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Haptic object matching by blind and sighted adults and children

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ABSTRACT

The present study describes a tactual object matching task based on the study of Lederman and Klatzky (1987) for the dimensions Exact shape, Weight, Volume and Texture. Participants were congenitally blind children and their sighted classmates, congenitally blind adults and sighted adults. To study a possible effect of familiarity the task was performed four times. Based on Millar’s CAPIN (Convergent Active Processes in Interrelated Networks) model of spatial processing (Millar, 1994) it was thought that this manipulation would add redundant information to the experiment from which the children and blind participants could benefit. The results showed that accuracy was affected more by age than visual status, especially for the dimension Exact Shape. With regard to response times, children were in most cases faster than adults, especially the sighted adults. Familiarization had a significant effect on response times for all dimensions. Extra exercise only increased accuracy for the dimension Texture. These results were generally in line with the CAPIN model.

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1. Introduction

For obvious reasons, blind people have to rely on other senses than vision. In case of blindness, touch is the most likely sense to replace vision for the acquisition of spatial knowledge of the environment and object properties (Hatwell, 2003a,b). However, as Heller (2000) has pointed out, studying touch in blind persons is subject to several practical problems. First of all, we do not really know what a “normal” blind person is due to heterogeneity in the population of blind people and the difficulty of finding a representative sample. More importantly, it is hard to define what “normal” touch is. We have norms for several hearing and visual functions but not for touch skills, since reliable and valid tests are generally lacking. In previous work, we have made an attempt to design an assessment instrument to document touch skills in educational and everyday situations of children with blindness (Withagen, Vervloed, Janssen, Knoors, & Verhoeven, 2010a) and looked at skills that were specifically difficult for them (Withagen, Vervloed, Janssen, Knoors, & Verhoeven, 2010b). The blind children aged zero to 16 years of age mastered roughly 94% of the tactual tasks they could encounter in daily living situations. However, a direct comparison with sighted children was lacking.

From previous studies, it was also unclear how task performance differed between sighted and blind children.

1.1. Object matching

Given its theoretical and clinical relevance, object matching was chosen as subject for this study. The present study builds on Lederman & Klatzky, 1987 on the distinctive role of ‘weight’, ‘exact shape’, ‘volume’ and ‘texture’ in object matching in the absence of sight while taking into account the participants’ age and visual status. We compared the performance of congenitally blind children, sighted classmates, congenitally blind adults and sighted adults with regard to accuracy and speed in a tactual object matching task.

1.2. The CAPIN model

The work of Millar, who studied the two modalities touch and vision as separate senses, but also in relation to each other in sighted as well as visually impaired children (see Millar, 1994a, 1997, 2000, 2005, 2008) is very relevant to the current study. She introduced the CAPIN (Convergent Active Processes in Interrelated Networks) model to observe and describe spatial development. It is primarily a connectionist model taking into account neuropsychological as well as behavioural findings (Millar, 1997). The assumption of active processing in interrelated networks refers, firstly, to the constant changes during cerebral development, secondly to individual variation within this development, and
thirdly to the interplay of maturational processes with patterns of incoming information, and interrelations between perceptual processes, spatial organisation and task demands. The sense modalities provide specialised and complementary inputs, hence the emphasis on ‘convergent’ active processing. A key element in the CAPIN model is that it assumes that the convergence and overlap of inputs provide the redundancy that is needed for their organisation as reference anchors or frames. According to Millar (1997), visually impaired children need substantial redundancy in their information to come to the same conclusions as sighted children. The absence of vision alters the balance of internal and external inputs of information. Vision normally provides information about the relation between external cues. Totally blind people have to rely on body-centred and sequential movement information to get information about spatial cues and their positions towards each other.

1.3. Exploratory procedures

For identifying functions and properties of small objects, such as form, weight or texture, people normally use specific haptic strategies called Exploratory Procedures (EP’s). Lederman and Klatzky (1987) showed that people use EP’s to discriminate different object dimensions. These purposive hand movements appear critical for haptic experiencing specific material properties. Klatzky, Lederman, and Matula (1991, 1993) studied the haptic exploration of object properties in the presence of vision. It seemed that vision and touch interact in haptic object exploration and manipulation. When difficult judgements about materials had to be made, touch was used more often, whereas for judgements about geometric forms, vision was the preferred sense.

