Individual Differences, Imagery and the Visual Impedance Effect

Lupita Estefania Gazzo Castañeda (Estefania.Gazzo@psychol.uni-giessen.de)
Justus-Liebig University, Experimental Psychology and Cognitive Science, Otto-Behaghel-Str. 10F,
35394 Giessen, Germany

Markus Knauff (Markus.Knauff@psychol.uni-giessen.de)
Justus-Liebig University, Experimental Psychology and Cognitive Science, Otto-Behaghel-Str. 10F,
35394 Giessen, Germany

Abstract

The visual impedance effect describes the fact that unnecessary visual information can impede reasoning (Knauff & Johnson-Laird, 2002). We explored how this effect is modulated by individual differences in reasoning styles. The main hypothesis of the present work is that the magnitude of the impedance effect depends on the degree to which people use visual mental images during thinking. We conducted two experiments with participants with highly imagistic and highly verbal reasoning strategies. The relational inferences differed in how easily they could be visualized. Our results indicate that (1) verbalizers do not show the visual impedance effect, and (2) that people with a high preference for mental imagery try to imagine even non-visual information visually, always showing the strongest impedance by visualization.

Keywords: Reasoning, individual differences, cognitive styles, visual impedance effect

Introduction

Many theories have been developed to explain human reasoning (Clark, 1969; Johnson-Laird & Byrne, 1991; Oaksford & Chater, 2009; Rips, 1994). A problem common to these theories is that they often exclude the possibility of individual differences in reasoning (Bacon, Handley, & Newstead, 2003; Ford, 1995). If people are asked how they solve reasoning problems, they usually report different ways of reasoning. While some people report the use of visual imagery (e.g. Egan & Grimes-Farrow, 1982; Richardson, 1977), others report more language based approaches like rehearsal (Polk & Newell, 1995), and yet others to think in a more abstract manner (Egan & Grimes-Farrow, 1982). Based on such observations, Richardson (1977) proposed the differentiation between verbalizers and visualizers. Both were conceptualized as the extremes of a continuum. Visualizers were described as people with high visual imagery, but with poor verbal abilities, and verbalizers were described with the reverse tendencies. Over the years this dichotomy was expanded in accordance with newer neurological findings, and visualizers were divided into object- and spatial- visualizers (e.g. Kozhevnikov, Kosslyn, & Shepard, 2005). While object visualizers are described as being able to construct vivid, high resolution images, spatial visualizers are described as being especially good in the processing of spatial information (Blazhenkova & Kozhevnikov, 2009). Such differences in cognitive styles are important because unlike strategies, cognitive styles should be understood as relatively stable and durable (Blazhenkova & Kozhevnikov, 2009; Riding & Cheema, 1991).

The influence of cognitive styles on tasks like anagrams and mental rotation (e.g. Just & Carpenter, 1985) has already been investigated. Also, individual differences in spatial abilities and mechanical reasoning have been examined (Hegarty & Sims, 1994). Nevertheless, only few studies analyzed the influence of individual differences on deductive reasoning (e.g. Bacon et al., 2003; Ford, 1995; Sternberg & Weil, 1980). With the help of verbal protocols, Ford (1995) and Bacon et al. (2003) argued that people resolve syllogisms in two different ways. Some of the participants used a "verbal" strategy and resolved the syllogism via substitution of the terms. Other participants used a "spatial" strategy and resolved the syllogism with the help of schematic drawings which closely resembled Euler circles. However, almost no differences in performance were found (Bacon et al., 2003). Sternberg and Weil (1980) trained their participants to use either visual or rule based strategies in resolving relational inferences. One group of participants received no training. They found an interaction between skill and strategy: the effectiveness of the strategy depended on the verbal or spatial skills of the participant. More importantly, in the same study Sternberg and Weil found that a rule-based strategy lead to the fastest response times. Beyond these initial results, the question of the influence of individual differences based on imagery on other reasoning tasks like relational reasoning problems still remains open. This is surprising, insofar as the role of visual imagery on relational reasoning has been a topic of much controversy (Knauff, 2013).

