Mental rotation capacity in children with obesity is reduced, but only in those with motor impairments

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Background Motor impairments are relatively common in children with obesity and evidence suggests that these difficulties go beyond those expected based on the extra weight. This study aims to investigate the mental rotation capacity in children with obesity, more in particular the capacity to use motor imagery as a proxy of motor planning and control.

Methods. Fifty children (age range: 7-11 y) of which 19 with obesity and conjoined motor impairments (OB-), 13 with obesity without motor impairments (OB+) and 18 control children with a healthy weight (HW), were submitted to a classic mental rotation task. Sitting at a desk the children were instructed to indicate the laterality of a picture of a hand as quickly and as accurately as possible.

Results. The findings indicate no differences in response time between groups. The OB- group, however, had significantly lower accuracy rates and inverse efficiency scores than the HW group. Interestingly, no difference was observed between the OB+ and HW group. In all groups, slower and more error-prone responses were observed when the angle of rotation was larger and when the hand on display was incongruent with the posture of the participants (palm).

Conclusion. Children with obesity and motor impairments have a reduced spatial reasoning capacity compared to their counterparts without motor impairments and children with a healthy weight. All groups appear to engage in motor imagery, however, this notion needs to be investigated further in children with obesity and motor impairments, given their generally lower accuracy and decreased efficiency.

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Abstract

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Conclusion. Children with obesity and motor impairments have a reduced spatial reasoning capacity compared to their counterparts without motor impairments and children with a healthy weight. All groups appear to engage in motor imagery, however, this notion needs to be investigated further in children with obesity and motor impairments, given their generally lower accuracy and decreased efficiency.

Introduction

While recent figures indicate that the increase in body mass index (BMI) in children and adolescents has plateaued in high-income countries, the level is still at an all-time high. Moreover, trends still are accelerating in other parts of the world (e.g. in Asia), which makes pediatric obesity arguably one of today's largest health challenges (1–3). There is indisputable evidence that children with obesity are more likely to stay obese during adolescence and adulthood, which is associated with an increased risk for non-communicable diseases such as cardiovascular diseases, diabetes, musculoskeletal problems and certain types of cancer (4). The focus of the current paper is on motor impairment in obesity, an associated symptom of this disease that has received relatively little attention. In their recent review, however, Robinson et al. conclude that motor skill competence should be considered an important moderator and mediator of lifelong physical activity, and hence influences an individual's health and well-being (5).

There is now a wealth of evidence that the general motor competence of children with obesity is significantly below the level of their peers. In fact, according to our previous work between 50 and 70 % of children with obesity demonstrate levels of motor competence below the 5th percentile, which would indicate a motor impairment (6–8). Important to note, this motor impairment cannot be attributed solely to the presence of excess (fat) mass, which evidently complicates movements of all sorts, but seems to be associated with more fundamental motor control problems too. For example, even in reaction time and eye-hand coordination tracking tasks children with obesity perform slower and less accurate than healthy weight control children (9–11). These fine motor tasks require only small movements of arm and hand, therefore compromised control due to larger inertial forces related to the extra mass can only partially explain weaker performance in obese children. Instead, difficulties during the execution of these tasks suggests deficient central processes related to perception, planning and control of motor actions similar to those found in children with mild motor impairments such as developmental coordination disorder (DCD) (12). These deficits may act as a major constraint on motor skill acquisition and performance, and may be an indirect threat to the individual's health, given its relationship with physical activity and fitness.

Other evidence for impaired mental processes related to perception and action in children who are overweight or obese stems from research into mental rotation. Mental rotation can be defined as the ability to mentally view a representation of spatial information and to transform this representation through rotation (13). This ability, which engages both visual-spatial and action representation processes, is typically tested by asking a subject to judge whether a 2D or 3D geometric shape on display is identical to a reference shape that may have a different orientation. Chronometric studies have demonstrated that the response time of this judgment increases with increasing angular disparity between the stimulus on display and the reference (13). In addition to that, neuroimaging studies have shown that mental rotation engages motor areas such as the premotor and supplementary motor area (14), especially when the stimulus on display is body-related (15–17). This suggests that the mental rotation is somehow paralleled by imagery of the movement. Consistent with this notion, the response times in a hand laterality task, where the subject is instructed to judge the laterality of pictures of hands rather than geometric objects, are found to be bound by anatomical and biomechanical constraints of the actual movements (18,19). That is, pictures of laterally rotated hands, which are biomechanically more complex, lead to longer response times than medially rotated hands. Furthermore, response times are longer when the posture of the subject is incongruent with the posture of the stimulus, e.g. participants hold hands with palms down while the hand on display is faced with palms up. Based on these findings, it has been suggested that the performance on a mental rotation task, in particular when body-related stimuli are used, can be regarded as a proxy for an individual's internal action representation ability.