Most of what we know about EP’s is based on experiments with sighted adults. What is unknown is whether children are as efficient as adults. It is also largely unknown whether children perform at adult level with regard to the pattern of manipulations, accuracy and speed.

1.4. The effects of blindness

Task demands and prior knowledge or experience may influence the haptic strategies one chooses in object identification and manipulation (Millar, 2005). On the one hand, blind children and adults could be more accurate, and possibly also faster, than sighted persons, due to the fact that they are more trained and experienced in using touch to identify and compare objects. On the other hand, sighted persons can rely on visual memory and imagery making them possibly better performers than blind people. During object identification congenitally blind people cannot draw on visual experience. Recent studies showed brain reorganization in blind people. The occipital lobe, the main location for processing visual information, is also used by blind persons during touching, which might compensate for their lack of visual memory and visual processing in object identification (see e.g., Gizewski, Gasser, de Greiff, Boehm, & Forsting, 2003; Sadato, Okada, Honda, & Yonekura, 2002; Sathian, 2000, 2005; Sathian & Stilla, 2010).

Familiarity with the task might also benefit blind people since they are used to identify objects by touch. It might also be a distinguishing characteristic between children and adults, simply because adults have more years of experience. Davidson (1972) and Davidson and Whitson (1974) observed that blindfolded sighted persons had less efficient modes of exploration than people blinded early in life. To evaluate the curvature of a stimulus (convex or concave), the blind favoured procedures using the whole hand whereas sighted people used only two fingers. The sighted adults thus decreased the size of their perceptual field as much as possible; in contrast, the blind adults enlarged it by using all their fingers. It turned out that the blind participants were more accurate than the sighted. After familiarizing the sighted participants by forcing them to use the same mode of exploration as the blind the two groups produced similar results.

A familiarity effect was also found by Grant, Thagrarajah, and Sathian (2000) who compared the discrimination performances of blind Braille-readers and sighted subjects on haptic tasks. Initially, the blind outperformed the sighted on a hyperacuity task in which they had to judge Braille-like dot patterns, but after training, the sighted performed at the same level as the blind did. According to Craig (1988) blind persons do not truly develop better tactile sensitivity, but rather learn to use the haptic sense more proficiently. Grant, Thiagara and Sathian, as well as Craig conducted their studies while the participants could use active touch, that is purposive exploration of the stimulus field. For passive tactile acuity, perception based solely upon stimulation of the cutaneous sense of an immobile observer, a familiarity effect was also found by Goldreich and Kanics (2003). Tactile acuity in the blind was significantly superior over that of sighted people. Unfortunately no training was given to the sighted participants in this study, so it remains unknown whether familiarizing the sighted persons with the task would have enhanced their performance. In order to study a possible familiarization effect our experiments will be performed four times.

1.5. Developmental aspects

According to Millar (1997), visually impaired children need more redundancy in their information due to the fact that they are both visually impaired and young. The effects of visual impairment were discussed above, but what about the developmental aspect? Bushnell and Boudreau (1991, 1998) studied the sorts of hand movements children were capable of making at various ages, starting in infancy. The EP ‘Enclosure’, for instance, is already observed in four months old babies (clutching behaviour). Between four to nine months of age the manual behaviours of the babies were considered to be similar to the ones of adults for the EP’s ‘Pressure’ and ‘Lateral motion’. However, the intention of using the EP was different in infants than in adults. Babies were waving, banging and passing objects from one hand to another. These behaviours were considered to be similar to the adult EP ‘Unsupported Holding’. A difference in performance between younger and older children was described by Alexander, Johnson, and Schreiber (2002). Participants were children between four and nine years of age, with varying levels of knowledge of dinosaurs. The older children explored the models more exhaustively and discovered more differentiating tactile features than did the younger children and they also made fewer errors. For task accuracy, the haptic strategies used by the older children proved to be more important than their a priori level of knowledge about the objects.

