MENTAL ROTATION OF LETTERS IN DYSLEXICS
AND IMPLICATIONS FOR DIAGNOSIS AND EDUCATIONAL TREATMENT

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Abstract

A classical mental rotation task (Cooper & Shepard, 1975) was performed with dyslexics and non-dyslexics. Group differences were found for mean reaction time but there was no difference in mental rotation effects between the groups. The results were interpreted within the framework of the Functional Coordination Deficit model (Lachmann, 2002). It was concluded that dyslexics rotate the letters mentally just as good as non-dyslexics but have a problem to finally decide, whether the letter is normal or mirrored. This problem occurred because of a failure in suppression of symmetry in the representation of graphemes. Dyslexics represent letter like objects. Therefore, they fail to discriminate between orientational alternatives and for the same reason fail to establish unambiguous relation between grapheme and phoneme representations.

According to the International Classification of Diseases, developmental dyslexia is a specific disability in learning to read and to spell adequately despite of at least normal intelligence, adequate instruction and socio-cultural opportunities. Furthermore, sensory defects in vision and hearing should be excluded as to be responsible for the problems in reading and writing.

One of the major symptoms of dyslexia are reversal errors, that is, the children confuse letters which are horizontally or vertically symmetrical to each other or rotated (e.g., p / q; b / d; p / d). These errors are normal in beginning readers but become very rare after practice. In dyslexics, however, they still occur even after years of reading experience. Orton (1925, 1928) postulated that these problems reflect the cardinal symptom of developmental dyslexia. He assumed that these confusion errors (strephosymbolia) are caused by a faulty development of cerebral dominance and interhemispheric communication. Later on, phonological skills were considered as to be more relevant to explain dyslexia (e.g., Bradley & Bryant, 1978; Liberman et al., 1971). In this context, it was often argued that Orton believed that dyslexics have a perceptual deficit and actually see letters in a wrong orientation (Vellutino, 1977). However, as argued by others (Corballis & Beale, 1993; Lachmann, 2002; Lachmann & Geyer, 2003), Orton assumed reversals to be the result of labeling problems in memory and not of problems in visual perception.

There are a couple of alternative models which try to connect the original ideas of Orton with more recent neurological theories (Corballis & Beale, 1993) and experimental results (Lachmann & Geyer, 2003; Brendler & Lachmann, 2001). One is the multicausal Functional Coordination Deficit
(FCD) model (Lachmann, 2002). Within this model, reversal errors are explained as a result of a failure in suppressing symmetry generalization in reading. Symmetry generalization, as a result of evolutionary and individual development, is assumed to be learned as an infant to warrant behavioral advantages, such as object constancy. In reading, however, this mechanism may be a hindrance, because graphemes are visual symbols, and as such they have to have a non-ambiguous relation to the respective phonological information they represent (Friederici & Lachmann, 2002). In this context, it is argued that learning to read is comprised of learning to treat graphemes as symbols instead of objects. This skill is achieved very early, during the first stage of reading acquisition. A failure in complete suppression of symmetrical information in the representation of visual symbols during reading produces ambiguous relations between visual and phonological information and thus disturbs the functional coordination and may cause problems in learning to read. In this respect, reversal errors do not reflect a visual perceptual deficit (Vellutino, 1977) or an incomplete hemispheric dominance (Orton, 1925), and they do not reflect the one and only cardinal symptom of dyslexia. Instead, the FCD assumes that this kind of problem occurs in a subgroup but not in all dyslexics (Lachmann, 2002; Lachmann & Geyer, 2003).

This assumption indicates that reversals are not necessarily the result of problems in the processing of spatial information per se, neither for objects nor for symbols. They are rather an effect of a disability to represent symbols, such as graphemes, strictly view-point dependent. In particular, problems occur when different orientations have to be represented and performed distinctly to be connected unambiguously with distinct phoneme categories. This hypothesis was tested using a classical mental rotation task (Lachmann, Rusiak, Brendler & Jaskowski, in preparation). In this task a rotation has to be performed mentally in order to decide whether a letter is of normal or mirrored orientation. It is predicted that dyslexics rotate the visible letter as good as others in their imagination, but have a problem to finally decide upon the orientation of this letter. They know that the letter is, for instance, a „R”, but they have problems to match this activated phoneme to the corresponding grapheme orientation. This will result in increased response latencies and error rates because of increased decision time but not in differences in the mental rotation. If the problem is more related to spatial operations, however, there should be an increase in the operation time with rotational angle. The experiment will be described in more detail in later sections after we reviewed some studies of mental rotation.