Using a typical letter rotation paradigm, Jansen et al. found that the mental rotation capacity of 10-year-old children who are overweight was impaired (20). While the response time and the performance profile were similar to that of their healthy weight counterparts, children with overweight had significantly larger error rates, especially in the more complex trials (i.e. when the difference in angular orientation was larger). Furthermore, regression analysis indicated that almost 30% of the variance in mental rotation performance was explained by children's motor competence. While this link was only evident for one aspect of motor skill, i.e. one-legged stance, this might suggest that the motor problems found in children with overweight or obesity may be partially due to difficulties with mental rotation. Yet, given that only non-body related stimuli (i.e. letters) were used, this is merely reflective of compromised visual-spatial function, which is consistent with previous observations in this population (21,22).

However, to test whether internal action representations are affected too, body-related stimuli are required. Mental rotation tasks of non-body related stimuli may be solved using a third-person perspective, also known as visual imagery, which requires visual-spatial processes that are relatively independent of motor processes. When body-related stimuli are used (e.g. hands) the task may be solved using either a third-person perspective or a first-person, embodied perspective, or motor imagery. Only in the latter instance, the imagery of the rotation of the stimuli is influenced by motor processes and the response is subject to the anatomical and biomechanical constraints as discussed earlier (15–17). This is important because this effect provides insight into the internal action representation capacities, which, in turn, are considered to be related to advanced (predictive) motor control (23,24).

The capacity to mentally rotate body-related stimuli, henceforth motor imagery, develops through childhood, between the ages of 5 and 12 (18,25,26). Accumulating evidence indicates that motor imagery is related to actual motor competence. For example, individuals with DCD, a neurodevelopmental disorder characterized by difficulties with the acquisition and execution of motor skills, consistently show slower and/or decreased accuracy on the hand laterality task (27–33). Some researchers have also found atypical response profiles that reflect absence or reduced influence of motor involvement in this population (34). These findings are suggested to indicate compromised internal representations in this population, which would explain difficulties with predictive control (23,24).

In summary, the study of Jansen and colleagues using non-body related stimuli indicated found reduced visuo-spatial function in children with obesity (20). To investigate whether children with obesity may have compromised internal action representations too, the aim of this study was to test mental rotation performance using body-related stimuli. Slower, less accurate performance, or reduced influence of anatomical or biomechanical constraints would indicate impaired motor imagery ability, and therefore support the notion that the reduced motor skill competence of children with obesity may also have a central origin, related to processes of action planning, perception and control.

Materials & Methods

Participants

For this study we initially recruited fifty-seven children, aged between 7 and 11 years. Thirty-two participants were children with obesity (14 boys, 18 girls; mean age = 9.6 ± 1.1), recruited from a specialized rehabilitation center at the start of the actual treatment. Obesity was determined using international cut-off points standardized for age published by Cole and Lobstein (35). The healthy weight control children (N = 25, 18 boys, 7 girls, mean age = 9.5 ± 1.6) were randomly selected from a local database of primary school children considering the age range of the group with obesity (range: +/- 6 months). All children of the control group attended regular schools, whereas five children with obesity (2 boys, 3 girls) included in this study attended a school for special education, which might indicate sub-normal IQ levels although not below 70. The parents of all children gave written informed consent prior to data collection and the protocol of the study was approved by the Ethics Committee of the Anonymized, in accordance with the Anonymized declaration.

Materials and procedure

Children's body height (0.1 cm) was measured barefoot using a calibrated stadiometer (Harpenden, Holtain Ltd., Crymych, UK). Additionally, body mass (0.1 kg) and percentage body fat (0.1%) were obtained by means of a digital balance scale with bioelectrical impedance (Tanita, BC420SMA, Weda B.V., Naarden, Holland). BMI (kg/m^2) was calculated based on body height and body mass. Finally, waist circumference (0.1 cm) was measured using a flexible tape measure.

