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The format of children's mental images: Penetrability of spatial images

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Abstract

To investigate the format of mental images and the penetrability of mental imagery

performance to top-down influences in the form of gravity information, children (4-, 6-, 8-

and 10-year-olds) and adults ($N = 112$) performed mental rotation tasks. A linear increase in

response time with rotation angle emerged at 6-years, suggesting that spatial properties are

represented in children's mental images. Moreover, 6-, 8-, and 10-year-olds, but not 4-year-

olds or adults, took longer to respond to rotated stimuli pairs when gravity information was

incongruent with the direction of rotation rather than congruent. Overall, findings suggest that

in contrast to adults', 6- to 10-year-olds' mental rotation performance was penetrated by top-

down information. This research a) provides insight into the format of young children's

mental images and b) shows that children's mental ~~imagery~~ rotation performance is

penetrable by top-down influences.

Keywords: mental imagery; mental rotation; imagery format; visuo-spatial processes

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Research with adults in mental imagery over the last 30 years has revealed that our images are depictive representations that preserve metric qualities such as space and distance (e.g., Kosslyn, Ganis, & Thompson, 2003).

Support for this depictive account comes from mental rotation tasks, whereby participants judge whether pairs of objects are the same or mirror images of one another when one of the pair is rotated to different degrees. A key finding is that response times increase linearly with increasing difference in rotation angle between objects (Shepard & Metzler, 1971). Such findings demonstrate that mental images incorporate the spatial information present in the original object; whole patterns are mentally rotated until aligned in orientation of the other object, and patterns possess a structure similar to representations that arise from perception (Kosslyn et al., 2003). This linear increase in rotation time with angle is already evident in 5-and 6-year-old children (Estes, 1998; Frick, Daum, Walser, & Mast, 2009; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Marmor, 1975), indicating a depictive format of children's mental images.

However, it has also been shown that mental images are susceptible to top-down influences, and are thus *cognitively penetrable*: visual perceptual and mental experiences can vary as a function of participants' beliefs, expectations, and knowledge (Pylyshyn, 2002; Kosslyn et al., 2003). In visual perception, adults and children are more likely to perceive alternative interpretations of ambiguous figures when they have knowledge of ambiguity (Doherty & Wimmer, 2005; Gregory, 2009; Wimmer & Doherty, 2011). Similarly, in mental imagery adults can reverse between alternative interpretations of ambiguous figures when cues are provided (Mast & Kosslyn, 2002; Peterson, Kihlstrom, Rose, & Glisky, 1992). Thus, evidence shows that adults' mental images are depictive in format (Kosslyn et al., 2003) but also cognitively penetrable by top-down information (Mast & Kosslyn, 2002; Peterson, et al., 1992). However a fundamental question remains whether the mental depiction of visual

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information can be penetrated by top-down knowledge in children. Surprisingly little is

known about conceptual penetrability of children's mental imagery, and of mental rotation

processes in particular.

        To date, there is evidence of penetrability of mental rotation processes by motor

processes in children and adults. Specifically, both children and adults take longer to

mentally rotate kinetic stimuli when they are~~that when they~~ incongruent~~in~~

~~interference~~~~incongruent~~ with motoric components ((such as ~~incongruent~~ hand movements))

compared to when they are~~compared to when they are~~ ~~versus~~ congruent ~~ones~~ (Funk, Brugger,

& Wilkening, 2005; Ionta, Fourkas, Fiorio, & Aglioti, 2007; Parsons, 1994). ~~Specifically~~T,

hese types of mental rotation processes become increasingly differentiated from motor

processes with increasing age (Frick et al., 2009; Funk, ~~Brugger, & Wilkening~~et al., 2005). In

contrast to 11-year-olds and adults, 5- and 8-year-olds are faster at responding to rotated

stimuli when a manual rotation of their hands is in line with the stimulus rotation direction,

rather than in reverse (Frick et al., 2009; Funk et al., 2005). ~~These~~Thus, findings indicate that

young children's ~~but not adults'~~kinetic mental rotation processes are guided to a larger extent

by motor processes than adults (see~~ ~~ Kosslyn, Ganis, & Thompson, 2001; Kosslyn,

