SPATIAL REPRESENTATION AND HAPTIC MENTAL ROTATION

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Abstract: In this paper it is argued that it is legitimate to talk about mental imagery, and thus, to claim that spatial information is coded in an analogue mode. Evidence from research with blind people indicate that they can perform mental rotation and that analogue spatial cognition does not depend on visual information. It is therefore proposed that, if the blind can perform mental rotation in an analogue mode, there exists a common mode, for processing spatial information, which is not modality specific. The results of the presented study, which was conducted on eight blind subjects, and was intended to extend previous findings, was not conclusive. Reaction time of a haptic mental rotation task could not directly be shown to be a linear function of angular disparity. An alternative theory, based on two different cognitive strategies, is considered as an alternative explanation of the experimental results.

1. INTRODUCTION

For a rather long time there has been a controversy over the way spatial information is coded. The major issue in the debate, which has been going on for the last two decades, has been over the accuracy of the concept of "mental imagery"[1] in relation to the representation of spatial information. Is it legitimate to talk about mental images or can we reduce them to propositional representations, as the computationalists claim? This will be the first question that I want to discuss in this paper. Arguing for the need of mental images to explain our spatial cognition, I will proceed to address the question of whether mental images need to contain visual information or if it suffices that they contain the abstract geometric properties of the world they represent. Concluding that mental imagery does not need to depend on visual information the third and final question here is whether we can propose the existence of a single mode for spatial representation, of an analogue character, featuring geometric properties.

[1] Some people use the concept of 'imagery' as a name of an empirical phenomenon, meaning that they expect to find a physical object and/or space in the brain. In this paper I use the term in accordance with its expanatory force or, if you, like as a theoretical term. This means that I regard imagery as a mode of representation of something external without there being a need to know the physical structure which underlies this process. Much of the controversy over mental imagery stems from conflating the empirical and explanatory meanings of the concept.

2. ARE THERE ANALOGUE SPATIAL REPRESENTATIONS OR IS IT ALL MENTALESE?

The first question to be addressed in this paper is whether we have reasons to speak about such a thing as analogue representations or if we can do without them. Shepard and his colleagues have, in an ingenious series of experiments, produced results indicating that mental manipulation of images involves a sequence of transformations similar to those that would be carried out in manipulating real objects (Shepard and Metzler 1971, Shepard and Cooper 1986). In these experiments on mental imagery, which have by now become paradigmatic, subjects were presented with two perspective drawings that portrayed the same three-dimensional shape. The objects were depicted in very different orientations and with variable angular disparities. The subjects had to determine whether the two perspective drawings depicted the same object or whether they depicted different ones. The hypothesis tested by Shepard et. al. was if the subjects, in order to answer, had to mentally rotate the drawings in their head to determine if they could be brought into congruence.

The result of these experiments demonstrate that the time taken to mentally rotate objects is directly proportional to the angular disparity between the objects. The linearity of the function has been taken by many cognitive scientists as evidence that our spatial representation has an analogical nature. By this we should understand that mental images take up some sort of *mental space*.

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There are those, on the other side of the mental imagery debate, who argue against the notion of mental images as such, while favoring the distinctive non-pictorial character of mental images (Pylyshyn 1978). With the term "non-pictorial" Pylyshyn means that the representational structure of spatial information is based on a common articulated descriptive system whose nature is symbolic rather than iconic-like. In other words, he claims that instead of the concept of "imagery", there exists a basic code, a *Mentalese*, in which all cognitive activities are performed.

Pylyshyn believes that such an articulated system of symbols is sufficient to account for many of the phenomena that we call mental imagery. According to Pylyshyn and the propositionalists, what we refer to as "images" are not really a different form of representation, but rather a different way to render propositionally coded information. Thus, the controversy over mental imagery stems from the question if cognition, and with it spatial representation, should solely be analyzed in propositional terms or if it is represented in an analogue mode which is irreducible to a propositional structure.

One of Pylyshyn's arguments against the notion of mental imagery is that if there exists an analogue mode of representation then there should exists a high degree of correspondence between the operations in the world and our mental operations. But he points out that this correspondence, which the analogue representation theory proposes, is highly partial. The correspondence is partial since our mental operations are subject to many constraints for which there are no physical counterparts. For example, he says, that we cannot imagine a familiar scene, imagine it upside down, out of focus and as if viewed through a green filter. We simply cannot keep track of all the relations.