The participant's motor competence was measured using the Movement Assessment Battery for Children, 2nd version (MABC-2) (36,37). The MABC-2 consists of 8 items, clustered into three domains (i.e. manual dexterity, ball skills and balance) and has good reliability and validity. Using the available norms for Dutch children, the raw scores were converted into standard scores and a percentile score, both for the total general motor competence score and per cluster. In accordance with the M-ABC2 guidelines, general motor competence scores at or below the 5th percentile were considered to indicate a motor impairment, scores at or below the 16th percentile were considered to indicate children "at risk" of a motor impairment.

Motor imagery was tested with a classic hand laterality judgment task (HLT). Single-hand stimuli (9 by 8 cm) were presented on a laptop screen (Dell Precision M6700, 17-inch) using OpenSesame (version 3.0.7) (38). The participant sat at a distance of approximately 60 cm from the screen and was instructed to indicate the laterality of the stimulus by pressing the keyboard (i.e. letter "d" or "k" on an qwerty keyboard for a left or right hand, respectively), while imagining that the hand on display was his/her own hand.
The pictures of the hands were presented with palm facing up or down at an angle of 0°, 60°, 120°, 180°, 240°, or 300° (see Figure 1). Before presentation of the stimulus a fixation cross was shown in the center of the screen, which was replaced by the actual hand stimulus after a random duration between 1300 and 1800 ms. After a practice and familiarization period of five trials, during which it was ensured that the participants understood the instructions, each combination of stimuli [N=24; 2 hands (left, right), 2 sides (palm, back), 6 orientations (0°-300°)] was shown twice per block. A total of three blocks was recorded, giving a total of 144 trials per participants. In addition to the number of correct responses, response times (RsTs) were recorded to the nearest ms.

Analysis and statistics

An initial check of the motor competence scores indicated that 19 out of 32 children with obesity had a general motor impairment, as indicated by a motor competence score at or below the 5th percentile on the MABC-2. This group will be labeled OB-. Of the other children with (OB+; N = 13), six scored above the 16th percentile and seven had scores between percentile 6 and 16. In the group with children with HW, 2 children had general motor competence scores at or below the 5th percentile, and 5 scored at or below the 16th percentile. As we wanted to compare the performance of the children with OB against a group without motor impairments we excluded these children from the analyses, which resulted in sample of 18 children with HW.

After deletion of anticipatory responses (RsT < 250 ms) and late or absent responses (RsT ≥ 8000 ms), mean RsTs of the remaining trials (correct and incorrect) were computed at each of the stimulus presentation conditions per individual. Note that the orientations of both hands were flipped such that angles between 0° and 180° represented medial rotations; angles between 180° and 360° represented lateral rotations. In addition to that, accuracy (ACC) was calculated as the proportion of correct responses at each of the stimulus presentation conditions per individual. As preliminary analysis indicated that there was a positive linear relationship between overall mean RsT and ACC, it was deemed appropriate to calculate the inverse efficiency score (IES), by dividing the RsT by the proportion of correct responses at each stimulus presentation (Townsend & Ashby, 1978; Townsend & Ashby, 1983). IES combines speed and error in one metric, yet it inflates variance disproportionally in cases were proportion correct is below chance (see Bruyer & Brysbaert (41) for a detailed argumentation). Our data indicate proportion correct values ranging from 0.48 to 0.97, therefore it was decided to calculate IES only for those subjects who had proportion correct scores above chance level. Based on a binomial distribution with $p = 0.50$ for each trial, individual performance was significantly above chance level when more than 76 out 144 trials (52.8%) were correct.

Between-group differences in anthropometric measurements and M-ABC2 scores were examined using separate univariate ANOVAs. Bonferroni post-hoc tests were used to explore significant effects. To investigate group differences in motor imagery performance three separate repeated measures ANOVA were run for the dependent variables RsT, ACC and IES with Group (obese, healthy weight) as between groups factor and Hand (left, right), Side (palm, back), and Angle (0°, 60°, 120°, 180°, 240°, 300°) as within group factors. Within these analyses our first focus was on the effect of rotation, including potential interactions with the factor Group. Larger RsTs and smaller ACC for greater deviations from the normal orientation (i.e. with the fingers pointing upwards) were indicative of the use of mental rotation to judge laterality. Secondly, we looked at the difference between medial and lateral rotations and the effect of Side to examine whether the anatomical and biomechanical constraints that affect actual movements also hold for mental rotations. Here, smaller RsTs for medial vs. lateral rotations and for hand back vs. hand palm were indicating the use of motor imagery. Furthermore, to examine the potential association between motor competence and mental rotation performance a Pearson correlation coefficient was calculated between general motor competence on the MABC-2, including the three cluster scores, and RsT, ACC and IES for the whole group and for the three groups separately. All analyses were run with IBM SPSS Statistics version 25. Effects with $p < 0.05$ were considered significant and partial eta squared values (η^2) were reported to indicate effect size where appropriate.