Digirolamo, Thompson, & Alpert, 1998 for neuroimaging evidence supporting the role of

motor processes in kinetic rotation in adults). Together with findings that children's visual

perceptual processes are penetrated by top-down influences (Wimmer & Doherty, 2011), one

would predict that children's mental rotation processes may also be influenced by top-down

processes and possibly to a larger extent than adults' (Funk et al., 2005).

        The aim of the present research was two-fold. First, to examine further whether young

children's mental images are depictive in nature, we assessed whether children show the

typical linear increase in mental rotation response times with angle. This provides insight into

the format of their images. Second, we asked whether children's and adults' mental ~~imagery~~

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rotation performance is penetrable by top-down information. If children preserve spatial

properties in their mental images and their rotation is influenced by top-down factors then

this suggests that children's mental images are pictorial in nature and that performance can be

penetrated by conceptual factors. Further, if the differentiation of mental rotation processes

from motor processes previously reported (Frick et al., 2009; Funk et al., 2005) reflects

development of imagery processes *per se*, then one would also predict less top-down

influence on mental rotation processes with increasing age.

To manipulate top-down conceptual information, we used stimuli of a monkey

standing on a table with one leg that was shorter than the other, suggesting that table and

monkey would fall in the direction towards the shorter leg. This was either congruent or

incongruent with the direction of the rotated stimulus. Using this top-down information

required basic knowledge of gravity. Previous work has shown that 4-year-olds are around

90% and 60% correct at judging from photographs whether an abstract symmetrical/

asymmetrical (respectively) object would fall off a partially supporting block (Krist, 2010);

that children as young as 3 years of age are sensitive to gravity (Kim & Spelke, 1999); and

41/2-months-olds have "intuition" about physical support (Needham & Baillargeon, 1993).

Thus, the present task should pose no difficulties in conceptual understanding for 4-year-olds.

Nevertheless, we checked children's understanding at the end of the task.

If children's mental images are pictorial in nature, then they should demonstrate a

linear increase in response times with increasing rotation angles. If children's and adults'

mental images are penetrated by top-down conceptual information about gravity then they

should be faster in the congruent trials (table falling in the same direction as the rotated

monkey) than in incongruent trials (table falling in the opposite direction).

Method

Participants

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Overall 112 participants participated. Eighty-eight were children [17 4-year-olds (M = 4.46 years, range = 4.05-5.03; 13 male, 4 female), 31 6-year-olds (M = 6.38 years, range = 6.04-7.05; 19 male, 12 female), 16 8-year-olds (M = 8.32 years, range = 8.05-9.04; 9 male, 7 female), 24 10-year-olds (M = 10.39 years, range = 10.00-11.05; 10 male, 14 female)]; 24 were adults (M = 21.46 years, range = 18-46; 4 male, 20 female). Children were recruited from two primary schools and predominately White, middle class. Adults were students recruited from the university's online participation system and participated for course credit.

Materials and procedure

Participants were seen in a quiet area outside the classroom (children) or at the university laboratory (adults). Tasks were computerized and presented on a 17.3 inch laptop PC running with the program Visual Basic that recorded the two dependent measures: (i) correctness and (ii) time taken to respond (reaction time from stimulus onset to button press).

The images used throughout were taken from the monkey pairs from Estes (1998) which were adapted by adding extra stimuli. Participants' task was to judge whether two monkeys appearing next to each other held up the same or different arms. The monkey on the left hand side was always upright and stood on a table with one leg cut off (see Figure 1). There were two different table versions: Either the monkey looked likely to fall to the right (congruent: towards the rotated monkey on the right hand side) or the monkey looked likely to fall to the left (incongruent: away from the rotated monkey on the right hand side). The monkey on the right hand side was shown in 7 different rotation angles, from 0° to 180° at 30° increments. Both stimuli remained in view, so no memory assessment or control condition was required.