**Mental rotation**

Mental rotation is a task which requires visuo-spatial processing of images. Usually, participants are asked to decide whether or not two items, presented either simultaneously or in succession, are the same or different regardless of their orientation. Shepard & Metzler (1971) published the first study on mental rotation. They were able to show that the reaction time (RT) increased linearly with the 3-dimensionally angular difference of the objects presented, suggesting that the shown image is rotated in the individuals’ minds just as they would physically manipulate the object. The mental rotation effect has been replicated in many studies irrespective of the type of stimuli used in these experiments and even for other tasks than a same-different task (Cohen et al., 1996; Kosslyn et al., 1998; Harris et al., 2000; Jordan et al., 2001). Cooper & Shepard (1988), for instance, displayed isolated letters of different orientation, and the task was to decide whether the letter was shown in normal or mirrored parity. Ruthruff, Miller & Lachmann (1995) used a mental rotation task within a dual-task setting and concluded that this operation requires central capacity.

Neuronal mechanisms underlying mental rotation are still discussed. The results are at odds as to which brain areas or neural networks are involved in the mental rotation processing, which hemisphere plays an important role in transformational operations performed on images of objects. However, most of the studies indicated that the parietal lobe, especially the posterior part, played a major role in mental rotation (Cohen et al., 1996; Richter et al., 1997; Jordan et al., 2001; Kosslyn et al., 1998; Alivisatos and Petrides, 1997).
Mental rotation and reading performance

From the background of our hypothesis two studies may be reviewed here, one using letters and the other using non-linguistic stimuli. In the latter study, Karadi et al. (2001) used pictures of right and left hands as stimuli. They were presented at angle of 0°, 50°, 90° and 180° clockwise from the normal upright. The participants’ task was to decide whether a left or a right hand was shown on the screen and to press the corresponding key. The results indicated that dyslexics perform this task with a higher speed but with lower accuracy. Moreover mental rotation occurred in non-dyslexics but not in dyslexic children. The authors interpreted the results in terms of a dysfunction of the parietal cortex. They concluded that dyslexics have general problems in the processing of spatial information (and thus in mental rotation tasks) which may result in a variety of reading and writing difficulties.

In the study of Corballis et al. (1985) 12 years old dyslexics and non-dyslexics had to name disoriented letters in the left or the right visual field. They found no differences in mean error rates and RT between the groups. The effect of normal over backward letters was clearly significant, but there was no effect of mental rotation in both groups. The interaction between visual field and letter orientation failed also to reach significance. Corballis et al. (1985) concluded that reading-disabled children do not show an abnormally high degree of left-right equivalence (as it was proposed by Orton, 1925).

The experiment

In one of their experiments, Lachmann, Rusiak, Brendler & Jaskowski (in preparation) asked 15 dyslexic and 14 non-dyslexic teenagers to take part in a classical mental rotation experiment. The participants’ IQs were estimated with the Wechsler Adult Intelligence Scales – Polish version (WAIS-R [PL]). Moreover, a reading test using chain-words and the chain-sentences (Ober et al., 1998) was performed.

For the mental rotation experiment, all stimuli were displayed on the computer monitor. The stimuli were black letters: R, F, G, e, k and the exact mirror-images of those letters. They were presented against a white background in the center of the monitor. The letters were displayed in different angular orientations: 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° clockwise from the normal upright. The participants’ heads were fixated. The participants were instructed to look at the fixation cross and to decide whether the subsequent stimulus was a normal or mirrored letter regardless of its orientation by pressing corresponding keys. All participants were asked to perform the task as quickly and as accurately as possible.

Results and conclusion

To statistically evaluate the results of mental rotation an ANOVA was performed for response times (RT) and performance accuracy with one between-subject (group) and one within-subject factor (rotation angle).