The Visual Impedance Effect

For a long time, the role of visual imagery during reasoning was not clear. While some researchers reported imagery as a helpful tool for reasoning (Clement & Falmagne, 1986; Shaver, Pierson, & Lang, 1975), others reported opposite results (Johnson-Laird, Byrne, & Tabossi, 1989; Richardson, 1987; for a detailed review see Knauff 2013; Knauff & Johnson-Laird, 2002). In search of clarification, Knauff and Johnson-Laird (2002) postulated that these discrepancies are based on a confounding in the items. Many items which are called "visual" are visual as well as spatial. Thus, in order to investigate the role of imagery during reasoning, it is important to disentangle the visual from the spatial features of a given reasoning problem. By doing this, Knauff and Johnson-Laird (2002) showed that unnecessary visual information is an unnecessary cognitive load in working memory that leads to longer reaction times. They called this effect the visual impedance effect. They adapted their findings to the Theory of Mental Models (Johnson Laird & Byrne, 1991) and proposed that mental models are spatial and not visual, as other groups propose (e.g. De Soto, London, & Andel, 1965; Huttenlocher, 1968). This visual impedance effect has been corroborated in experiments with blind persons (Knauff & May, 2006).

The visual impedance effect and the existence of more or less imagery-based cognitive styles motivated us to assume that people with different abilities in imagery should also perform differently in logical reasoning. We expected that the magnitude of the visual impedance effect would depend on the ability to use imagery during reasoning. Thus, the visual impedance effect should be increased for people with high visual imagery compared to those without a special preference for visual imagery or with a more linguistic cognitive style. Because of their cognitive style, this last group should hardly be affected by unnecessary visual information in tasks and thus show a better performance in relational problems compared to people with high visual imagery, especially in items with unnecessary visual information. To investigate these assumptions we conducted two experiments. In both experiments participants with different preferences for imagery had to solve relational problems. The content of these problems was manipulated in such way that problems were easy or hard to visualize.

Experiment 1

In the first experiment, we measured the differences in cognitive style with a German version of the Verbalizer-Visualizer Questionnaire (VVQ) from Richardson (1977). In a pilot study, we administered a German Version of the VVQ to 120 undergraduate psychology students at the University of Giessen. Using cut-off points at 5 and 12 points we found clearly distinguishable groups of verbalizers and visualizers (the scale ranged from 0 to 15 points).

Method

Participants 22 participants (18 female, 4 male) from the pilot study participated in the experiment. Half of them were visualizers, the other half were verbalizers. The mean age was 22.8 years (*SD* = 4.55) and they participated for academic credit points.

Materials and Design We created 32 relational inferences. All of them described the same relation (left-right), but the term was either easy (fruits, tools, cutlery or office implements) or hard (nonsense syllables) to visualize. Half of the problems had valid conclusions; the other half had invalid conclusions. Here is an example for an easily visualizable problem with a valid conclusion:

Premise 1: Apple left of Kiwi
Premise 2: Kiwi left of pear
Conclusion: Pear right of apple

The design was a 2 x 2 design. The cognitive style of the participants was treated as a between-subjects factor. The ease of visualization for the terms was treated as a within-subjects factor.

Procedure The experiment took place on a computer in a quiet room, and was programed in Cedrus SuperLab™. The participants were tested individually. Premises and conclusions were presented on separate slides. The premises were written in black while the conclusion was written in red. The background was white. By pressing the space bar, participants decided when to pass from one premise to the next premise or to the conclusion. The task for the participants was to decide whether the conclusion was valid or not. They gave their decision by pressing one of two keys for "correct" or "false". Between each item, the participants had the opportunity to take a break. Before starting the actual experiment, the participants practiced on four items. To avoid learning effects the terms of these problems were abstract (the letters A, B, C). Dependent measures were premise reading times (not reported here), the mean number of logically correct responses, and the decision times for conclusion-evaluations.