(Figure 1 about here)

There were 56 stimulus pairs: Half of them were "same" pairs (right arm-right arm/left arm-left arm) and half were "different" pairs (right arm-left arm/left arm-right arm).

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Half of the pairs appeared in a congruent fashion (monkey standing on a table that looked as if it would fall towards the direction of the rotated monkey) and half in an incongruent fashion (monkey standing on a table that looked as if it would fall away from the direction of the rotated monkey).

Children were shown half the stimuli (28) to ensure concentration throughout the experiment. Children saw one "congruent same" (either right-right arm or left-left arm), one "incongruent same" (either right-right or left-left), one "congruent different" (either right-left or left-right) and one "incongruent different" pair (either right-left or left-right), each in seven rotation angles ($0°$-$180°$). Adults were shown all 56 stimuli, for example, both "incongruent same" right-right and left-left, and so forth.

The task was to judge whether monkeys held up the same or different arms. Participants received four practice trials, containing first one "same" and one "different" monkey-pair (without the table) at $0°$ and then one "same" and one "different" pair at $30°$. Practice was repeated if participants did not understand the task or answered more than one trial incorrectly. After a maximum of two repetitions all participants answered all practice trials correctly. In the test trials adults pressed the 'S' for same and 'D' for different keys, indicating whether the monkeys held up the same or different arms. Children either said "same" or "different" and the naïve experimenter was instructed to look at the children and pressed the appropriate response button for them. This minimised working memory demands and avoided the known risk of interference between button presses and imagery processes (Kail, 1988; 1991).

After the test trials, children were asked in which direction the monkey on the table would fall. Only one 4-year-old answered incorrectly that the monkey on the table would fall in the direction of the longer leg. He was excluded from the analysis of the direction of the fall.

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Results

Table 1 shows mean accuracy and response times for each direction condition
(congruent vs. incongruent). Figure 2 shows mean response times on trials with accurate
responses for each rotation angle and direction condition across age groups. Bonferroni
confidence interval adjustments and post-hoc analysis were used throughout.

Accuracy

The effects of age group (4-, vs. 6-, vs. 8-, vs., 10-, vs. adults), rotation angle (0 vs. 30
vs. 60 vs. 90 vs. 120 vs. 150 vs. 180), and direction condition (congruent vs. incongruent) on
mean accuracy (range 0 to 1 fully accurate) were examined in a mixed ANOVA where age
group was the between participants variable. Accuracy increased with age, $F(4, 107) = 20.03$,
$p < .001$, $\eta p^2 = .43$. Four-year-olds ($M = .68$) were less accurate than all older age groups (all
$ps < .01$). Six- year-olds ($M = .82$) were also less accurate than all older age groups (all $ps <
.02$). There was no difference in accuracy between 8-year-olds ($M = .92$), 10-year-olds ($M =
.97$) and adults ($M = .96$), all $ps > .15$. Overall, accuracy decreased with increasing rotation
angle, $F(6, 642) = 9.32$, $p < .001$, $\eta p^2 = .08$. Moreover, there was an age group x angle
interaction, $F(24, 642) = 4.06$, $p < .001$, $\eta p^2 = .13$. Post-hoc analyses revealed that only 4-
year-olds showed a significant diminution in accuracy with increasing angle ($p < .001$). All
older age groups did not show a significant decrease in accuracy with increasing angle (all $ps
> .05$).

For congruency of the fall, participants were equally accurate whether the direction of
potential fall was congruent or incongruent with the direction of rotation, $F(1, 642) = .51$, $p =
.48$, $\eta p^2 = .01$, and this was the case for all age groups as indicated by the non-significant
interaction, $F(4, 642) = 1.07$, $p = .37$, $\eta p^2 = .04$ (Table 1). Furthermore, there was no rotation
direction x angle interaction, $F(6, 642) = 1.18$, $p = .31$, $\eta p^2 = .01$.