However, Pylyshyn forgets that this is true exactly because the concept "analogue" does not mean that images can and should have exactly the same properties and constraints as the physical world. Mental images are neither a thing in the head that can be manipulated like a physical object, nor pictures which can be put upside down and seen from different perspectives. The concept "analogue" rather refers to the structural similarity, i.e. the isomorphism, between the spatial dimension of the physical world and the metric relations in the representation of this world in our mental space. Thus the concept analogue should not be understood as literally as Pylyshyn takes it, but rather in a much more abstract sense.

A finding that supports the view that there exists a structural isomorphism between our mental representations and the world they represent, is that mental images seem to preserve metric spatial information (Kosslyn et. al. 1978). Their hypothesis was that if mental images really do preserve geometric information then the actual distance between parts of an imagined object should effect scanning time. For their study they used fictual visual maps which the subjects had to memorize. They were then given the name of an object on the imaginary map and were asked to focus on that particular object. A few seconds later, a second object was named and subjects where instructed to scan from the first object to the second. If the scanning time was not effected by the distances on the map, then it should be evidence of subjects processing non-imagery structures of symbols. However, the result was that the time taken to evaluate the mental image was directly proportional to the distance between parts of the imagined map.

Still, the propositionalist can try to interpret this evidence within his propositional framework. A propositional representation can represent an object in different orientations. An upright letter could thus be represented by predicates that specify the features of the letter that are to the right, left, top and bottom. Rotating a letter 180° would simply be equal to letting the top and bottom predicate switch places. But if this propositional description was true, should we not expect all rotations to take equal time since they would always include the same number of propositional steps? Instead, the experimental results indicate a direct proportionality between the time taken to mentally rotate an object and the number of degrees that it is rotated in the world. Why should geometric relations in a perceived object influence the scanning time if there was no trace of structural isomorphism between the mental image and the represented object?

If people were accessing some sort of underlying list structure, as the propositionalists claim, then it is difficult to explain the above mentioned results. Would it not be odd if the time taken to access different symbols was proportional to the time taken to scan a subjective image of an object? Would not the absence of structural similarity yield a constant chronometric interval for image scanning, or at least yield a non proportional relation to the size of the image? The image scanning experiments suggest that parts of images depict corresponding portions of the objects which are being represented. Therefore, in at least one respect, we can say that mental images have spatial properties.

The scanning experiments also suggest that images can be reconstructed. This is further supported by three experiments in which Finke et. al. (1989) demonstrated, that given suitable conditions, people can reconstruct, reinterpret and give a new conceptual description to a pattern that has been represented as an image. For example, they asked subjects to perform the following task:

1. Imagine a capital letter 'D'. (Guess #1)
2. Rotate the figure 90 degrees to the left. (Guess #2)
3. Now place a capital letter 'J' at the bottom." (Final identification)

The subjects answered that they could "see" an umbrella. It might be possible that the symbolic propositional coding for the capital letter 'D' when rotated left and the proposition for the capital letter 'J' placed at the bottom, produces in this combination the propositional symbol for an umbrella. But why should a symbolic string denoting a symbol, which in turn denotes an alphabetic sound, when put in a certain geometric relation to the string of symbols denoting another alphabetical symbol, result in the symbol of an artefact that we use when it rains? And by the way how cognitive does such a procedure sound to you?

How can a computationalist claim that mental images are only symbolic descriptions stripped of geometrical information when people, at the same time, can discover new patterns in an image? One highly plausible answer that the propositionalist must seriously take into consideration is that mental images, in some way, contain geometric information which is available for interpretation.

3. Is visual information necessary for mental imagery?

If imagery has spatial elements, as suggested in the previous section, the question to pose is how close the relationship is to visual perception. Does spatial representation and mental imagery depend on visual information? One way of determining the role of vision in mental imagery is to let blind people perform tasks which require spatial representation and to compare with the performance of sighted people. Ungar et. al. (1995) has shown that blind children do not seem to code stimulus differently to sighted children. Visually impaired children are able to learn a tactile array with complex spatial relations. Further, Kerr (1983) has shown that congenitally blind adults are capable of preserving and processing spatial images in a very similar manner to that of sighted subjects, and that their spatial images preserve spatial information. The results of the blind and the sighted were similar in the performance of haptic tasks which involved spatial abilities.

It is important to keep in mind that congenitally blind subjects lack a visually based mental representational skill. Thus, Kerr concludes that "There is no reason to expect that, with the exception of specially visual components, the mental experience of blind people is any less rich or varied than that of the sighted." (Kerr 1983 p. 274). She emphasizes that spatial imagery processing ability need not depend on visual perceptual experience.