Results and Discussion

We first analyzed the percentage of correct responses[1]. Examining the problems that were easy to visualize, verbalizers responded correctly to 95.75% (*SD* = 5.39) of them, while visualizers responded correctly only to 90.91% (*SD* = 11.65) (U-Test, z = -1.095, p = .273). Examining the problems that were hard to visualize, verbalizers responded correctly to 95.15% (*SD* = 7.94), while visualizers scored 92.73% (*SD* = 9.17) (U-Test, z = -.643, p = .520). The main effect did not reach statistical significance, which is in accordance with our pervious results (Knauff & Johnson-Laird, 2002). In the second step, we analyzed the decision times for correct responses. The results are illustrated in figure 1. As expected, visualizers (*M* = 6212 ms, *SD* = 1550) needed more time to resolve problems that were easy to visualize compared to verbalizers (*M* = 4917 ms, *SD* = 1769). This effect was marginally significant (U-Test, z = -1.937, p = .053). For the problems that were hard to visualize, verbalizers (*M* = 5700 ms, *SD* = 2310) were not significantly faster than visualizers (*M* = 6053 ms, *SD* = 1703), (U-Test, z = -.624, p = .533). But contrary to what is implied by the visual impedance effect, decision times for problems that were hard to visualize were no smaller than the ones for problems that were easy to visualize. On the contrary, verbalizers were significantly slower solving problems that were hard to visualize compared to those that were not (Wilcoxon test, z = -1.956, p = .050). Visualizers showed no difference between both types of problems

[1] Because of technical problems, two of the 32 items had to be eliminated from all computations.

(Wilcoxon test, $z = -.533$, $p = .594$). So there was something like a visual impedance effect for verbalizers, but not for visualizers. This unexpected result can be explained in two ways. One possible reason might be that nonsense syllables are not only hard to visualize, but also unknown and therefore probably also hard to memorize. This difficulty in memorizing the terms may have led to more cognitive load in working memory and thus to longer decision times compared to items which are known. This would explain the sudden increase in decision time for verbalizers. However, another reason for this unexpected result can be found in the reports many participants made after the experiment. Visualizers in particular, reported visualizing even the nonsense syllables. They reported that the nonsense syllables were visualized as phantasy creatures or names of foreign persons. Obviously, visualizer are so strongly biased towards using visual imagery, that even in tasks where no such visual information is available they transform the given information in such a way that they can use their typical visual thinking style. If so, then visualizers should not show the typical visual impedance effect, but instead of it something like a visual impedance effect on the subjects level. Thus visualizers should always have problems with relational problems, because all problems would be treated as highly visual problems. To test this hypothesis, it is important to use problems with familiar terms which are known, but which are still not easy to visualize. Therefore, in the second study we used the original material from Knauff and Johnson-Laird (2002).

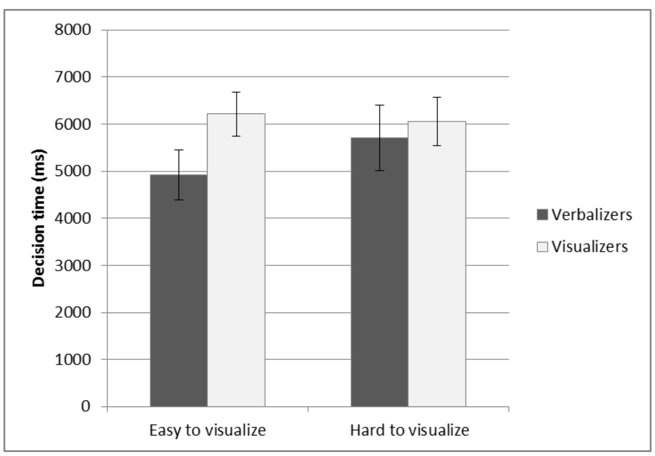

Figure 1: Mean decision times for the conclusion. Error bars represent standard errors.