(Table 1 about here)

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Response times

To examine the effects of age, angle, and direction of fall on response times, only participants who performed significantly above chance ($p < .05$) were included (at least 19 out of 28 trials correct for child participants; at least 35 correct out of 56 trials for adult participants) (Binomial-test). In total 95 out of 112 participants met this criterion (8 out of 17 4-year-olds, 25 out of 31 6-year-olds, 14 out of 16 8-year-olds, all 10-year-olds and adults). However, the same findings emerged when all participants were included, and above chance performance was observed for each of the ages as an overall group (all $ps < .001$).

Outlier trials for each age group, those greater than twice the median response time per angle, were excluded (4-year-olds: 6.7% of all trials, 6-year-ols: 4.5%; 8-year-olds: 3.3%; 10-year-olds: 2.9%, adults: 1.5%).

0˚ Trials. To examine the stimulus encoding and comparison time between direction condition (congruent versus incongruent) and across age groups when stimuli were unrotated, mean response times of correctly solved 0˚ trials were submitted to a mixed Linear Model based on maximum likelihood method.

Mean response times decreased with increasing age, $F(4, 175) = 60.15$, $p < .001$. Adults' ($M = 117$ms) encoding and comparison time was faster ($p < .001$) than all child age groups (10-year-olds: $M = 2018$ms; 8-year-olds: $M = 2698$ms; 6-year-olds: $M = 3064$ms; 4-year-olds: $M = 2984$). Ten-year-olds were also faster than all younger age groups ($p < .001$), and 8-year-olds were faster than 6-year-ols ($p < .05$) but did not differ from 4-year-olds ($p = .18$). The youngest two age groups did not differ ($p = .68$). Further, participants responded more quickly in congruent trials (when the stimulus on the table appeared falling towards the comparison stimulus) ($M = 2184$ms) than in incongruent trials ($M = 2589$ms), $F(1, 175) = 14.24$, $p < .001$. However, this effect was due to 6- and 8-year-olds who took longer to respond on incongruent 0˚ trials ($p < .001$) whereas the remaining age groups showed no

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difference in response times on congruent and incongruent 0˚ trials (all ps > .18), shown by

the age group x direction interaction, $F(4, 175) = 6.17$, $p < .001$ (Figure 2).

Congruent versus incongruent response times. The effects of age group (4-, vs. 6-,

vs. 8-, vs., 10-, vs. adults), angle (30 vs. 60 vs. 90 vs. 120 vs. 150 vs. 180), and direction

(congruent vs. incongruent) on mean response times of trials solved correctly, were examined

in a Linear Mixed Model based on maximum likelihood method. For a results overview see

Figure 2.

(Figure 2 about here)

Response times decreased with increasing age, $F(4, 1049) = 221.047$, $p < .001$.

Decreases occurred between all adjacent age groups (all ps < .001) (adults: $M = 1630$ms; 10-

year-olds: $M = 2244$ms; 8-year-olds: $M = 2287$ms) except between 6- ($M = 3256$ms) and 4-

year-olds ($M = 3270$ms) who did not differ ($p = .87$). Additionally, response times increased

with increasing rotation angle, $F(5, 1049) = 9.34$, $p < .001$. Response times differed between

all rotation angle pairs (all ps < .01) except between 30˚-90˚, and 120˚-180˚ (ps > .06).