Marmor & Zaback (1976) made investigations into the relation between vision and mental imagery, in which they tactually presented congenitally blind, adventiously blind, and blindfolded sighted adults with Plexiglas forms. Two forms were presented in the same orientation, or one form was rotated by a certain amount. The subjects were then asked to make same–different judgments. The reaction time for the congenitally blind as well as for the adventiously blind increased as a linear function of angular disparity. Further, Carpenter & Eisenberg (1978) presented congenitally blind with a haptic letter-judgment task. A letter was tactually presented in a rotated orientation while the subjects judged whether it was a normal letter or a mirror image one. The result indicated a linear increase in response time with the rotation of the letters away from upright. It can therefore be suggested that blind subjects can perform mental rotation successfully, and that they can operate on a spatial representation that does not have any specific visual component. The same conclusion is reached by Millar (1982).

Together, the above results seems to suggest that mental imagery does not depend upon visual imagery since, apparently, even blind people, who lack visual perception, perform successfully.

Proponents of propositional theories might say that the fact that blind subjects can solve tasks which involve mental rotation only confirms that imagery processing must be propositional in its nature. They might claim that imagery could not possibly be in analogue form since blind people lack the visual information from the external world to which the mental image is supposed to be analogue. If there is no visual perception, then there is nothing with which a mental image could be isomorphic. But this assumption is based on the belief that representation of spatial relationships, and thus mental imagery, is tied to a specific modality, namely, that of vision.

Several researchers (Röder et al. 1993, Millar 1988), who have performed studies of spatial relations on blind people, suggest that representation of spatial relations is not tied to a specific modality. If the result of blind people performing mental rotation tasks yields a linear relationship this would mean that mental rotation must have a common base with the visual–analogue representation. Further, if blind people yield a linear function in mental rotation tasks, it would mean that the most important determinant of the mental rotation function is the spatial component that is common to both visual and haptic modalities, rather than any uniquely visual or haptic characteristics.

Previous research (Marmor and Zaback 1976; Carpenter and Eisenberg 1978) suggests that mental rotation by the blind presents such a linear relationship. The experiment conducted by the author has a similar design to the studies presented above, when it comes to making same–different comparisons as well as in using tactual stimuli. One of the main differences is that in the present study the stimuli material was not haptic letter-forms or Plexiglas shapes, but rather three-dimensional blocks based on the perspective drawings that Shepard used. The advantage of using fully three-dimensional blocks instead of contour haptic shapes is that the spatial dimensions can be better explored. The research presented here was designed to extend the earlier presented findings and, thus, support the theory that spatial information is coded in a analogue way, and not tied to any specific modality.

4. EXPERIMENT

4.1 Pilot studies

Two pilot studies on blindfolded sighted subjects and one with a blind subject were conducted. Three different shapes of wooden blocks were tested on the blindfolded sighted subjects in order to determine how the shape factor contributed to the difficulty of the experimental task. It was found that blocks based on some of the perspective drawings used by Shepard in his studies were too difficult. It was estimated that these shapes would probably yield an error percentage that would be unacceptably high. The set of blocks that was found appropriate for the study is presented under the heading "4.3 Apparatus".

The pilot study with the blind subject revealed the importance of the instructions being clear enough so the subject understood the task properly. It is quite easy to understand that blind people develop a very sophisticated haptic sense. The blind subject discovered far more details on the blocks than would a person with normal sight who is not trained in haptic perception. It was concluded that it would be important to make it clear to the subjects that it was the shape of the blocks which was to be compared and no other feature.

4.2 Subjects

The subjects were contacted with a Braille letter describing the nature of the experiment and parts of its purpose. The author was assisted in the above matter by "Synskadades Riksförbund" which is the Swedish national organization for the blind. Three of the subjects were men and five were women. The youngest subject was 29 years old and the oldest was 58. They had attended a special school for visually disabled and are all Braille readers. When asked before, as well as after the experiment, they reported that they had never before participated in the performance of any similar task. The subjects were not paid for their participation.