Results

Individual characteristics

Descriptive statistics of the anthropometric measurements and motor competence scores are shown in Table 1. The ANOVAs revealed that children with obesity (OB- and OB+) were significantly heavier ($p \leq 0.001$) and had a higher percentage of body fat ($p \leq 0.001$), waist circumference ($p \leq 0.001$) and body mass index ($p \leq 0.001$) compared to HW controls. No significant differences in anthropometric measurements were observed between the OB+ and

OB- group ($p>0.05$). For general motor competence, significant between-group differences were observed, with HW group performing better than the OB+ ($p=0.016$) and OB- group ($p<0.001$), and the OB+ group performing better than the OB- group ($p<0.001$). A similar result was found for the sub-score on balance. For manual dexterity and ball skills the performances of the HW and OB+ group did not differ, but both groups had significantly higher scores than the OB- group.

Mental rotation and motor imagery performance

The ANOVAs indicated that the effect of Hand stimulus (right or left) was not significant and was not involved in any interaction effects for any of the dependent variables (RsT, ACC, and IES). Therefore, this independent factor was left out of further analyses.

For the RsT, we observed a significant effect of Side [$F(1,47)= 41.689$, $p<0.001$, $\eta^2=0.470$], Angle [$F(5,235)=35.225$, $p<0.001$, $\eta^2=0.428$], and an interaction effect between these factors [Side x Angle $F(5,235)=18.237$, $p<0.001$, $\eta^2=0.280$]. Further investigation indicated that responses to stimuli of hand palm were generally slower than responses to hand back (2910 ± 98 ms vs. 2543 ± 88 ms). For the effect of Angle, it was found that for both sides RsTs to medially rotated stimuli (60° and 120°) were smaller than RsTs to laterally rotated stimuli (240° and 300°), however, this effect was more prominent for back of hand vs. palm of hand (see Figure 2A and 2B). A main effect of Group or any interaction with this factor remained absent.

Proportion correct (ACC) was smaller in OB- group (72.0 ± 2.0%) compared with the OB+ (85.7 ± 3.6%) and HW group [88.5 ± 3.0%; main effect of Group: $F(2,47)=7.525$, $p=0.001$, $\eta^2=0.243$]. No difference was found in ACC between the HW and OB+ children. Furthermore, a main effect of Side [$F(1,47)=19.623$, $p<0.001$, $\eta^2=0.295$] and Angle [$F(5,235)=15.224$, $p<0.001$, $\eta^2=0.245$], as well as an interaction between these two factors was observed [$F(5,235)=5.823$, $p<0.001$, $\eta^2=0.110$]. Closer inspection of these effects revealed better ACC when the stimulus was rotated over 0°, 60° or 120° vs. rotations over 180° or 240°, with different profiles for palms and backs (see Figure 2C and 2D). No interactions with Group were found.

Six participants, one of the HW and five of the OB- group, demonstrated ACC scores below chance (range: 47.9 – 52.1%). After omitting the results of these participants, the ANOVA on the IES indicated a main effect of the factors Group [$F(2,40)=3.384$, $p=0.044$, $\eta^2=0.145$], Side [$F(1,40)=13.410$, $p=0.001$, $\eta^2=0.251$] and Angle [$F(5,200)=16.266$, $p<0.001$, $\eta^2=0.289$]. Furthermore, there was a two-way interaction between Side and Angle [$F(5,200)=3.894$, $p=0.002$, $\eta^2=0.089$] and a three-way interaction between Group, Angle and Side [$F(10,200)=2.253$, $p=0.016$, $\eta^2=0.089$]. Post-hoc inspection showed that efficiency was generally better (i.e. IES smaller) in for the back of the hand vs. palm of the hand. In addition, the HW group had better IES than the OB- group ($p = 0.050$), in particular at angles of 0°, 240° and 300°

for palms and 180°, 240° and 300° for backs. No significant difference was found between the OB- and the OB+ group, or between the OB+ group and the HW group (see Figure 2E & 2F).