The abovementioned studies were all carried out with sighted children, but what about blind children? Simpkins (1979), Schellingerhout, Smitsman, and Van Galen (1997, 1998), Morrongiello, Humphrey, et al. (1994) and Bradley-Johnson, Johnson, Swanson, and Jackson (2004) found no differences between blind and sighted children in the number and range of exploratory behaviours and in the way they adapted their actions to object properties. In contrast to the previous studies, Millar (1974) did find differences between blind and sighted children in several experiments with small nonsense shapes. During a comparison task, the children were distracted in different ways: unfiled delay, rehearsal, exposure to a verbal distractor, and a movement distractor. Although the distractors had highly significant effects on different experiments, the influence was the same for blind and sighted children. However, in general, the blind children were less accurate but also faster than the sighted children. Millar (1974) suggested that the speed-accuracy trade off probably indicated a difference in strategy rather than in retention. Also Hatwell (1978) found differences between blind and sighted children. She compared the results of congenitally blind and blindfolded sighted children on a shape recognition task. According to Hatwell haptic pattern perception in blind children develops slower than visual perception in sighted
children, but does seem to follow the same line of development. 
D’Angiulli, Kennedy, and Heller (1998) observed the performances of blind and sighted children in picture perception. They were specifically interested in the exploration skills of both groups. If the sighted children did not get any help or guidance in the exploration of pictures, the blind outperformed the sighted children. However, sighted children who were given passive guidance performed at the same level as the blind children.

An age effect was found by Simpkins (1979), who compared blind children with sighted and low vision children in a shape recognition task. Tactual recognition of shapes improved between 4 and 7 years of age and with age manual acts changed as well. Also Morrongiello et al. (1994) found an age effect in their study on object exploration and object recognition in sighted and blind children between 3 and 8 years of age with common objects of different sizes. Their results showed a distinct developmental pattern; older children were faster, recognized more objects and were more thorough in their exploratory strategies than the younger children. According to Hatwell (2003a,b), children tend to use global strategies (for instance, lateral motion) in a shape discrimination task, which is not optimal for solving the task efficiently. When children grow older, they shift to using adult-like patterns of exploration, such as contour following. Hatwell observed that in bimodal situations, where vision and touch can be used simultaneously, the haptic system is scarcely used in spatial tasks. For discrimination of other object properties, such as texture or hardness, the haptic system is more likely to be activated and preferred above vision. Hatwell’s analyses showed also that perception and action are narrowly linked in haptic acts. Not only do exploratory actions determine what is perceived, but also how it is perceived.

1.6. Hypotheses

Based on the aforementioned literature, we expected that adults would be more accurate and faster than children, because they will have more experience with touching than children (familiarity aspect) and possess a fully developed neurological system. The need for more redundancy in the information processing of children would reflect itself in longer response times and/or a speed—accuracy trade-off, that is short response times will result in reduced accuracy. Redundancy of information is reflected both in the density of cues on objects and the possible ways of how to obtain this information. Most of the literature showed that although blind people have to rely more often on touch and consequently have more practice in touch-objects than sighted people have, they normally do not perform any better than sighted people. For the current study we expected both in the density of cues on objects and the possible ways of how to obtain this information. Most of the literature showed that although blind people have to rely more often on touch and consequently have more practice in touch-objects than sighted people have, they normally do not perform any better than sighted people. For the current study we expected to replicate this finding. New in the current study was that experience and familiarity is manipulated by performing the experiment four times. We expected that children, as less proficient performers, would profit from repetition both with regard to speed as well as accuracy, whereas for adults we expected mainly speed of responding to improve. Since sighted adults and children might be less familiar with touching than blind people, the repetitions also familiarised them with the task. Individual variation was studied in two ways, namely by looking at correlations between dimensions and by looking at possible speed—accuracy trade-offs.

Given the varying degrees of involvement of vision, we expected the groups of blind and sighted participants to vary in speed and accuracy. For those tasks that normally rely on vision, we expected better performance of blind participants than the sighted ones, because they might be used to perform this task as a result of daily experiences and familiarisation. However, since tasks that are solved primarily by touch offer less redundant information than visual tasks, both blind and sighted people might perform equally well once vision is eliminated in the task. Since weight is normally more dependent on touch and haptics than vision, we expected weight not to differ between the groups of blind and sighted participants. However since young children need more redundant information than adults we expect them to perform worse in all tasks than adults.

2. Methods

2.1. Participants

Sixty-one participants took part in the experiment. The group consisted of thirty-one adults (age range 21–56) and thirty (age range 7–13) children, all naive to the aims of the experiment.