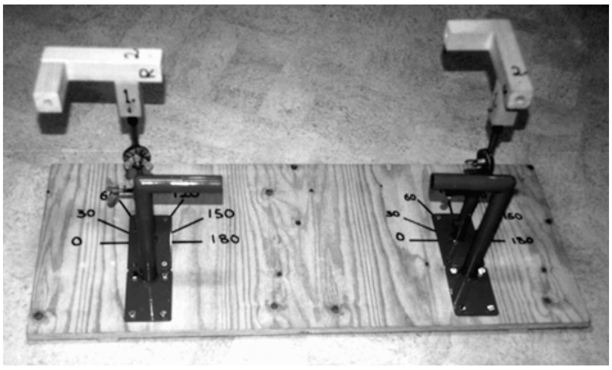
The reasons for the subjects' blindness were all medical and in no case was an accident the cause (cf. Table 1). The two subjects suffering from diabetic retinopathy had fully normal sight until the age of 29 and 23 respectively. The subject with retinal detachment had light perception, which means that she can discriminate light from darkness. The subjects with congenital glaucoma have, during certain periods of their lives, also had light perception which they now have lost completely. The two subjects with retrolental fibroplasia and with a developmental congenital disorder have never experienced any kind of visual stimuli at all.

Causes	Blind before the age of 5	Blind after the age of 5
Diabetic retinopathy	0	2
Retinal detachment	0	1
Retrolental fibroplasia (RLF)[1]	1	0
Congenital glaucoma	2	1
Congenital developmental disorder[2]	1	0
Total	4	4

Table 1. The causes of blindness in the subjects. [1]This disorder has come to be called retinopathy of prematurity (ROP). In ROP, excessive oxygen administered to premature infants leads to damage of the retina. [2]In this case the blindness is due to a tumor, developed during infancy, that presses on the optical nerve.

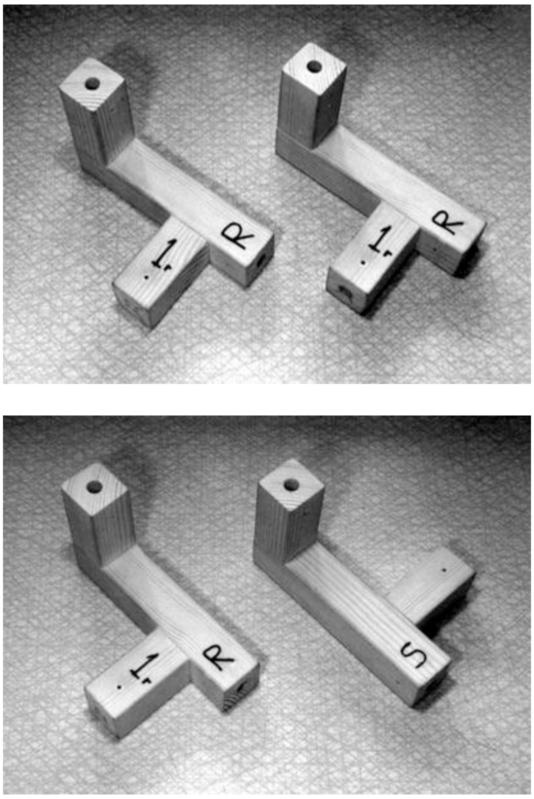
4.3 Apparatus

The apparatus constructed and used for the study was a wooden board with a pair of handles, as well as two devices for fastening blocks (cf. Picture 1). The fastening devices were constructed in such a way as to permit total rotation of the attached block along a horizontal plane.



Picture 1. The apparatus used in the experiment.

Three wooden blocks were constructed so that the shape contained two angles along two directions. The size of the blocks were approximately 13 by 7 cm. Two of the blocks were identical and denoted as "same". The third block was mirror reversed and denoted as "different". The mirror reversed block cannot be brought into congruence with the "same" block by any rotation (cf. Picture 2).



Picture 2. The shapes of the two blocks that the subjects were asked to compare. The left picture shows the pair of 'same' blocks while the right one shows the 'mirror reversed' blocks.

4.4 Method and design

The subjects were asked to compare the blocks in pairs. First hey had to position their hands on the handles of the apparatus. On a given signal, which initiated an electronical timer, the subjects removed their hands from the handlebars and put them on the stimulus. When they responded either "same" or "different" the chronometer was stopped. The fact that the handlebars constituted the starting position for the comparison made it possible to chronometrically, in an accurate way, guarabtee that the task was equal for all subjects and that no variations, due to time taken to reach and locate the stimulus, could influence the measured time intervals. It was pointed out to the subjects that they should answer as quickly as possible. During the instruction phase the word "rotation" was not used. The whole experiment was videotaped.

Blocks which were mirror images of each other were used in order to prevent subjects from discovering some distinctive geometrical feature that only one of the two objects possessed, and thereby being able to reach a decision without having to perform a mental rotation. Prior to the chronometric task the subjects were familiarized with the board by touching it. They also went through a practice session with the stimuli in order to properly understand the nature of the task and to comprehend the extent of the difference between the same and the mirror reversed shape.