These main effects were qualified by an age x angle interaction, $F(20, 1049) = 2.65$, p

< .001. To interpret this interaction, we examined which ages showed a linear increase in

response times of accurate trials with increasing angles. The best-fitting linear function was

calculated by the method-of-least-squares within each age group separately for participants

who performed significantly above chance. Response times increased linearly with increasing

angle for most age groups: 6-year-olds, $R^2 = .03$, $F(1, 284) = 9.47$, $p = .002$; 10-year-olds, R^2

$= .06$, $F(1, 285) = 16.50$, $p < .001$; and adults, $R^2 = .63$, $F(1, 286) = 184.17$, $p < .001$. Both, 4-

year-olds and 8-year-olds, however, did not show a significant linear increase in response

times with angle: $R^2 = .02$, $F(1, 89) = .1.72$, $p = .19$; $R^2 = .01$, $F(1, 160) = .02$, $p = .89$,

respectively. The lack of linear increase in 8-year-olds is hard to explain but closer inspection

of Figure 2 reveals large variation of response times on individual stimulus orientations.

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Moreover, response times were longer in incongruent directions (when the table potentially fell away from the direction of rotation of the monkey) (M = 2707ms) compared with congruent ones (M = 2487ms), $F(1, 1049) = 21.35$, $p < .001$. However, this was not the case for all age groups: the age group x fall direction interaction was significant, $F(4, 1049) = 4.75$, $p < .001$. Neither 4-year-olds' nor adults' response times differed for fall direction ($ps > .79$). In contrast, all intermediate age groups, 6-, 8-, and 10-year-olds, took longer to respond on incongruent than on congruent trials (all $ps < .04$) (Table 1). There were no further interactions.

Discussion

The current aim was to provide novel insights into the conceptual penetrability of children's mental rotation processes. Two main findings emerged. First, 6-year-old children's but not 4-year-olds' response times for rotated stimuli increased linearly with increasing rotation angle, consistent with previous mental rotation research (Estes, 1998; Frick, Ferrera, & Newcombe, 2013; Frick, et al., 2009; Funk et al., 2005; Kosslyn et al., 1990; Marmor, 1975). This suggests that mental images are quasi-pictorial in format at age 6: children preserve spatial relations in their mental images. Four-year-old children did not show this effect, however fewer than half the children this age group performed above chance. Thus, 4-year-olds might have been guessing and not, in fact, mentally rotating. The drop in accuracy with increasing rotation angle supports this supposition and indicates that the task was too difficult for them. Moreover, the remaining sample, once those who performed below chance were excluded, left only eight 4-year-old children the analysis; even if these children mentally rotated the sample may have lacked power to detect an effect. Although the majority of 8-year-olds performed above chance (14 out of 16), they also did not reveal a linear increase in response times with rotation angle. However, closer inspection of Figure 2 reveals

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great variation of response times at different angles and this age group also had a small sample size ($N = 14$). Thus the sample may have suffered from low power.

The second novel key finding is that 6-, 8-, and 10-year-olds took longer to rotate stimuli when the direction of rotation of the monkey on the right hand side was incongruent with the potential direction of fall of the monkey on the left hand side. Thus, between 6 and 10 years of age children's mental ~~imagery~~ rotation performance varied with conceptual information concerning the effect of gravity on the monkey on the left. In contrast, adults' response times of rotated stimuli did not differ with the congruency of the potential direction of fall, suggesting no effects of conceptual penetrability on mental rotation.

This pattern of conceptual penetrability is in line with previous research on interference of motor processes on mental rotation (Frick et al., 2009; Funk et al., 2005). Taken together, the findings suggest that mental and motor processes become increasingly differentiated with increasing age. In line with this notion, current findings indicate that 6- ~~to~~ and 10-year-olds,' but not adults,' mental rotation processes are cognitively penetrable. With increasing age, mental rotation processes not only become increasingly differentiated from motor processes (Frick et al., 2009; Funk et al., 2005) but also from top-down processes (current findings). This raises the possibility that mental ~~imagery~~ rotation performance in childhood is supported both by sensorimotor processes and by conceptual processes. However, it should be noted that the current findings examined kinetic mental rotation.~~;~~ Further research should investigate whether this also extends to visuo-spatial rotation of objects (see e.g., Kosslyn et al., 1998). Moreover, including a more balanced gender adult sample might be preferable since there are well documented advantages for males in mental rotation tasks (Collins & Kimura, 1997; Palermo, Iaria, & Guariglia, 2008; Voyer, Voyer, & Bryden, 1995) that may also elicit differences in cognitive penetrability.