Finally, in the whole group analysis, a weak significant correlation was observed between ACC in the mental rotation task and all motor competence variables (see Table 2). No other correlations were found using this analysis. In the HW group, a moderate positive correlation was observed between ACC and Ball skills and between IES and Balance. A moderate negative correlation was found between ACC and Balance and between IES and Ball skills. There were no significant correlations between any of the mental rotation outcome variables and motor competence in the OB group.

Discussion

This study set out to examine mental rotation performance in children with obesity with (OB-) and without motor impairments (OB+), and more in particular their capacity to enlist motor imagery. Using a classic hand laterality task, it was found that responses of children with obesity (OB- and OB+) were as fast as those in healthy weight control children (HW). Proportion of correct responses and efficiency were smaller in the group with obesity and motor impairments, but the judgements were influenced by the side of the stimulus and its angle of rotation to a similar extent in all three groups. Finally, mean accuracy on the mental rotation task correlated significantly with general motor competence and its sub-components.

Consistent with previous studies, stimuli with greater angular deviations resulted in slower responses, which indicates that mental rotation was used to judge the laterality of the hand on display. Indeed, the hand laterality task requires visual spatial cognition and reasoning, and it has been shown that the duration of these processes increases with angular disparity between the orientation of the stimulus and the “normal” orientation. There is evidence that this ability is related to problem solving (42) and the acquisition of mathematical knowledge (43), and is likely to be involved in sport and movement skills (44). The behavior of children with obesity and motor impairments, whose response times were influenced by the orientation of the stimulus but who made more errors and were less efficient than controls, indicates a deficit in these spatial reasoning skills. Interestingly, though, proportion correct and inverse efficiency scores in children with obesity without motor impairments were not different from those in healthy weight children. The difference between the two groups with obesity suggests that the deficit in spatial reasoning is related to the motor difficulties. In support of this, a significant, albeit weak, correlation was found between mental rotation accuracy and general motor competence for the whole group. While this correlation did not reach the level of significance within the group with obesity, this finding highlights the association between spatial reasoning and motor competence. The analyses also indicate a negative correlation between ACC and Balance and between IES and Ball skills within the HW group, however these results should be interpreted with caution.

Within this group, the range of scores on both sub-components of the motor test battery is relatively limited (23-38 for Ball skills and 23-39 for Balance in HW vs. 6-38 for Ball skills and 3-39 for Balance in the whole group). This inflates the impact of extreme influential values and puts the validity of the correlation at risk.

The current results provide a new perspective on the findings of Jansen et al. (20). Using a similar mental rotation paradigm with non-body related stimuli, they seemed to suggest that mental rotation difficulties were a general symptom of children with obesity. By contrasting children with and without motor impairments we showed that this is not the case. Although the underlying mechanisms of this relationship fall outside the scope of this study, it seems relevant to note that children with motor impairments often withdraw from movement opportunities (45). A restricted movement activity pattern may have a negative impact on the development of spatial cognition (46). On the other hand, nutritional research in rats has shown that diet-induced obesity due to excess sucrose intake may lead to impaired spatial learning and long-term spatial memory too (47). So, when addressing cognitive impairments in individuals with obesity both dietary-factors and motor competence have to be considered.

Another objective of this research was to investigate the embodied nature of mental rotation or motor imagery in hand laterality judgments in children with obesity with and without motor impairments. This is important as internal action representation capacity is deemed to be essential for motor planning and control (24). In all three groups response times were longer when the side of the hand on display was incongruent with the posture of the participant (longer response time for palm vs. back). In addition, stimuli rotated to the lateral side (300º and 240º) led to longer response times than stimuli rotated to the medial side 60º and 120º. In other words, the behavior of all three groups complied with the anatomical and/or biomechanical constraints that act on actual hand rotations, which indicates that the judgments involved motor imagery. Irrespective of group, hand laterality judgements appear to be solved using embodied mental spatial transformations of the viewer (1^{st} person perspective) rather than of the viewed object (3^{rd} person perspective). This is in contrast with other populations with motor impairments such as children with DCD or cerebral palsy (CP) (e.g. 29,33).