The results indicate that RT for both groups increased with increasing angle of rotation from the upright orientation. The RT differed significantly between the groups; dyslexics were slower than normal readers. Dyslexics needed 300 ms more to decide, whether the letter presented was normal or mirrored. However, as can be seen in Figure 1, the slope is the same in both groups, that is, the effect is additive with rotation angle between the groups. The null finding of an interaction between the factors confirmed the interpretation that dyslexics show no difference in mental rotation performance. Instead the reason for the dramatically increase in RT is either before or after the mental operation under investigation.
The analysis of accuracy rate revealed no difference between dyslexics and non-dyslexics during mental rotation task. However, as can be seen in Figure 2, the mean errors of dyslexics at 180° degrees were much higher than normal readers.

![Fig. 2. Accuracy rate (%) as a function of angle of rotation in the dyslexic and normal reader group.](image)

### Discussion and conclusions

According to the FCD model, which assumes orientation errors in dyslexics to occur from a failure in suppressing symmetry generalization in the representation of graphemes, the difference in RT between the groups may be caused by a decision problem, that is, after the mental rotation process
has been completed. In simple words, once the dyslexics have finished the rotation they still do not know whether the letter is normal or mirrored because to distinguish this is exactly their problem. This problem produces higher decision times and more errors which, of course, are independent from the degree of rotation.

The present results are somehow in opposite to what was obtained by Karadi and coworkers (2001). This, however, is expected by FCD, because they use non-linguistic stimuli. Also the null-finding of group differences in the study of Corballis and colleagues (1985) is in good accordance with the FCD model. Dyslexics who make a lot of reversal errors and fail in the present task may not have a problem in naming the letter, but in differentiate the normal from the mirrored, because both versions represent the grapheme, whereas in non-dyslexics only the normal letter is connected with the phoneme representation (but not the mirrored).

Of course, this interpretation is not exclusive. It could also be argued that this particular group of dyslexics tested here, has a problem in encoding the stimuli or in other processing stages prior mental rotation. Therefore, a number of other studies are planed to test this interpretation directly and indirectly. A direct way could be to use electrophysiological methods. Heil & Rolke (2002) introduced a method in which Event Related Potentials (ERP) can be used to localize mental rotation in space and time. If the deficit is indeed located after mental rotation, there should be no difference in this ERP component between the groups. However, if the relevant peak will appear later in dyslexics than in non-dyslexics it could be concluded that the deficit is located before mental rotation (Rusiak & Jaskowski, in preparation).

An indirect way was used by Lachmann, Rusiak, Brendler & Jaskowski (in preparation) who compared the performance of 9 years old dyslexics and non-dyslexics in same-different tasks with lowercase letters as lexical, and dot-patterns as non-lexical material. The children had to compare two successively presented items, i.e., one in memory with one visible, which could either be the same in shape and orientation (identity matches), the same in shape but different in orientation (categorical matches) or different in shape (non matches). The instruction differed between two sessions (counterbalanced between participants). In the physical instruction participants were asked to respond with same only to physical identity, that is, when both stimuli were the same in shape and orientation. Thus, configurations which were reflected or rotated versions of each other had to be judged as being different, just as well as the ones differing in shape. In contrast, the categorical instruction required the participants to judge the two stimuli according to their shape only; the orientation had to be ignored. In other words, symmetry generalization may be helpful in the latter case, whereas in the physical condition, symmetry in the representation has to be suppressed.

The authors were able to show that dyslexics have in deed problems in suppressing symmetry in the representation of a grapheme, indicated by increased response latencies and error rates for the physical and categorical matches under the physical instruction, but not under the categorical instruction, as well as by the fact that the difficulty is especially prominent for letters. Because for both instructions the same stimuli and procedure were used but a group effect was found for the physical instructions only, it was concluded that the problem of dyslexics in the mental rotation task may not be caused by an early processing deficit. Instead the interpretation of a decision deficit was supported.

These finding are relevant for educational treatment, as far as they emphasize the importance of practice grapheme-phoneme convention skills. The FCD model is a multi-causal model, a deficit in functional coordination can be the result of a number of underlying deficits. However, it can be concluded from a number of studies that it is very unlikely that dyslexics benefit from a training of visual segmentation or Gestalt perception, which are still part of training programs. For the diagnosis of dyslexia visual segmentations skills are not a good predictor either.
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References