In half of the trials the subjects were presented with two identical blocks and in the other half with dissimilar (i. e. one of the blocks was mirror reversed). The starting angular positions of the blocks was completely randomized. On each comparison the blocks were presented so that the angular disparity between the left-hand and the right-hand block was one of the following: 0°, 60°, 120°, or 180°. In total, there were 4 angular disparities (0°, 60°, 120°, and 180°) x 2 different modes of attaching the pair of blocks (horizontally and vertically) x 2 blocks (same , mirror reversed) x 2 trials on each comparison. The complete factorial design required 32 trials per subject. The internal order of the 32 comparisons was also randomized. For practical reasons the experiment was conducted at the homes of each blind subject. The time taken to complete a series of 32 comparisons was approximately 30 minutes.

4.5 Results

An analysis of variance was performed on the reaction times for the total amount of comparisons, as for the correct responses only. The correct responses were 79% of the total amount of responses. The equivalent figure in Shepard's experiment was 97%, but then it has to be kept in mind that he presented subjects with two-dimensional perspective drawings and not with three-dimensional blocks as in the present experiment. The rate of correct answers reported by Marmor and Zaback (1976) is 91% for the early blinded and 96% for the late blind.

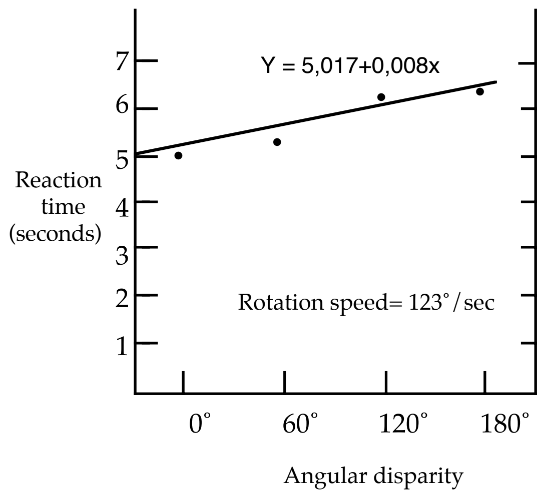


Figure 1. Reaction time means and the least squares line as a function of the angular disparity of the stimuli for all answers.

The rather high error percentage in the present study can be due to the complexity of the blocks that the subjects were asked to compare. Figure 1 shows the least squares line for all the answers, while figure 2 shows the same slope calculated on the correct answers. The effects yielded were $p = 0.028$ for all the answers and $p = 0.135$ for the correct answers. The slope of the best fitting least squares line relating reaction time to the angle of rotation was

0.008 for all the answers and 0.006 for the correct answers, while the y-intercept was 5.017 and 4.956 respectively. The two figures also show the accuracy with which these lines can be used to predict the mean reaction times at different angular disparities. The correlation coefficient R was 0.138 for all answers and 0.105 for the correct answers.

Reaction time means averaged across individuals 4950, 5230, 6210 and 6330 msec at 0°, 60°, 120° and 180° respectively. The average response time increased with 1380 msec from 0° to 180°. The speed of mental rotation based on the slope suggest approximately 123°/sec for all answers and 167°/sec for correct answers.

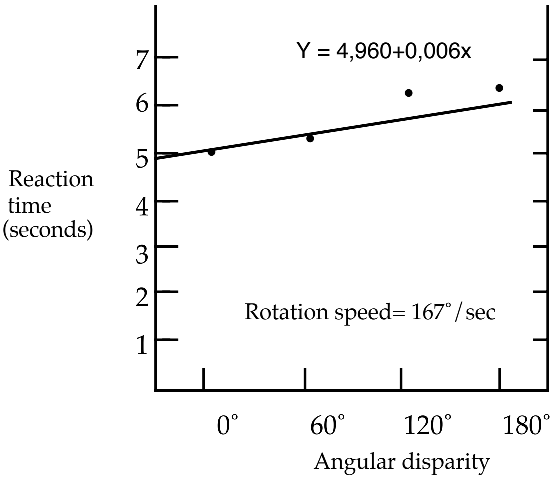


Figure 2. Reaction time means and the least squares as a function of the angular disparity of the stimuli for correct answers.

This difference, in the rate of mental rotation, between all answers and the correct answers, probably shows that the subjects are much quicker when making correct block comparisons. The Plexiglas forms used in the experiment conducted by Marmor and Zaback (1976) were rotated at approximately 59°/sec by the early blind and at 114°/sec by the late blind. The speed of mental rotation of the two-dimensional perspective drawings in Shepherd's experiment was roughly 60°/sec. The mirror reversed blocks took 6070 msec to compare on average while the identical blocks took 5420 msec to compare. Thus mirror-reversed blocks took on average 605 msec longer to compare than the identical blocks.