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However, tThe question further arises whether findings reflect top-down influences on mental imagery rotation performance, or could be explained by bottom-up sensorimotor representations, that is, *representational momentum* (Freyd & Finke, 1984). The typical effect is that the anticipation of a moving stimulus' end position is exaggerated in direction of the stimuli's anticipated motion (Freyd & Finke, 1984). Representational momentum for moving stimuli is already present in 2-year-olds (Perry, Smith, & Hockema, 2008), and the effect is larger in 5-8-year-olds than in adults (Hubbard, Matzenbacher, & Davis, 1999). For static stimuli the effect of representational momentum is equally pronounced in 8-, 10-year-olds and adults (e.g., remembering a photograph of someone walking as further along) (Futterweit & Beilin, 1994). Given that the current findings revealed less of an effect in adults and differences between 10-year-olds and adults, the current data do not fit well with a representational momentum explanation.

However, the finding that 6- and 8-year-olds showed different response times for congruent and incongruent trials under no rotation raises the possibility that their congruency effects for rotated stimuli were a result of decreased attention in incongruent trials away from the comparison stimulus, rather than reflecting top-down influences on mental rotation. If so then we would expect lower accuracy in these trials, which was not the case. Rather, findings suggest that at age 6 children's mental images are depictive, as shown by their linear increase in response times with increasing angle, and their imagery mental rotation performance is influenced by conceptual factors. Overall, this indicates an early reliance on the perceptual properties of images, with children spontaneously utilising conceptual information to guide their mental imagery. This finding adds to earlier work by Estes (1998), who reported that by age 6, children were similar to adults in demonstrating conscious awareness of the process of imaging the rotation path of a visual image. Four-year-olds, by contrast, were poorer at describing the mental process of rotation, thus indicating less metacognitive awareness in the

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process of mental rotation. An insight into one's own mental states may be necessary in order

for mental imagery performance to be conceptually penetrated.

In sum, children's mental ~~imagery~~ <u>rotation</u> performance can be penetrated by top-

down knowledge and this effect decreases with age. The developmental approach taken here

provides novel insights into the emergence of the effects of top-down knowledge on ~~imagery~~

<u>mental rotation</u> performance and the depictive nature of mental images.

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Table 1.

Mean accuracy and response times (ms) of accurate trials from participants who performed

significantly ($p < .05$) above chance (standard deviation in parenthesis) as a function of

rotation direction (excluding 0˚).

|		4-year-olds	6-year-olds	8-year-olds	10-year-olds	Adults
Congruent	Accuracy	.71	.81	.91	.97	.96
		(.16)	(.20)	(.20)	(.05)	(.06)
	Response	3238	3095	2303	2169	1622
	Times	(667)	(952)	(496)	(618)	(511)
Incongruent	Accuracy	.66	.83	.91	.97	.95
		(.14)	(.16)	(.14)	(.05)	(.05)
	Response	3283	3418	2874	2319	1634
	Times	(889)	(1040)	(937)	(597)	(566)

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Figure Captions

Figure 1. Stimuli pairs examples (from top left clockwise): Incongruent direction, both

monkeys hold their left arms up, the monkey on the right is rotated 30˚: Incongruent-

