from above, ANOVA revealed a significant main effect of age group [$F(4,110)=20.87$, $p<0.0001$, $\eta_p^2=0.43$] a significant interaction between perspectives and age group [$F(1,110)=4.22$, $p=0.003$, $\eta_p^2=0.13$], and a slightly significant main effect of perspective [$F(1,110)=4.08$, $p=0.046$, $\eta_p^2=0.03$]. The similar pattern of results for the two grasping actions suggests that the developmental trajectory and the perspective effects are general and do not depend on the type of reaching movement. Grasping from the side is more comfortable for the smaller object, while grasping from above is more comfortable for the larger object. Consistently, we observed a small response bias for the two types of grasping (by side 12% ± 3.88 and by above 8.2% ± 2.79 of response small). Note that the discrimination (d') was not affected by the shift in criteria or bias, which allows us to perform separate analysis for the two grasping.

To investigate further the difference in size discrimination between the grasping configurations, we performed a mixed-design ANOVA on d' with age group as the

between-participant factor and grasping configuration (Side and Above) as the within-participants factor. We found a significant main effect of age group [$F(4,110)=33.79$, $p<0.0001$, $\eta_p^2=0.55$] with mean d' increasing with age.

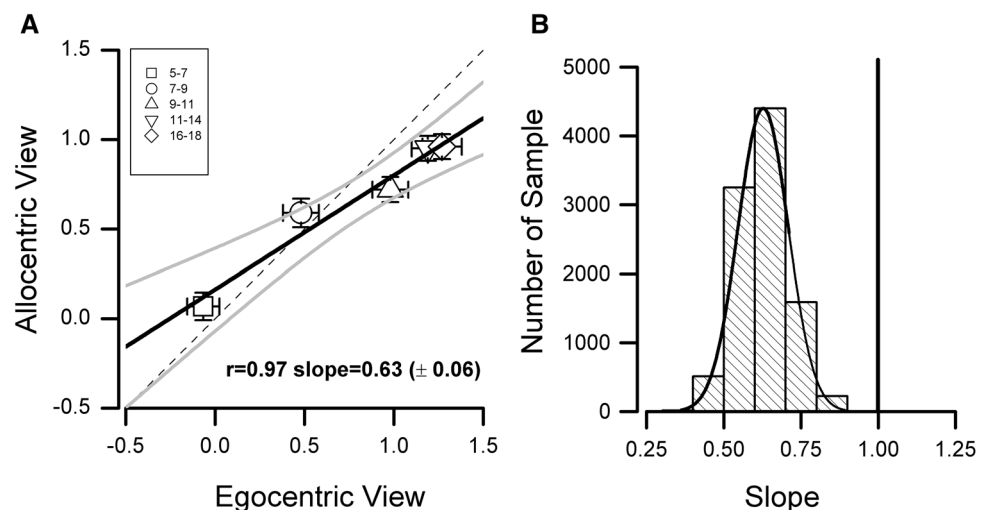
The ANOVA revealed neither a statistically significant main effect of grasping configuration [$F(1,110)=0.13$, $p=0.71$, $\eta_p^2=0.001$] nor a statistically significant interaction [$F(4,110)=2.29$, $p=0.06$, $\eta_p^2=0.07$].

We compared directly the size identification performance (d') in egocentric and allocentric perspective for the different age groups in Fig. 3a. The points of the older subjects lay below the equality line, indicating a preference for the egocentric view. The best linear fit of the data has [$R^2=0.95$, $F(1,3)=70.17$, $p=0.003$] a slope of 0.63 (± 0.06) and an intercept of 0.16 (± 0.06). Figure 3b shows the distribution of the fitted slopes after bootstrapping the data with 1000 iterations (see “Data Analysis”). The slope has a high probability assuming a value less than 1 ($p<0.0001$). Figure 3a reinforces the results of the ANOVA showing that size discrimination in egocentric and allocentric view point develops at different rates, and reach adult-like difference in sensitivity by 18 years of age (Campanella et al. 2011).

Discussion

This study is the first, to our knowledge, to examine the ability of recognizing object size by observing grasping kinematics towards the object-goal in children and adolescents. Children younger than 7 years of age were unable to do the task. We did not measure biological motion discrimination, but previous data show that this already mature at this age, with a similar sensitivity to that of adults (Blake

Fig. 3 **a** Mean d' in allocentric perspective as function of mean d' in egocentric perspective across all age groups and grasping configuration. *Black solid line* represents the best-fitting linear curve ($y=0.16+0.63x$, $R^2=0.95$). **b** Bootstrapped distribution (10,000 iterations) of the slope coefficient, clearly less than one



et al. 2003; Pavlova et al. 2001; Sweeny et al. 2013; Zhao et al. 2014). For this reason we believe that it is unlikely that our findings reflect immaturity purely visual motion mechanisms or an immaturity of the attentional allocation to the biological motion. More likely, the impaired performance could reflect an impaired understanding of the goal of the action.

The first important result of this study is the progressive maturation with age, both in the egocentric and allocentric perspectives. At 18 years of age, the performance was slightly less than that measured by Campanella et al. (2011) in a 24 year-old group that used a more sensitive measure based on 4 multiple choices. The maturation with age is gradual and overall similar for the allocentric and egocentric perspectives and only late in adolescence the preference for egocentric viewpoint becomes predominant.