The implication is that the internal action representation capacity of children with obesity, even those with motor impairments, seems to be intact. That is not to say that central processes related to planning and control may not be implicated in the motor problems of children with obesity and motor impairments. Based on the current findings, however, the deficits in central processes are more likely related to spatial reasoning, and not internal action representation. Still, it should be noted that low accuracy and efficiency in this hand laterality task, which we observed in the obese group with motor impairments, may be interpreted as a general sign of reduced internal action representation capacity. This would be consistent with earlier findings in individuals with DCD (30,31), where it was found that efficiency in motor imagery correlates with the ability to correct the movement trajectory during unimanual reaching (31). It is possible that the children with motor impairments in the present study had undiagnosed DCD and therefore require special treatment that goes beyond weight management and includes motor therapy.

The present findings corroborate the view that a proportion of children with obesity suffer from motor impairments and that these impairments are not only due to their excess mass, but also to central processes related to spatial cognition and motor control. Some limitations need to be considered, however. The children with obesity were recruited from a specialized rehabilitation center, meaning that sampling was not fully randomized. In fact, the children are referred to this center by their general practitioner or pediatrician based on the severity of their weight problem and failure of conventional care. Therefore, the sample does not necessarily represent all children with obesity. Also, data on the intellectual capacity of our sample are not available. Given that spatial cognition is known to correlate with mathematical capacity it would have been desirable to control for this factor. Finally, our results only provide insight into one specific aspect of the central processes related to spatial cognition and motor control, i.e. mental rotation capacity and motor imagery. To unravel the motor impairments of children with obesity further, more research is needed.

Conclusions

In summary, the findings of this study indicate that children with obesity and conjoined motor impairments have a reduced spatial reasoning capacity compared to their counterparts without motor impairments and children with a healthy weight. The fact that the speed of the judgements in this mental rotation task conforms the anatomical and biomechanical constraints suggests that all children used motor imagery to solve the task. However, this notion needs to be investigated further in children with obesity and motor impairments, given their generally lower accuracy and decreased efficiency. Future research is also required to examine the role of diet and/or lack of movement experience in the development of this deficit. For practitioners, it is important to acknowledge the potential presence of motor impairments in children with obesity.

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Table 1(on next page)

Descriptive statistics (mean ± standard deviation) for anthropometric measurements and motor competence of the three groups.

Children with obesity + motor impairment (OB-), children with obesity without motor impairment (OB+) and children with healthy weight without motor impairment (HW). The final column reports the outcome of the ANOVA to explore between between-group differences.

Table 1 Descriptive statistics (mean ± standard deviation) for anthropometric measurements and motor competence of the three groups: children with obesity + motor impairment (OB-), children with obesity without motor impairment (OB+) and children with healthy weight without motor impairment (HW). The final column reports the outcome of the ANOVA to explore between between-group differences.

	OB- **N=19**	**OB+** **N=13**	**HW** **N=18**	**ANOVA** **F(2,47)**
Demographic characteristics				
Gender (boys / girls)	6 / 13	7/6	14 / 4	/
Age	9.9 ± 1.1	9.2 ± 1.0	9.5 ± 1.3	1.269
Anthropometric measurements				
Body height (cm)	145.2 ± 7.8	141.9 ± 7.8	140.2 ± 8.9	1.739
Body weight (kg)	68.7 ± 18.3	59.9 ± 8.8	33.4 ± 5.7	37.993*
Body fat (%)	44.8 ± 9.1	43.8 ± 5.9	16.8 ± 4.2	93.079*
Waist circumference (cm)	94.7 ± 13.3	91.3 ± 7.5	61.1 ± 4.5	67.735*
Body mass index (kg/m^2)	32.2 ± 6.5	29.7 ± 2.5	16.9 ± 1.2	64.891*
Motor competence				
General motor competence	46.8±12.2	71.9±10.1	82.4±6.5	62.311*
Manual dexterity	18.8±8.1	27.3±6.2	30.2±4.3	15.497*
Ball skills	14.4±5.5	19.7±5.0	21.1±4.5	8.886*
Balance skills	13.6±5.5	24.9±7.0	31.1±3.3	51.394*

* p≤0.001

Table 2 (on next page)

Correlation coefficients for the associations between the mental rotation outcome variables (RsT, ACC and IES) and motor competence

R-value and p-value (in parentheses)

Table 2 Correlation coefficients for the associations between the mental rotation outcome variables (RsT, ACC and IES) and motor competence (r-value; p in parentheses).