Experiment 2

In the second experiment, we decided to measure the differences in cognitive style with the German version of Blazhenkova and Kozhevnikov's (2009) Object-Spatial Imagery and Verbal Questionnaire (OSIVQ). This questionnaire has the benefit that it accounts for the difference between visual imagery and spatial imagery. Thus the OSIVQ makes the same distinctions as the items used by Knauff and Johnson-Laird (2002).

In a pilot study we administered the German Version of the OSIVQ to 148 students at the University of Giessen. We selected our participants on the basis of their scores on the three scales contained within the OSIVQ: the visual scale, the spatial scale, and the verbal scale. We considered a participant as belonging to one of the three cognitive styles, if she or he scored above the sample mean of one scale, but below the sample means of the other scales[2]. Participants with higher deviations were preferred over those with fewer deviations. We selected 13 object visualizers, 6 spatial visualizers and 10 verbalizers. Additionally to these three experimental groups, we also selected a control group, whose scores on the scales did not differ from the sample scale means. The control group consisted of 10 participants.

Method

Participants All selected participants from the pilot study participated in the experiment. All object visualizers were female ($n = 13$), with a mean age of $M = 22.54$ ($SD = 2.3$). The group of the spatial visualizers consisted of 3 female and 3 male participants. Their mean age was $M = 22.67$ ($SD = 3.14$). The group of the verbalizers consisted of 9 female and 1 male participant. Their mean age was $M = 22.8$ ($SD = 8.16$). Finally, the control group consisted of 7 female and 3 male participants. Their mean age was $M = 22.6$ ($SD = 2.59$). The participants participated for academic credit points or candies.

Materials and Design We used the relational inferences from Knauff and Johnson-Laird (2002; see table 1). These relations have been evaluated empirically (Knauff & Johnson-Laird, 2002) and differ in the relative degree to which they can be imagined either visually or spatially. Using these relational terms it is possible to create 32 items. All items consisted of the same terms (dog, cat, ape). Again, half of the problems had valid conclusions; the other half had invalid conclusions. An example for a valid visual problem is:

Premise 1: The dog is cleaner than the cat
Premise 2: The ape is dirtier than the cat
Conclusion: The ape is dirtier than the dog

The design was a 4 x 4 design. The cognitive style of the participants was treated as a between-subjects factor. The ease of visualization was treated as a within-subjects factor.

Additionally to the inference task, we also measured spatial, verbal and visual abilities of the participants. The idea was to validate the cognitive style of our participants. A similar procedure was also used by the developers of the OSIVQ (Blazhenkova & Kozhevnikov, 2009). As a measure for visual abilities we used the Vividness of Visual Imagery Questionnaire (VVIQ: Marks, 1973). It consists of 16 items which examine how easily the participant is able to imagine, visually and vividly, different scenes with open and with closed eyes. As a measure of spatial ability we used a

[2] In five exceptional cases people were also accepted, whose scores between the corresponding scale and the other scales differed around one scale unity.

mental rotation task, based on the one by Shepard and Metzler (1971). It consisted of the presentation of a target 3D figure, in combination with another similar figure which was either the same in one of six rotated degrees, or a rotated mirror image. The task for the participant was to decide whether both images were the same or not. This task consisted of 48 items. Finally, as a measure of verbal ability we used the subtest "Masselon" from the Berliner Intelligenzstruktur Test (BIS: Jäger, Süß, & Beauducel, 1997). In this test the participant is confronted with three words (human, feeling, technology) and must then create as many sentences as they can with these three words. For better comparisons with experiment 1, we also administered a German Version of Richardson's (1977) VVQ.