The participants were divided into four groups:

1. 16 congenitally blind adults (mean age = 38.8, SD = 8.1; 8 females, 8 males)
2. 15 sighted adults, matched on age, gender and level of education with the blind adults (mean age = 39.4, SD = 10.7; 8 females, 7 males)
3. 15 congenitally blind children attending mainstream schools in the Netherlands and Flanders (mean age = 9.3, SD = 1.7; 7 girls, 8 boys)
4. 15 sighted classmates of the blind children, matched on age, gender and level of education (mean age = 9.0, SD = 1.5; 7 girls, 8 boys) in the Netherlands and Flanders.

The blind children were recruited by itinerant teachers who visited them at their mainstream schools. The sighted children were matched on age and sex and came from the same class as the blind children. Parents were asked permission to enrol their child in the experiment. They all agreed and signed a declaration of informed consent. The setting of the experiment was the child’s own school and the experiment was conducted during class hours. Considering the difficulty level of the questions on exact shape, volume and weight, it was decided not to recruit children younger than 7 in order not to confound the experiment with differences in cognitive level.

About one third of the blind adults worked as a volunteer in a museum devoted to visual impairment (they had a regular job next to this job). The other blind adults were recruited through a website for blind adults in the Netherlands and the social network of the first author. Many of the sighted adults worked at the administration office of an institution for the blind. They were not familiar with haptic strategies, nor with teaching or guiding the blind. The participants were not paid for their participation in the experiment, and they all gave informed consent. The experiment was given to them under standardized conditions either at their homes or at their workplace.

2.2. Material

The object sets for the dimensions texture, weight, volume and exact shape were selected out of the nine original object sets of Lederman and Klatzky (1987). The sets were reproduced with permission and help of these authors. All the objects were unfamiliar, meaningless and functionless objects and therefore difficult to label. For each object dimension there were 16 three dimensional-stimuli, divided into 4 sets. Each set comprised of one standard object and three comparison objects, of which one was the best, but not identical, match to the standard. There was one partial exception to this rule. In the object sets ‘Exact Shape’ the comparison object was identical in exact shape but still not completely identical because the objects differed in height and size to the standard object. In the other object sets irrelevant dimensions were added to the task in order to deliberately introduce some degree of difficulty to the task. For instance in the object sets ‘Weight’ different materials were used. In total there were 64 objects (four sets of four for each of the four dimensions). Fig. 1 shows the different object sets (A,B,C and D). All objects could be enclosed in one or two hands. A more detailed
description of the object sets can be found in Lederman and Klatzky (1987, p. 350).

2.3. Procedure

The procedure was a partial replication of the study of Lederman and Klatzky (1987). Since our study included children, we carried out a pilot-study to evaluate the procedure on its aptitude for both children and adults. The pilot study was executed with twenty participants, ten adults and ten children, none of whom participated in the final study. As a result of the outcomes of this pilot study it was decided not to blindfold the subjects, because several children did not like to wear a blindfold for an extended period of time. A second adaptation concerned the verbal instruction to suit children. This was done by adding descriptions of the object dimensions in simple words. Lastly, in order to signal the end of a trial the following instruction was added ‘when ready stretch your hands, palms upward upon the table’. This way it was easier to observe and score the exact time of exploring.

During the experiment, the participant sat opposite the experimenter with a curtain blocking the subjects’ view of the stimuli. This curtain hung over a stage, positioned just below eye level in the middle of the table between the subject and the experimenter. The participants were asked to put their hands under the curtain at the side of the experimenter. This way, the participants could not see any of the stimuli nor their own hands and at the same time they were not hindered by a blindfold. Behind the experimenter’s shoulder a tripod with a digital video camera was installed. The camera recorded all experimental trials, except practice trials.

Every experiment started with a practice session, in which the participants got clarification about the concepts of the dimensions and could practice the procedure of matching one of the objects with the standard. In accordance with the original study, participants were asked to cup their hands. The experimenter first presented the standard object, which they were asked to explore for one of four dimensions: texture, weight, volume, or exact shape. Next, the three comparison stimuli were given one after the other and the

![Fig. 1. The object-set. The standard object is on the left side, followed by the comparison objects in the same row; the second object in each row is the best match. Object sets for the dimensions: 'Texture' (A), 'Weight' (B), 'Volume' (C), 'Exact Shape' (D).](image-url)
participants were asked which of the three matched the standard best with regard to the required dimension. The participants were told that there would be no identical match to the standard. A simultaneous comparison of the stimuli was not possible and there was no time limit for responding.