4.6 Errors

The subjects responded incorrectly on an average of 21% of the trials with individual error rates ranging from 0% to 34%. It is interesting to note that the overwhelming majority of the errors were made at angular disparities of 120° and 180° (cf. Table 2). This result should be reasonably easy to explain if an analogue mode of spatial representation is assumed. The more the mental image is rotated, the more difficult it becomes and thus increases the error latency. It can be observed that there were almost no errors at disparities of 0° and 60° while the error percentage at 120° and 180° was very high. It is difficult to explain why the error latency does not increase proportionally with the angular disparity. Comparisons at 120° and 180° disparity seem to be equally difficult.

It is also interesting to note that 78% of the errors were made when the subjects were comparing identical blocks while only 22% of the errors were made when comparing mirror reversed blocks. This finding can be explained by the fact that subjects were confused when comparing identical blocks that were rotated against each other with 120° or 180°. The mental rotation simply became too difficult. It seems that it was easier to answer correctly when the blocks were mirror-reversed at a high angular disparity. This finding could possibly be explained by the fact that in mirror reversed comparisons the blocks exhibited clearer and more obvious differences than when comparing identical blocks.

	Angular disparity 0°	60°	120°	180°	
Identical	2	2	35	39	78
Reversed	0	0	11	11	22
Total error percentage	2	2	46	50	100

Table 2. Error distribution in percent of the total amount of errors. Note how the majority of the errors occur at angular disparities 120° and 180° and that the subjects were especially prone to erroneous answers when comparing identical blocks.

4.7 Introspective reports

In the discussion following the experiment subjects made various comments on their performance as well as on the task itself. Most of the subjects stated that they experienced the task as rather confusing and mentally demanding on occasion. Two of the subjects, who described themselves as having excellent spatial abilities and who performed very accurately and consistently, used the Swedish words for 'twist' and 'turn' ('vrida' and 'vända') when commenting on their performance. They both said that they had to turn the objects in their heads in order to try to match them. Another subject, who made less errors than the average, said that she found the task rather easy since she has practiced rotationg shapes in her mind when reading Braille reversed; from the right to the left. Two subjects seemed, based on their verbal reports, to use a block-centered strategy. They reported that they thought of the blocks as reference points while they tried to imagine themselves moving around them to see what they looked like from another perspective. The rest of the subjects could not describe their performance verbally.

4.8 Discussion

The results of the conducted experiment cannot in a conclusive way be said to support the hypothesis that haptic mental rotation yields a linear relationship. One explanation of the deviations from the linear function, especially at the higher angular disparities, is that the number of subjects used in the study was rather small, which means that the result of one, very deviant subject's performance could be enough to strongly effect the overall result. Another explanation of the deviations from the least squares line is the fact that the blocks constructed and used in the present study might have been too complex. However, neither is the result presented by Carpenter and Eisenberg (1978) as linear as the one obtained by Shepard, suggesting that it might not be all that easy to design an experiment for mental rotation of three-dimensional objects, and at the same time receive perfectly linear results.

Since the presented results are not conclusive for the original hypothesis that the experiment wanted to test, a subsequent hypothesis of a different kind might be attempted in order to explain the results. Considering the deviations from the least squares line, and especially the distribution of errors over the angular disparities, it can be suggested that the blind subjects used, two distinct mechanisms when compairing the blocks. In other words an alternative hypothesis is that the subjects, at the lower angular disparities of 0° and 60°, used some sort of *situated cognitive strategy* while they, at the higher angular disparities of 120° and 180°, used *mental rotation*.

This alternative hypothesis is derived from an examination of the videorecordings of the experiment. An analysis of the subjects' hand motions over the blocks provide some evidence for a situated cognitive action. In certain cases, when comparing blocks with small or no angular disparity between them, the subjects did not seem to haptically examine the blocks. Rather, they placed their hands on them and let 'something out there' determine their response. Still no subject, when commenting on their performance afterwards, reported a strategy by which they judged whether the block was "a left sided one" or "a right sided one".

An analysis of variance (ANOVA) compared the means of the results obtained at 0° and 60° with the results obtained at 120° and 180° in order to establish whether a significant difference existed between these two groups of angular disparities. The results of the analysis of variance were $F (1.7) = 13.65$, $p < 0.01$, indicating that there does exist a significant difference between the two groups of angular disparities. Further, a subsequent analysis of variance was performed to establish if there existed significant differences between the angular disparities within each group i.e. in the 0° and 60° group, and in the 120° and 180°. No significant difference was found, $F (1.7) = 0.182$. The results can thereby be viewed as supporting the hypothesis that these are two, internally homogeneous, processes.