Procedure The experiment always began with the relational inference task, which was programed in SuperLab™. The procedure for the relational inference task was the same as experiment 1. After completing the relational task, the VVIQ tasks, the rotation task, and the Masselon tasks were presented in a random order. Finally, the participants answered the VVQ and provided written comments on how they believed they solved the tasks. Again, we measured the reading time for each premise (not reported here), the decision time for the conclusion, and whether the task was solved correctly or not.

Table 1: Relations used in Experiment 2, with a description of how easy they were to imagine either as a visual image or a spatial array (adapted from Knauff and Johnson-Laird (2002; p. 368)).

Relations	Description
Visual	
cleaner-dirtier fatter-thinner	Ease to envisage visually, but hard to envisage spatially
Control	
better-worse smarter-dumber	Hard to envisage visually and spatially
Visuospatial	
above-below front-back	Easy to envisage visually and spatially
Spatial	
north-south ancestor-descendant	Hard to envisage visually, but easy to envisage spatially

Results and Discussion

VVIQ, mental rotation, and verbal abilities The results from the three tasks indicate that our selection of the exponents of the different cognitive styles was successful. The VVIQ was computed in such a way that high scores (max. 80 points) indicated good visual abilities, whereas low scores (min. 16 points) indicated a lack of it. Object visualizers (*M* = 51.08, *SD* = 5.61) reached a higher score than verbalizers (*M* = 39.75, *SD* = 8.72) on the VVIQ (U-Test, *z* = -3.072, *p* = .002). They also reached a higher score than spatial visualizers (*M* = 40.83, *SD* = 13.45) and the control group (*M* = 43.70, *SD* = 6.87), but these last two differences did not reach the adjusted alpha level (U-Test, *z* = -1.931, *p* = .053 for the comparison with spatial visualizers; U-Test, *z* = -2.576, *p* = .01 for the comparison with the control group).

Even if there was no significant main effect on the time needed to solve the items in the mental rotation task (Kruskal Wallis, Chi^2 = 5.440, *p* = .142), descriptively it was possible to see that, across all items, spatial visualizers (*M* = 4.99 s, *SD* = 1.88) were faster than verbalizers (*M* = 7.54 s, *SD* = 3.87), than object visualizers (*M* = 8.15 s, *SD* = 2.85) and the control group (*M* = 6.80 s, *SD* = 3.41). Poltrock and Brown (1984) proposed that the linear regression slopes of the latencies are an indicator of the rotation speed, in that the smaller the slope, the faster the rotation was performed. As expected, spatial visualizers rotated faster (*b* = 29.55, *SE* = 8.39) than verbalizers (*b* = 72.00, *SE* = 16.42), object visualizers (*b* = 55.79, *SE* = 9.75) and the control group (*b* = 48.16, *SE* = 16.77). The groups did not differ in the amount of errors made (Kruskal Wallis, Chi^2 = 2.641, *p* = .450).

Our analysis of the Masselon test was based on the amount of written words in valid sentences. Verbalizers (*M* = 43.30, *SD* = 11.37) wrote significantly more words than object visualizers (*M* = 30.54, *SD* = 7.93; U-Test, *z* = -2.86, *p* = .004) and spatial visualizers (*M* = 25.17; *SD* = 7.11; U-Test, *z* = -2.71, *p* = .007), but they did not differ from the control group (*M* = 34.70, *SD* = 12.60; U-Test, *z* = -1.34, *p* = .182).

The VVQ The comparison of the scores on the VVQ showed that the VVQ is only able to differentiate correctly between verbalizers (*M* = 7.20, *SD* = 2.35) and object visualizers (*M* = 10.46, *SD* = 2.22; U-test, *z* = -2.875, *p* = .004). Given that the VVQ does not consider spatial visualizers, spatial visualizers (*M* = 7.67, *SD* = 3.98) scored similar to verbalizers (U-test, *z* = -.174, *p* = .869) on the VVQ.