Both children and adults received the practice trials. These trials did not focus on the strategy to solve the task, but only on the understanding of the instructions. The participant received no feedback on task performance. Texture was described as, ‘how the object feels at the surface, ignoring shape or size’. Weight was described as, ‘how heavy or light an object feels in the hand’. Volume was described as, ‘this concerns the size of the object at all sides. Ignore the shape, but explore the magnitude’. For this dimension, an extra instruction was given if the participant did not understand the concept well enough. The experimenter would tell, ‘Imagine you can make a hole in the object and fill it with water. In which comparison object would fit about as much water as in the standard?’. Exact shape was explained as, ‘the precise outline of an object, ignoring the size of the object. It can be larger, smaller, thicker or thinner, than the standard.’

When the participant stopped exploring the object, they were instructed to indicate they were ready for the next stimulus by stretching their hands, palms upward and upon the table. On this signal the experimenter could subsequently remove the object. To help remembering the correct numbers of the objects the experimenter asked while offering the consecutive comparison stimuli, ‘Is it number one … number two … or number three?’ After the four objects were presented, the participants had to answer verbally which object best matched the standard item. No feedback was given regarding the correctness of the participants’ response. The experimenter reacted neutrally to all answers. The procedure was practiced twice for all object properties in one practice session. An extra set of 32 practice stimuli, not part of the experiment, was used for this purpose.

Immediately after the practice session the experiment started. There were 64 objects in total in each series (four sets of four for...
2.4. Analysis

Response times were only analysed for the correct answers and measured with the help of the Observer XT (Noldus Information Technology, 2008). The observer XT software can be used for the collection, management and analysis of observational data. Five observers, naïve to the experiment, scored the videotapes after training them to a sufficient level of agreement (coefficient Kappa above .80). Videotapes of the experiments of ten participants were selected to determine inter-rater reliability. Tapes were selected from the beginning, halfway and end of the study. The mean inter-rater reliability measured with coefficient Kappa was .89 (range .84–.93).

Only significant results are described in this paper. An exception is made for the age by group interaction, since this was a major hypothesis tested in this study.

Firstly, an age (adults-children)×visual status (blind-sighted)×series (4) General Linear Model (GLM) analysis was performed to analyse the accuracy and response times per dimension. Age and visual status were treated as between subjects and series as within subject. Analyses tested in this study.

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3. Results

3.1. Exact shape

Accuracy for Exact Shape is depicted in Fig. 2A for the four groups as a function of series. The data points reflect percentages correct responses (accuracy) averaged over the four sets within one dimension and one group. Likewise, the mean response times on correct answers are depicted in Fig. 2B, also as a function of series.

The accuracy for exact shape showed a main effect for age (F1,57 = 33.093, p < 0.001, ηp2 = .367). As can be seen in Fig. 2A, adults were more accurate than children. No significant interaction was found between age and visual status (F1,57 = 0.496, p = 0.484, ηp2 = .009).

For response times there was a main effect for age (F1,57 = 17.620, p < 0.001, ηp2 = .236). Adults were in general slower than children. The data also showed a main effect for visual status (F1,57 = 12.788, p < 0.001, ηp2 = .183). Blind participants responded faster than the sighted ones. There was also a significant interaction between age and visual status (F1,57 = 10.351, p = 0.002, ηp2 = .154). As can be seen in Fig. 2B, this is mainly caused by the sighted adults who were slower than the three other groups. The data also showed a main effect for series (F3,171 = 16.98, p < 0.001, ηp2 = .230). Response times decreased over the four sessions.

3.2. Weight

For the dimension weight age proved to be a significant main effect for accuracy (see Fig. 3A), (F1,57 = 11.041, p = 0.002, ηp2 = .162). Adults were in general more accurate than children. There was no significant interaction for age and visual status (F1,57 = 0.275, p = 0.602, ηp2 = .005).