In the light of the above obtained results, it can be suggested that the subjects could be using two distinct cognitive strategies.

However, to further describe the nature of the two different strategies that seem to have been used by the subjects requires further and more elaborate experimental data. In addition, a subsequent theoretical framework must be adopted or developed to properly account for the difference between the situated strategy and the one based on mental rotation. The sought for theoretical framework must also explain why and under which circumstances the shift in cognitive processes is made. One thing that can be established, based on the result of the present study, is the amount of time that the mental rotation mechanism in itself took. The mean response time for 0° and 60°, 5.220 sec, was subtracted from the mean response time for 120° and 180°, 6.264 sec, in order to calculate the time that the rotation mechanism took as such. The time required for the actual rotation mechanism, in the conducted experiment, was thus 1.044 msec.

5. General Discussion

> The extension, figures, and motions perceived by sight are specifically distinct from the ideas of touch called by the same names, nor is there any such thing as one idea or kind of idea common to both senses.
>
> George Berkeley – *An essay towards a new theory of vision 1709*

One of the computationalists' arguments for the propositional code theory focuses on the fact that we have a verbal and a nonverbal code in different formats. They point out that a third underlying code is required in order to explain how the verbal code can be related to the nonverbal. Their conclusion is that there must exist a basic mode which underlies all our cognitive activities. I don't think that too many people would disagree with this conclusion. The vital question however, and the origin of the controversy, is the nature of this mode and its degree of dependence on a specific modality. Computationalists have it that the common underlying mode is of a symbolic propositional structure; a Mentalese. Nevertheless, in the light of the discussion in the beginning of this paper it is equally possible to postulate that the common mode underlying both the verbal and the nonverbal codes has geometric and spatial properties.

One such mode is the *image schema* that has been proposed by Johnson (1987). By an image schema Johnson means a dynamic pattern that functions as an abstract structure of an image. According to Johnson "...'image schemata' have a certain kinaesthetic character – they are not tied to any single perceptual modality, though our visual schemata seem to predominate." (Johnson 1987 p. 25). He carefully points out that it is not a question of concrete mental pictures.[2] Further, he makes clear that the nature of these image schemata is not propositional, but rather analogue. He believes that the contours of our spatial representation shape our cognitive function in a structural way. What is interesting for my purpose is that this theory of conceptual information processing contains the elementary features of an analogue spatial representation. Further, it is proposed that this common mode, which is of an analogical nature and which underlies our cognitive processes, can be derived from all modalities. In other words imagery is not tied to any specific modality but can be derived from all sensory modalities. We can call this position for *the multimodality theory*.

What evidence supports the multimodality theory? One piece of evidence comes from previous research (Carpenter and Eisenberg, Marmor and Zaback, Röder et. al.) where it is suggested that blind subjects can perform mental rotation in an analogue mode – though it could not conclusively be established in the experiment presented here. These results fit very well with the belief that the representational mode for spatial information is not tied to the visual or the haptic modality since sighted as well as blind people can perform mental rotation.

Another argument to support the multimodal thesis is the fact that there seems to exist many similarities between vision and haptics. The Canadian psychologist Kennedy (1993), who has conducted numerous studies with blind persons and their drawing abilities, has concluded that the geometry of objects discovered by touch, is in principle the same as the ones found by vision, as far as direction and distance are concerned. Apart from the fact that using touch requires more time to explore a scene, he claims that touch can, just as vision, yield an impression of an array of objects in space. But not only is it direction and distance which can be obtained through touch, but also perspective. These findings are further supported by Morton (1991) who suggests that blind people have as good spatial abilities as the sighted. Kennedy notes that:

> To consider touch as proximal is to set its confines too narrowly. Touch is distal as well as proximal in its everyday use. It uses many of the features of central concern to vision, allowing perception of relief, including surface layout, with occlusion, corners, and vantage points. [...] The geometry of the objects that are found by touch is in principle the same as the geometry found by vision, so far as matters of direction and distance are concerned. (Kennedy 1993 p. 297)

Interestingly, he also shows how drawings of blind exhibit metaphor. It is of course a question of pictorial metaphors but nonetheless it is a very important finding. Blind people include features in their drawings that represent how a man is running and not standing still, or how a wheel is spinning and not motionless.