Relational inferences Similar to Knauff and Johnson-Laird (2002), we encountered some problems with the spatial relations. On the one hand, several participants reported that they still imagined them in a visual way (e.g. as animals on maps). On the other hand, the spatial terms created "illogical" constellations (e.g. the dog is descendant of the cat), whose difficulty probably confounded the decision times. Therefore, the spatial relational terms were not purely spatial and had to be removed from our analysis. The reported results are based solely on the correct responses to the other three kinds of relational terms.

Based on the results of experiment 1, we assumed that people with a high preference for imagery would not only have difficulties in visual relational problems, but also in non-visual relational problems. Because of their cognitive style, object visualizers would try to imagine even non visual information visually, regardless of how difficult this is, and be impeded by this visualization. To analyze these hypotheses we first considered the percentage of errors made by our participants. As in experiment 1, there were no significant differences between the participants with different cognitive styles in the percentage of correct answers (Kruskal Wallis, $Chi^2 = 2.060$, $p = .560$). However, there was a significant main effect in the response times when we compared the groups of object-visualizers, spatial visualizers, and verbalizers (Kruskal Wallis, $Chi^2 = 6.855$, $p = .032$). Pairwise comparisons showed that, as expected, object visualizers (M = 4608 ms, SD = 2671) took longer to resolve the tasks compared to verbalizers, (M = 2777 ms, SD = 645). This difference was also significant (U-test, z = -2.481, p = .012). Object visualizers were not significantly slower than spatial visualizers (M = 3857ms, SD = 1159; U-test, z = -0.614, p = .579) and verbalizers still tended to answer faster than spatial visualizers (U-test, z = -1.735, p = .093). As can be seen in figure 2, neither object visualizers nor verbalizers showed the classical visual impedance effect. In neither group a main effect on decision times for the different kinds of items could be found (Friedman Test, $Chi^2 = 1.077$, $p = .584$ for object visualizers; $Chi^2 = .200$, $p = .905$ for verbalizers). The only group that showed a pattern resembling the classical visual impedance effect were the spatial visualizers. However, because of the small sample size (n = 6), the main effect did not reach significance (Friedman Test, $Chi^2 = 3.000$, $p = .223$). This trend was not expected and should be investigated in further studies. Nevertheless, the missing visual impedance effect for verbalizers and the long decision times of object visualizers confirm our suppositions derived from experiment 1: while object visualizers do indeed try to visualize even nonvisual information, verbalizers never visualize anything. This leads to a lack of visual impedance effects on the item level, but instead causes visual impedance effects on the subject level.

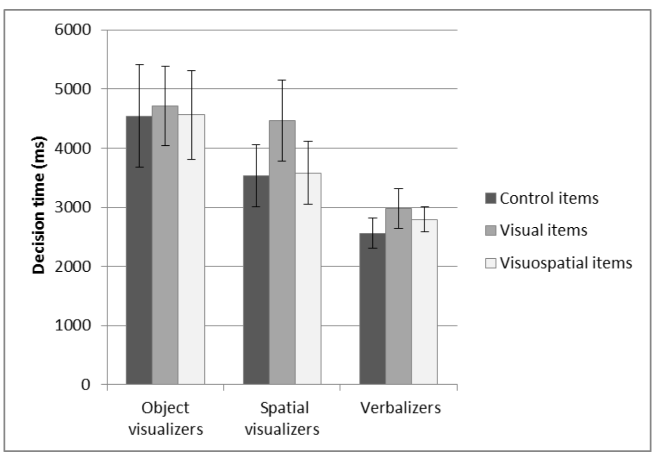

Figure 2: Mean decision times for the conclusion. Error bars represent standard errors.