		General MC	Manual Dexterity	Ball skills	Balance
Whole group	**RsT**	-0.031 (0.832)	0.077 (0.596)	-0.074 (0.612)	-0.083 (0.569)
	ACC	0.403 (0.004)	0.359 (0.010)	0.278 (0.050)	0.317 (0.025)
	IES	-0.216 (0.131)	-0.147 (0.308)	-0.255 (0.073)	-0.144 (0.088)
HW group	**RsT**	-0.128 (0.612)	0.024 (0.924)	-0.188 (0.454)	-0.026 (0.919)
	ACC	0.086 (0.734)	-0.105 (0.677)	0.616 (0.007)	-0.533 (0.023)
	IES	-0.080 (0.751)	0.157 (0.535)	-0.624 (0.006)	0.499 (0.035)
OB group	**RsT**	-0.054 (0.768)	0.084 (0.646)	-0.061 (0.742)	-0.153 (0.403)
	ACC	0.275 (0.128)	0.305 (0.089)	0.036 (0.843)	0.223 (0.219)
	IES	-0184 (0.312)	-0.172 (0.347)	0.001 (0.997)	-0.201 (0.270)

RsT = response time, ACC = accuracy, IES = inverse efficiency score

Figure 1 (on next page)

Illustration of the different hand stimuli

Six stimuli, according to angle of palm/back of the left hand and the palm/back of the right hand.

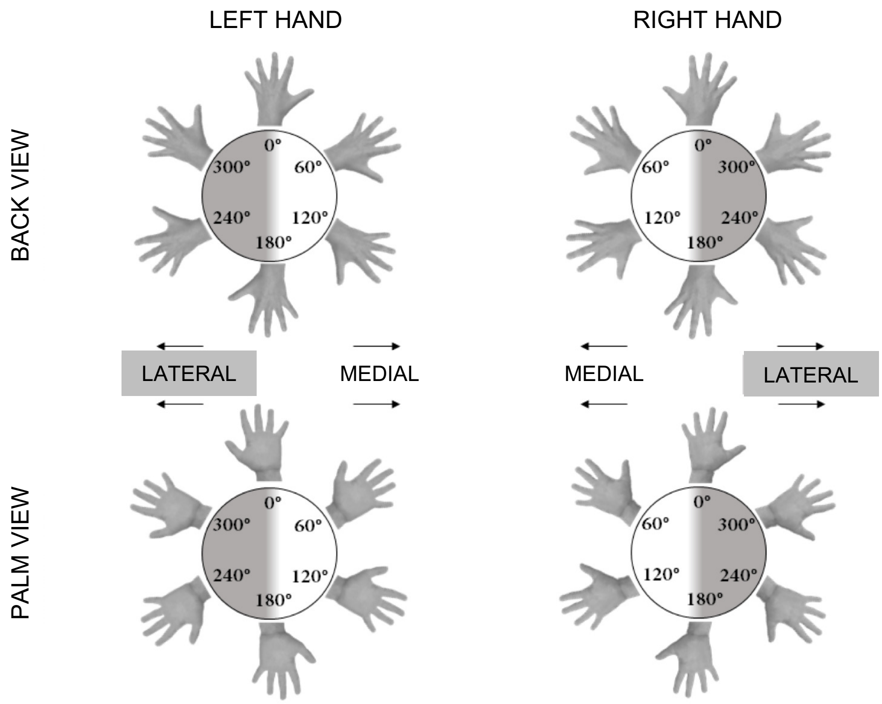

Figure 1. Illustration of the different hand stimuli.

Figure 2 (on next page)

Plots of Response Time (A & B), Proportion Correct (C & D) and Inverse Efficiency Score (E & F)

Each data point shows the mean per angle of rotation for the group of children with obesity and motor impairments (OB-) indicated with ♢, the group of children with obesity without motor impairments (OB+) indicated with ○, and the healthy weight control group (HW),indicated with ●. The stimulus on display was palm of the hand in the left panels (A, C, E), back of the hand in the right panels (B, D, F).