The response times for weight (see Fig. 3B) had a significant main effect for series, (F3,171 = 6.594, p < 0.001, ηp2 = .104) indicating that each of the four dimensions). Each participant performed four series. The dimensions were offered in a randomized order within each series. As a result of the four repeated series every participant got to touch 256 objects during the experiment. Response time and exploration time started when the participant received the object in their hands and stopped when the participant stretched their hands. All four series were presented on the same day.
the average response times over all four groups decreased with repetition of the series. However, there was also a significant interaction between series and age \((F_{3,171} = 7.523, p < 0.001, \eta^2_p = .117)\). Fig. 3B shows that children seem to become faster over the four sessions, whereas the response times of adults hardly changed. Finally, the dimension weight also showed an interaction effect between age and visual status \((F_{1,57} = 7.856, p = 0.007, \eta^2_p = .121)\). In blind participants the children were slower than the adults, whereas in sighted participants the adults were slower than the children.

3.3. Volume

Fig. 4A shows the accuracy for the dimension volume; there is a significant main effect for age \((F_{1,57} = 9.321, p = 0.003, \eta^2_p = .141)\).
The adults were in general more accurate than the children. There was no significant interaction between age and visual status ($F_{1,57} = 1.801, p = 0.185, \eta^2 = 0.031$).

Response times, as depicted in Fig. 4B, showed a main effect for series ($F_{3,171} = 17.995, p < 0.001, \eta^2 = 0.240$). Participants became faster over the four sessions. No significant interaction was found for age and visual status ($F_{3,171} = 0.052, p = 0.820, \eta^2 = 0.001$).

3.4. Texture

Fig. 5A shows the accuracies for the dimension texture. There was a main effect for age ($F_{1,57} = 8.538, p = 0.005, \eta^2 = 0.130$). In general the adults were more accurate than the children. The data also showed a main effect for series ($F_{3,171} = 2.933, p = 0.035, \eta^2 = 0.049$). The performance of the four groups improved over time. There was no significant interaction between age and visual status ($F_{3,171} = 1.117, p = 0.295, \eta^2 = 0.019$).

The response times for the dimension texture showed a main effect for series ($F_{3,171} = 18.068, p < 0.001, \eta^2 = 0.241$), indicating that subjects became faster over the series (see Fig. 5B). However, a significant interaction for series and age ($F_{3,171} = 3.097, p = 0.028, \eta^2 = 0.052$) indicated that response times of children decreased more over time than those of adults. As shown in Fig. 5B response times of sighted adults did not change over the four sessions, whereas the other three groups seem to respond faster over the four sessions.

There was no significant interaction effect between age and visual status ($F_{1,57} = 3.335, p = 0.073, \eta^2 = 0.055$).

3.5. Analysis for separate age groups

Since almost all the dimensions showed a main effect for age, the GLM analyses were also performed for children and adults separately to look for possible significant main effects of visual status and interactions between the repeated trials and visual status that might show up when age is no longer an independent variable.

These separate analyses showed significant effects for the response times, but not for accuracy. The response times for the dimension exact shape showed a main effect for visual status for the adult participants ($F_{1,29} = 14.315, p = 0.001, \eta^2 = 0.330$). Blind adults responded much faster than sighted adults. For the dimension weight, we also found a main effect for visual status in the group of children ($F_{1,29} = 9.007, p = 0.006, \eta^2 = 0.243$). The sighted children responded faster than the blind children. The dimension texture showed a significant interaction for series and visual status ($F_{3,87} = 3.095, p = 0.031, \eta^2 = 0.096$) in the adult participants but not in the children. Blind adults became faster over the series whereas the sighted adults’ response times hardly changed.

3.6. Speed-accuracy trade off

Given the fact that we were also interested in the relation between speed and accuracy for the four groups on four different dimensions, we calculated the correlations between response time and accuracy (averaged over the four series) both within groups and over the total group of participants. Positive correlations would indicate possible speed-accuracy trade-offs. Data of the separate groups showed only two significant correlations and these were negative. It concerned the dimension texture, where the sighted children showed a negative correlation of $r = -0.61 (p = 0.016)$ and the dimension exact shape, where the blind children had a negative correlation of $r = -0.61 (p = 0.016)$.

Table 1

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Accuracy</th>
<th>Response time</th>
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<tr>
<td>Volume</td>
<td>Weight</td>
<td>.08</td>
</tr>
<tr>
<td>Weight</td>
<td>Volume</td>
<td>.47**</td>
</tr>
</tbody>
</table>

* $p < 0.05$.
** $p < 0.001$. 