Left-Left_30, Congruent-Left-Left_30, Incongruent-Left-Right_30, Congruent-Left

Right_30

Figure 2. Mean response times and standard errors as a function of rotation angle, fall

direction (congruent vs. incongruent) and age group.
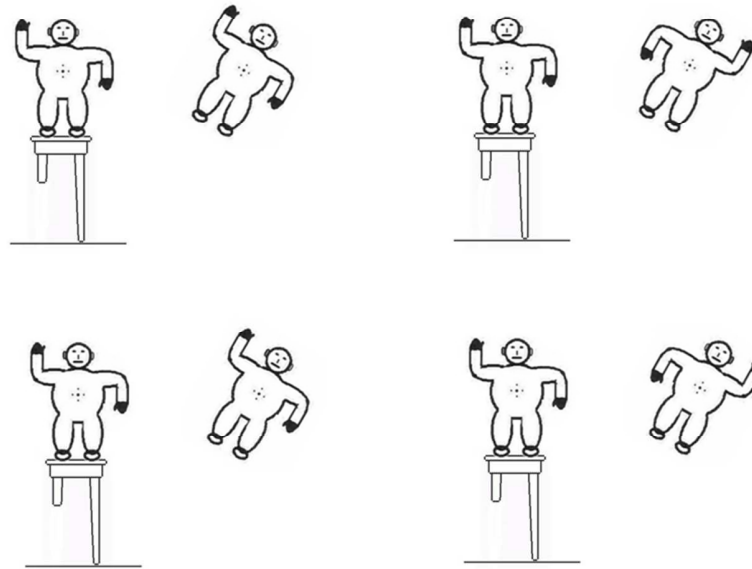
Figure 1. Stimuli pairs examples (from top left clockwise): Incongruent direction, both monkeys hold their left arms up, the monkey on the right is rotated 30˚: Incongruent-Left-Left_30, Congruent-Left-Left_30, Incongruent-Left-Right_30, Congruent-Left Right_30
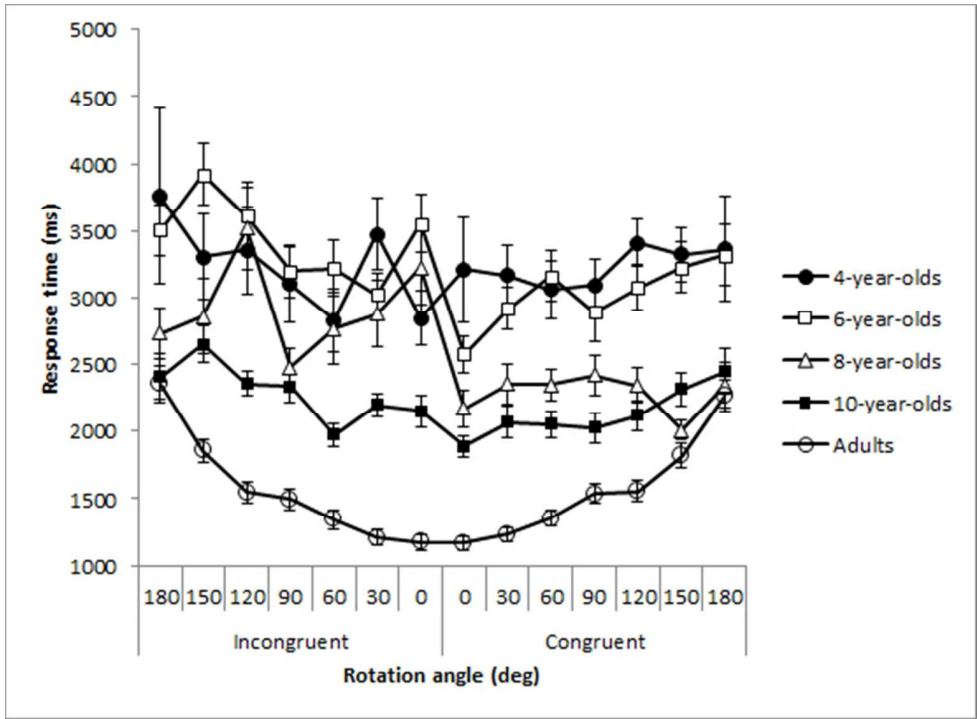
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Figure 2. Mean response times and standard errors as a function of rotation angle, fall direction (congruent vs. incongruent) and age group.

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