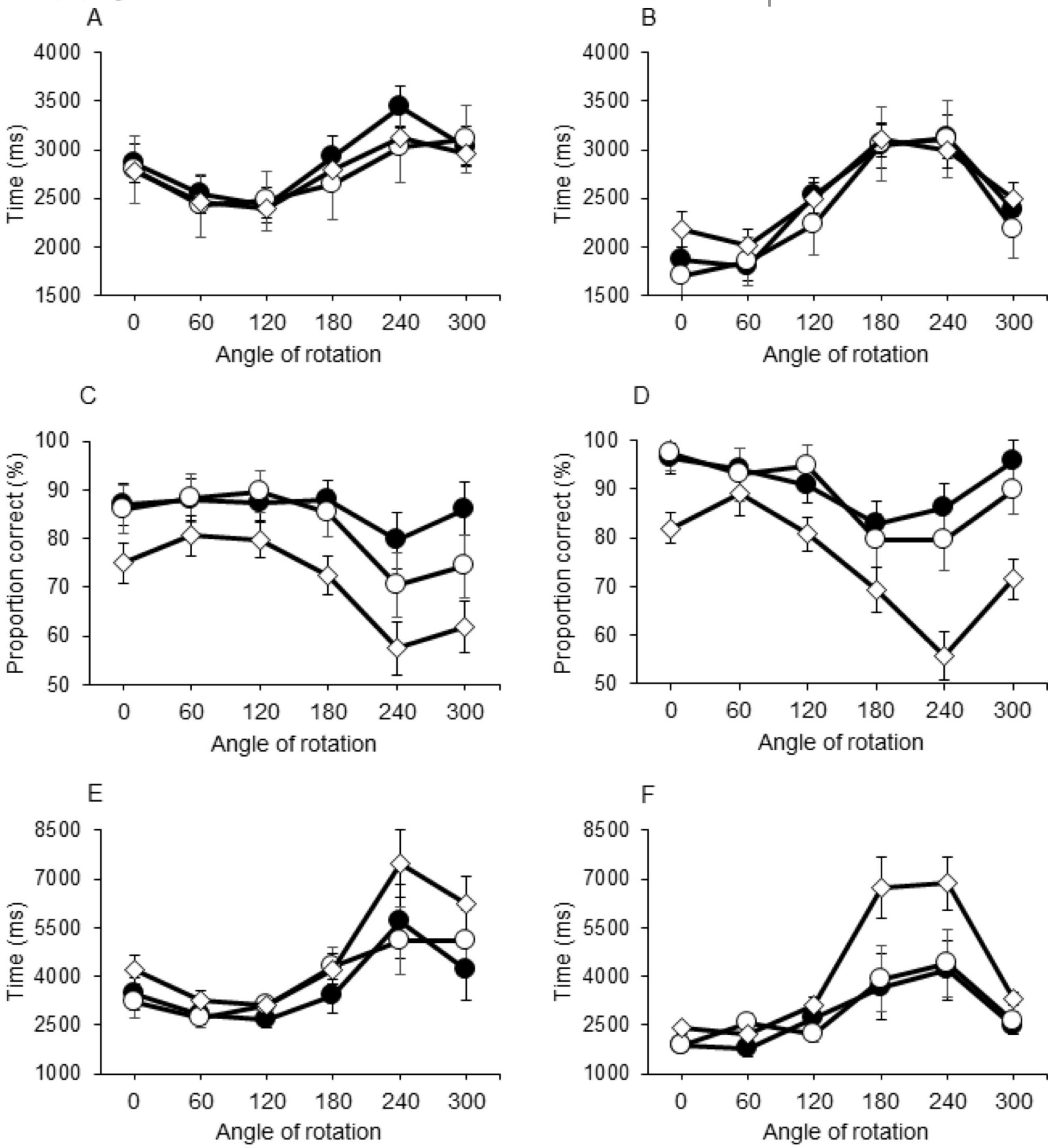

Figure 2. Plots of Response Time (A & B), Proportion Correct (C & D) and Inverse Efficiency Score (E & F) for the group of children with obesity and motor impairments (OB-, ◊), children with obesity without motor impairments (OB+, ○) and the healthy weight control group (HW, ●) for the six angles of rotation. Stimulus on display was palm of the hand in the left panels (A, C, E), back of the hand in the right panels (B, D, F).