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Fig. 5. Accuracy (A) and response times (B) for texture over four repeated series by age and visual status, error bars indicate standard error of measurement.
Table 2
Comparison of the data of series 1 with the original study of Lederman and Klatzky (1987) for accuracy on the four dimensions in %. L&K = Lederman and Klatzky (1987), M = Mean, SD = Standard Deviation, CI = 95% Confidence Interval.

<table>
<thead>
<tr>
<th></th>
<th>L&amp;K n=18</th>
<th>Sighted adults n=15</th>
<th>Blind adults n=15</th>
<th>Sighted children n=15</th>
<th>Blind children n=15</th>
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<tr>
<td></td>
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<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
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<tr>
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<td>97 (9)</td>
<td>92 (10)</td>
<td>88 (10)</td>
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<tr>
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<td>87 (10)</td>
<td>86 (18)</td>
<td>76 (9)</td>
<td>63 (19)</td>
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<tr>
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<td>86 (18)</td>
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<td>65 (18)</td>
<td>72 (9)</td>
<td>84 (22)</td>
<td>73 (9)</td>
<td>65 (26)</td>
</tr>
</tbody>
</table>

r = −0.68 (p = 0.006). In both cases the correlation was mainly caused by just a few participants who were both slow and inaccurate. There was only one positive correlation over the total group of participants, namely for the dimension exact shape (r = 0.31, p = 0.016). A subsequent partial correlation, controlling for age and visual status, found no significant correlation (p = 0.31), indicating that the positive correlation is probably due to group differences. Inspection of Fig. 2A and B suggests that the high performance but long response times of the sighted adults in comparison with the other groups is the major cause of this positive correlation.

3.7. Correlations between dimensions

Correlations between dimensions were calculated to study individual variation in accuracy and response times, that is whether subjects who were fast and/or accurate in one dimension were also fast/accurate in other dimensions. As age and visual status might affect these correlations, they were partialled out. Table 1 shows the partial correlations for accuracy and response times between the four dimensions. The correlations for accuracy were weakly positive (range .53 to .72). The intercorrelations for response times were stronger and in the medium to high range (.68 to .72).

3.8. Comparison with the Lederman and Klatzky data

Table 2 shows the accuracy of the participants in the original study of Lederman and Klatzky on the four dimensions in the left column. Unfortunately, only the mean scores are known and no standard deviations or standard errors of measurement. For ease of comparison and due to the fact that Lederman and Klatzky did not repeat the trials, the mean scores on accuracy of the four different groups in the other columns are only shown for series 1. The order of the accuracy scores is the same for the Lederman and Klatzky and our studies.

4. Discussion

4.1. Children versus adults

Adults were expected to be more accurate and faster than children, due to the assumption that children need more redundancy in their information processing (Millar, 1994a,b, 1997). This assumption was partly confirmed by the data. The adults were indeed significantly more accurate on all four dimensions but they were not faster than children. With the dimension ‘Exact Shape’, we saw the largest difference in accuracy between children and adults. This might be caused by the complexity of the task and the spatial skills needed to solve this task correctly. These spatial skills might not have been matured by the complexity of the task and the spatial skills needed to solve the largest stimuli were difficult to enclose for the children forcing them to use additional strategies.

According to Millar (1994a,b), children need more rehearsal and redundant information to interpret haptic and spatial information. Following this statement, we expected children to be slower than adults. However, our assumption proved to be wrong: adults did not perform significantly faster than children. On the contrary, on some tasks the children performed even faster than adults. We can only speculate about an explanation. Maybe children underestimated the complexity of the task or by responding fast they could relieve appeals to short time memory. Another explanation might be that sighted adults try to visualize the shape they feel and that this process takes extra time (Gibson, 1966; Révesz, 1950), while blind adults and all children skip this strategy. Redundant information from visualizing the shape obviously did not improve speed of performance, but apparently they needed this extra time to reach the same level of accuracy as blind adults. The faster performance of the blind adults may also be explained by the use of a more efficient haptic strategy (see also Davidson, 1972).