Campanella et al. (2011) used four different object shapes with two different sizes of the object section to be grasped. The results show that the shape of size-matched objects could never be discriminated from observation of the point-light movies, to be expected given that only the joint movements were represented in the movies. Importantly, however, size discrimination was always well above discrimination threshold. The previous work also dismissed several other possible confounds that could help the discrimination, like the spatial configuration of the fingertips at contact point or at maximum grip aperture. The strongest evidence that spatial configuration is not important for the discrimination was obtained by using movies played backwards (consistent with a release of grip), for which discrimination was at chance level (Campanella et al. 2011).

To optimize efficient data collection in children, we reduced the number of objects to only two: a large cube and a small cylinder. We chose the objects that were most distinctive, to reduce the cognitive complexity of the task. We also gave clear instructions to the children, and mimicked the action with real objects. Nevertheless, we cannot completely dismiss the possibility that the youngest subjects did not understand the task, explaining their chance performance levels. Interestingly, even in this youngest group, the performance bias was present for the grasping trajectory from the side or from above, reinforcing the idea that their judgment was not based on fingertip spatial configuration, but probably genuinely linked to a delayed development of this ability. Excluding this youngest age group does not change the pattern of the results, with the 7–9-year-old children performing above threshold, indicating that they clearly understood the task. Despite the large sample size ($N=20$), the 7–9-year-old group has equal sensitivity for the movies in the two perspectives, reinforcing the idea that the emergence of the effect is slow, reaching maturity only after 16 years of age. This strongly suggests that recognition of the affordance (size) of the object is not “innate”,

but improves with experience and learning of the visual and motor systems. Its acquisition proceeds well after the visual motion brain has attained adult-like sensitivity to biological motion (Blake et al. 2003; Pavlova et al. 2001). It would be of great interest, in the future, to study subjects with motor disability, particularly for the upper limbs, to test more directly whether the impairment of the motor planning system correlates with an impairment of the understanding of the action goal, strengthening the postulated causal relation between the two functions.

The motor cortex and its corticospinal projections are essential for the control of skilled hand movements (Forssberg 1999; Heinen et al. 1998; Kuhtz-Buschbeck et al. 1998). In non-human primates, corticospinal axons invade the spinal cord very early during development, and establish functional contacts with distal hand motor units mediating the early development of the precision grip (Armand et al. 1997; Olivier et al. 1997). In humans, the pattern of development is quite different. Direct cortico-motor projections develop in the first months of postnatal life and mediate voluntary independent finger movements (Armand et al. 1997; Forssberg 1999). Thereafter, corticospinal projections become fine-tuned, with the pruning of the majority of ipsilateral connections completed by the age of 24 months (Eyre 2003). However, at 10 years of age, children commonly exhibit symmetrical associative movements—the so-called mirror movements—probably related to the simultaneous activation of crossed corticospinal pathways. Later these connections become less prominent in driving the response, supposedly because of the inhibition action of the transcallosal projection and, at the same age and with the same trajectory (Heinen et al. 1998; Mayston et al. 1999), fine-movement control becomes more precise. At 10 years of age, the maturation of the synergy between coupling grip and load forces (Forssberg 1999) also start to develop.

Grasp control shifts with age from mainly a feedback control system (i.e. multi-segmented force increase) to an anticipatory strategy with uni-modal force rate trajectories targeted to an object’s weight and size (Forssberg 1999). The parametric control (i.e. control setting the parameters of pre-structured motor commands) develops gradually up to 8–10 years of age, and is thought to be limited by the immature internal neural representations of the object’s physical properties. This view is consistent with the present data. Young children could not perform the task, either because their internal representation of the visual object by memory was still immature, or because the understanding of the action goal was lacking. Interestingly visual size as well as haptic size discrimination (Gori et al. 2008) are immature up to the age of 10, suggesting that it is the internal representation of object size that limits the performance in children younger than

10 years. The performance in our children nearly doubled between 10 and 18 years, while in this age range visual and haptic sensitivity of size discrimination is mature as well as biological motion perception. This suggests a specific immaturity of the influence of the motor system on the perceptual judgments. Interestingly at this age range, we can demonstrate an advantage for the egocentric view, giving further support to this idea. Our data are also consistent with the recent study from Biagi et al. (2015) showing the fMRI responses of areas of the AON/MNS in children in this age span are immature compared with adults, particularly for complex grasping actions. They observed widespread activation of cortical regions compared to adults, and a progressive increase of the lateralization as a function of age. Both pieces of evidence clearly indicate that the anatomical structures mediating action representations change noticeably during adolescence, in coincidence with the emergence of the facilitation for the egocentric perspective observed here.

Allocentric and egocentric points of view activate different cerebral areas and circuitry, which may mature in different ways. During a motor imagery task different cerebral areas are activated when the subject imagines him or herself manipulating an object (1PP) or when he/she imagines the experimenter manipulating the respective object (3PP) (Ruby and Decety 2001). In the first case, only regions in the left hemisphere were activated, including the inferior parietal lobe, precentral gyrus, superior frontal gyrus, temporal-occipital junction, anterior insula and ipsilateral cerebellum. During imagination of third person object manipulation, the right hemisphere was activated, namely the inferior parietal cortex, precuneus, posterior cingulate and frontopolar cortex. We can hypothesize an advanced maturation of the cortical areas mediating the allocentric point of view, given the importance in real life imitating the actions of others for social learning, and for the acquisition of new knowledge. However, in concomitance with the acquisition of precision motor skills and the enrichment of motor repertoires, the preference between viewpoints shifts, demonstrating an influence in everyday life visual judgments of internal reverberation and the influence of motor planning and commands on perception.

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