It can be argued that if there really does exist a common structure for the processing of visual and haptic information, which is not modality specific, it would be easy enough to test. All we need to examine is if blind people who regain sight can see automatically. Since it should not matter whether it is through visual or haptic information that one has accessed spatial relations, a blind person regaining vision should without problem be able to see. This is the question that the seventeenth century philosopher William Molyneux posed to his friend John Locke about 300 years ago. Specifically Molyneux asked if a man born blind, who had lived all his life in a haptic world, was made to see could by his sight distinguish a cube from a sphere. In his "Essay concerning human understanding" Locke answered 'no' to this question. Two decades later George Berkeley concluded that there was no relation at all between sight and touch.

There are extremely few documented cases of congenitally blind people acquiring vision. The total amount of such cases known are reported to be no more than twenty over the last ten centuries. Nevertheless, the American neurologist Oliver Sacks describes just such a case, among other things, in his book "An anthropologist on Mars". The result was that the previously blind person could not, after the restoration of vision, "see" objects. Instead he became extremely confused by the information he received from his eyes. Now, does this case prove that the multimodal approach is erroneous? I do not believe so. The reason for this is that the person in question did not know what the visual information meant and even less knew how to relate it to his fifty year-old haptic world. This case, despite its facinations, only demonstrates that the perceptual information has to be interpreted and learned to be understood. Therefore, after some examination, the Molyneux question appears to address a totally different question than the one concerning the multimodality thesis.

A third argument in favor of the multimodal thesis is the fact that even blind people dream. A sighted person's first thoughts about dreams experienced by the blind, are likely to begin with an awareness of how dependent her own dreams seem to be on visual representations, and a sense of how difficult it must be to dream without such representations. But as Kerr et. al. (1982) have shown, there exists a general similarity of form between the dreams of blind and sighted subjects. Kerr et. al. conclude that verbal dream reports from blind people indicate that spatial knowledge does not need to be represented in any sensory-specific modality. The fact that the reports are linguistically mediated descriptions of the spatial experience in the dreams makes it even more interesting. If the multimodal thesis is correct, then spatial representation should be coded as well as reproduced by vision, audition, touch, and the language system. Lakoff and Johnson (1980) argue that the metaphors, which seem to be ubiquitous in our language, exhibit

[2] An 'image schema' should be considered as a tool for a theoretical analysis of spatial cognition. We do not expect to find things in the head having image structures.

a direct structural similarity with the space we perceive due to the fact that we are embodied. Thus, language and spatial perception have structural similarities which is exactly what we would expect if the multimodal theory was true.

Finally, it is important to have some neurological evidence to support the multimodality theory. Kosslyn (1988) argues that it can be shown that, under certain circumstances, the left cerebral hemisphere is better at mental imagery than the right hemisphere – something counterintuitive to many who identify the left hemisphere with language. He argues that neither hemisphere can be said to be the seat of mental imagery. Maybe this result is not conclusive enough, but there are other results which are more convincing.

Rösler et. al. (1993) presented blind and blindfolded sighted subjects with alphanumeric stimuli on a tactile display. They then tested, through EEG recording, whether the occipital cortex of blind subjects participated in the encoding of tactile stimuli or/and in the transformation of haptic representations. In both sighted and blind the same potential was found during mental rotation. Their conclusion is worth citing:

> In all of the studies, a slow negative potential was found during mental rotation which consistently had its relative topographical maximum over the parietal to central cortex and whose amplitude increased with increasing angular disparity, i.e. the maximum and the most systematic effect was found with visual stimuli exactly over the same brain areas as in the present study with tactile stimuli. Thus, one can assume that irrespective of the input modality and irrespective of the amount of visual experience of the subjects the same cortical areas are primarily involved when this type of analogue reasoning has to be performed. (Rösler et. al. 1993 p 156)

In other words maximum effect in sighted was not recorded in the primary and secondary visual projection areas as would be the result if visual imagery was of importance for mental imagery. Instead, the maximum effects occurred over the parietal areas which are known to be essential for cross sensory integration and for spatial representations.

6. Conclusion

The study presented in this paper could not in a conclusive way establish a linear relationship between response time and angular disparity for mental rotation of tactical stimuli. Therefore, the theory of analogue spatial representation could not be confirmed. Further experimental results will be needed to test whether there exists a mode for processing spatial information that is not dependent on a specific modality. As an explanation for the obtained results an alternative hypothesis is suggested, according to which, the subjects used a situated cognitive strategy at the lower angular disparities and mental rotation at the higher ones.

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