4.2. Sighted versus blind participants

Despite the haptic experience blind persons have in tasks which sighted people execute visually, we posed that the performance of blind and sighted participants would not differ once their performance is corrected for familiarisation. In previous studies, blind participants performed better on the first occasion, but sighted participants improved after a training, when they became more familiar with the task and learned which haptic strategy was efficient in solving the task (see e.g., Davidson, 1972; Davidson & Whitson, 1974; Grant et al., 2000). Since our experiment did not include a training session, it could have been possible that the blind participants would outperform the sighted. However, in our study we did not find any difference on accuracy between the two groups. The practice trials we offered to the participants, may have served as a training, resulting in no difference in performance between blind and sighted participants. This result was also found when adults and children were analysed separately. For children, this result is in accordance with the results of a study of Morrongiello et al. (1994).

4.3. Familiarity

We expected that performing the same task four times would only affect speed in adults, whereas for children we thought it might affect accuracy as well as speed of responding. However, the data showed that repeating the experiment had only a positive effect on the response times for the dimensions ‘Exact shape’ and ‘Volume’: all groups became faster over time. For the dimensions ‘Weight’ and ‘Texture’, only the response times of the children decreased over the series. Accuracy did not improve after repeating the experiment. This lack of improvement might have resulted from a ceiling effect or by the fact that no feedback was given.

4.4. Speed-accuracy trade-off

The relation between accuracy and speed was studied for the total group and within the four groups. Only one positive correlation was found for the total group. For the dimension ‘Exact Shape’ the significant
correlation was caused by a few very slow performing sighted adults, who were also very accurate. So differences between individuals within a group or differences between groups cannot be explained by a speed-accuracy trade-off.

4.5. Individual variation

Individual variation was studied by computing correlations for the four dimensions for both accuracy and response times, with age and visual status partialled out. Response times for all the dimensions correlated significantly. For accuracy, the correlations were weak and only significant in half of the cases. Our preliminary conclusion is that, since the speed of performance is relatively stable across tasks and since age and visual status were partialled out, the moderately strong correlations for response times can be thought of as individual response and learning styles: respondents react in tests of all four dimensions with rather the same speed, irrespective of their accuracy. In contrast, accuracy is much more dependent on the type of task, because there was large variation in accuracy between the four tasks, and accuracy varied largely within individuals, resulting in a lack of significant inter-correlations. This may indicate that tactual dimensions are picked up independently and there is no underlying capacity of the haptic system to pick up all dimensions with the same efficiency.

4.6. Comparison with the data of Lederman and Klatzky

The accuracy performance of the adults in the current study was comparable with the participants in the study of Lederman and Klatzky (1987). ‘Texture’ was easiest to match and ‘Weight’ most difficult. When we compare the 95% confidence interval of the data in the current study with the original data of Lederman and Klatzky, the sighted adults included in our study performed slightly better on all four dimensions. When we compare the Lederman and Klatzky data with the blind adults, accuracy is within the 95% confidence interval for three of the four dimensions. The data of the children also show a comparable organization in difficulty level. However, ‘Exact shape’ was about as difficult for the children as the dimension ‘Weight’. The individual variation was quite high, which might be explained by variation in developmental trajectories. When we compare the scores of adults in the study of Lederman and Klatzky with the blind children all the scores are within the 95% confidence interval. This is not the case for the sighted children: for the dimension ‘Exact Shape’ the adult score lies just above the confidence interval.

5. Conclusion

When we compare the data of the blind children and adults with their sighted peers, the results showed that the blind children did not perform any better than their sighted classmates with regard to accuracy and response times. The blind adults, however, were faster than the sighted adults on ‘Exact Shape’. The blind adults were not significantly faster than the children in this task, but they were more accurate. This difference may have been caused by the use of different strategies by blind and sighted adults. Until now this is unknown and a topic for future research.

Before the start of the study we expected the blind children to outperform the sighted children, due to the fact that blind children receive individual tactual training and sighted children for obvious reasons do not. Yet, the results did not confirm this expectation. One explanation might be that blind children are usually trained in skills other than the ones assessed in the current study. The results also showed that in adulthood blind people become faster in solving haptic spatial tasks in comparison to sighted people. Since object identification and discrimination is normally much faster accomplished by vision than touch, enhancing the speed of haptic object identification and discrimination must be useful for blind people. A clinical implication might therefore be that it makes sense to train these haptic skills to blind children early in childhood.

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