General Discussion

Our findings indicate that, depending on their cognitive style and how easily they are able to use imagery during reasoning, people are influenced in different ways by the imageability of the content of reasoning problems: On the one hand, verbalizers are typically not impeded by visual characteristics of reasoning problems. They seem to be immune to the visual impedance effect. On the other hand, people who tend to imagine the content of reasoning problems try to visualize even non-visual problems and therefore show a visual impedance effect on all problems, whether the problems are highly visual or not. These results notwithstanding, we are aware of the limitations of our study. In order to strengthen our results, it would be necessary to conduct studies with a greater sample size and to control for gender differences. An additional task for the future is to investigate during which phase of the inference individual differences take effect. Particularly, it remains unclear whether these individual differences play a role only during interpretation and encoding of the reasoning problem premises, or if the individual differences also have an effect on the reasoning process itself. Knauff (2009, 2013) proposes that relational reasoning problems are solved in three steps among which only the first step involves the construction of visual mental images and the other two steps comprise the “real” reasoning processes. However, in this work we did not distinguish between different cognitive styles and so it is still unclear how verbalizers solve such tasks. Do they also create such (irrelevant) initial picture-like representations? One approach that we took previously is to use functional brain imaging to study the neural basis of individual differences in reasoning (Ruff, Knauff, Fangmeier, & Spreer, 2003). By testing people with different cognitive styles in the scanner it might be possible to see during which phases of the reasoning process these cognitive styles take effect. By doing this, it would also be possible to see to what extent the steps proposed by Knauff (2009, 2013) are generalizable to all cognitive styles. The same could be also done with other individual differences. For example, it might be of interest to investigate whether people with either a holistic or an analytic cognitive style (see Riding & Cheema, 1991) differ in the construction of mental models.

Another task for the future is to replicate the present results using different formats of presentation. In both studies reported here our items were presented in written form. Considering that verbalizers are often described as having fun and being good at reading and language based tasks (see the relevant items of the VVQ and the OSIVQ), it seems possible that the superior performance of verbalizers resulted not only because they did not use imagery, but also because verbalizers might feel more comfortable with a task presented in their preferred format. Thus, in further studies it is important to present items in other formats, for example acoustically or in an iconic way.

In conclusion, our results support the visual impedance effect. Irrelevant visual details can be a nuisance in reasoning. However, the effect seems to be modulated by the different cognitive styles of individuals. Object visualizers are so profoundly driven by their visual thinking style that they try to visualize almost everything. Thus they show a visual impedance effect even for non-visual reasoning problems. Verbalizers, in contrast, are only marginally affected by the visual characteristics of reasoning problems. They use more abstract reasoning styles and therefore have no problems with disruptive visual images. We were also able to identify differences between object visualizers and spatial visualizers. Comparing both groups, our findings indicate that the use of spatial representations and processes is the most effective way to solve relational reasoning problems. However, individuals using spatial layout models (Knauff, 2013) seem not to be immune to irrelevant and side-tracking visual details and can therefore be impaired in solving highly visual inference problems. We will continue to explore this effect more thoroughly. A final important corollary of our study is that effects found in general populations (without considering differences in cognitive style) do not necessarily apply to every single person: visual items do not always impede reasoning, they only impede if subjects represent visual features in their mental representation of the task. That is why it is important to incorporate individual differences into theories of reasoning and to highlight such differences in the predictions and assumptions of those theories. Disregarding these differences may lead to unjustified overgeneralizations.

Acknowledgments

This work was supported by DFG grant KN 465/10-1 to Markus Knauff.

References

Bacon, A. M., Handley, S. J., & Newstead, S. E. (2003). Individual differences in strategies for syllogistic reasoning. *Thinking and Reasoning, 9*, 133-168.

Blazhenkova, O., & Kozhevnikov, M. (2009). The new object-spatial-verbal cognitive style model: Theory and measurement. *Applied Cognitive Psychology, 23*, 638-663.

Clark, H. H. (1969). Linguistic processes in deductive reasoning. *Psychological Review*, *76*, 387-404.

Clement, C. A., & Falmagne, R. J. (1986). Logical reasoning, world knowledge, and mental imagery: Interconnections in cognitive processes. *Memory & Cognition, 14*, 299-307.

De Soto, L. B., London, M., & Andel, M. S. (1965). Social reasoning and spatial paralogic. *Jorunal of Personality & Social Psychology, 2*, 513-521.

Egan, D. E., & Grimes-Farrow, D. D. (1982). Differences in mental representations spontaneously adopted for reasoning. *Memory & Cognition*, *10*, 297-307.

Ford, M. (1995). Two modes of mental representation and problem solution in syllogistic reasoning. *Cognition, 54*, 1-71.

Hegarty, M., & Sims, V. K. (1994) Individual differences in mental animation during mechanical reasoning. *Memory and. Cognition, 22*, 411–430.

Huttenlocher, J. (1968). Constructing spatial images: A strategy in reasoning. *Psychological Review*, *75*, 550-560.

Jäger, A. O., Süß, H. -M. & Beauducel, A. (1997). *Berliner Intelligenzstruktur - Test. Form 4.* Göttingen: Hogrefe.

Johnson-Laird, P. N., & Byrne, R. M. J. (1991). *Deduction.* Hove, U.K.: Erlbaum.

Johnson-Laird, P. N., Byrne, R. M. J., & Tabossi, P. (1989). Reasoning by model: The case of multiple quantification. *Psychological Review, 96*, 658-673.

Just, M. A., & Carpenter, P. A. (1985). Cognitive coordinate systems: Accounts of mental rotation and individual differences in spatial ability. *Psychological Review, 92*, 137-172.

Knauff, M. (2009). A neuro-cognitive theory of deductive relational reasoning with mental models and visual images. *Spatial Cognition and Computation, 9*, 109-137.

Knauff, M. (2013). *Space to Reason.* Cambridge, MA: MIT Press.

Knauff, M., & Johnson-Laird, P. N. (2002). Visual imagery can impede reasoning. *Memory & Cognition*, *30*, 363-371.

Knauff, M., & May, E. (2006). Mental imagery, reasoning, and blindness. *Quarterly Journal of Experimental Psychology, 59*, 161-177.

Kozhevnikov, M., Kosslyn, S., & Shephard, J. (2005). Spatial versus object visualizers: A new characterization of visual cognitive style. *Memory and Cognition, 33*, 710-726.

Marks, D. F. (1973). Visual imagery differences in the recall of pictures. *British Journal of Psychology, 64*, 17-24.

Oaksford, M., & Chater, N. (2009). Précis of bayesian rationality: The probabilistic approach to human reasoning. *Behavioral and Brian Sciences, 32*, 69-120.

Polk, T. A., & Newell, A. (1995). Deduction as verbal reasoning. *Psychological Review, 102*, 533-566.

Poltrock, S. E., & Brown, P. (1984). Individual differences in visual spatial ability. *Intelligence, 8*, 93-138.

Richardson, A. (1977). Verbalizer-Visualizer: a cognitive style dimension. *Journal of mental Imagery, 1*, 109-126.

Richardson, J. T. E. (1987). The role of mental imagery in models of transitive inference. *British Journal of Psychology*, *78*, 189-203.

Riding, R., & Cheema, I. (1991). Cognitive styles – an overview and integration. *Educational Psychology, 11*, 193-215.

Rips, L. J. (1994). *The psychology of proof.* Cambridge, MA: MIT Press.

Ruff, C. C., Knauff, M., Fangmeier, T., & Spreer, J. (2003). Reasoning and working memory: Common and distinct neuronal processes. *Neuropsychologia, 41*, 1241-1253.

Shaver, P., Pierson, L., & Lang, S. (1975). Converging evidence for the functional significance of imagery in problem solving. *Cognition, 3*, 359-375.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*, 701-703.

Sternberg, R. J., & Weil, E. M. (1980). An aptitude X strategy interaction in linear syllogistic reasoning. *Journal of Educational Psychology, 72*, 226-239.