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Facilitating recognition of spatial structures through animation and the role of mental rotation ability

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A B S T R A C T

The study examined the facilitating function of animations for the recognition of rotated spatial structures and considered the role of mental rotation ability. The task required a decision of whether a rotated version of a spatial structure was identical to a previously shown structure. Either a static picture of the spatial structure or an animation was studied. The animation presented a rotation of the structure. Results showed a large effect of animations for recognition times. Individual mental rotation ability was chronometrically measured based on reaction times in a standard mental rotation task with simple two-dimensional figures. An aptitude–treatment-interaction was found: Mental rotation ability explained a large portion of the variance in recognition times for rotated spatial structures with static study pictures ($r^2 = .52$) but it explained variance to a much lesser extent with animations ($r^2 = .12$). It was concluded that animations compensated for lower mental rotation ability.

1. Introduction

1.1. Rotation of spatial structures

In many domains, understanding of complex spatial structures is important (e.g., geography, architecture, anatomy, chemistry). Whereas static pictures of spatial structures may require the mental integration of pre-selected, separate views (such as cross-sectional view, rotated views), computer-based animations provide flexible visual access and show changes of viewpoint continuously (e.g., through zoom and rotation). Interactive visualizations of spatial structures based on virtual models have been developed. Learning about human anatomy in medical education is one example (Keehner, Khooshabeh, & Hegarty, 2008).

The present study focuses on the rotation of a spatial structure. A potentially beneficial effect of an animation (showing rotation explicitly) is examined in comparison to static pictures presumably requiring mental rotation. Correspondingly, the cognitive process of mental rotation (Shepard & Metzler, 1973) is considered. The role of mental rotation ability as a learner aptitude and its potential interaction with the visualization is investigated.

1.2. The role of spatial abilities in learning with animations

Internal spatial visualization abilities are cognitive processes and resources for storing and manipulating mental visual–spatial representations (see Hegarty & Waller, 2005, for a review). Individual differences in spatial abilities play an important role in learning from visualizations in general (see Höffler (2010), for a meta-analytic review). The exact nature of the role of spatial abilities in learning with *animations* appears less clear, however.

An interaction in which animations supported high-spatial ability individuals particularly was found in multimedia learning studies (e.g., Diaz & Sims, 2003; Huk, 2006; Huk & Steinke, 2007). This interaction has been termed "ability-as-enhancer" (Mayer & Sims, 1994). In contrast, the "ability-as-compensator" interaction means that high ability learners can compensate for a suboptimal visualization, implying that positive effects of beneficial visualizations would be found for low-ability learners only.

Consistent with "ability-as-compensator", it has been found that animations can compensate for low spatial abilities (e.g., Höffler & Leutner, 2011; Lee, 2007; Münzer, Seufert, & Brünken, 2009). The external animation can relieve otherwise effortful mental visual–spatial processing (facilitation function, Schnotz & Rasch, 2005; supplantation, Salomon, 1994). In a selective meta-analytic review, Höffler (2010) found evidence for compensatory effects of animations (vs. static pictures) as well as of 3D visualizations (vs. 2D visualizations) for low-spatial individuals. The review included 19 primary studies published between 1994 and 2009. It might be noted that in five of the studies,

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no significant interaction between spatial ability and treatment condition was found (Hannafin, Truxaw, Vermillion, & Liu, 2008; Hegarty, Kriz, & Cate, 2003; Massa & Mayer, 2006; Wender & Mühlböck, 2003; Westerman, 1997), and that in four primary studies the "ability-as-enhancer" interaction was obtained (Diaz & Sims, 2003; Huk, 2006; Huk & Steinke, 2007; Mayer & Sims, 1994). Two recent studies on learning about locomotion patterns did not find an interaction between spatial ability and static vs. dynamic visualizations (Imhof, Scheiter, Edelmann, & Gerjets, 2012; Imhof, Scheiter, & Gerjets, 2011).

In domains in which learning about spatial structures is the primary goal (e.g., anatomy learning, environmental cognition), studies have repeatedly demonstrated a decisive role of spatial abilities as a predictor of learning success with animations and interactive visualizations, e.g., in medical training (Garg, Norman, Spero, & Maheshwari, 1999; Garg, Norman, & Sperotable, 2001; Keehner, Lippa, Montello, Tendick, & Hegarty, 2006). Cohen and Hegarty (2007) showed that spatial ability mediated the efficient use of an animation in an anatomy-related task that demanded comprehending a cross-section through a spatial structure. Spatial abilities are involved in route and layout learning about large-scale spaces from virtual environments and videos (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Münzer & Stahl, 2011; Waller, 2000). The finding that high spatial abilities are needed to benefit from dynamic visualizations implies that low-spatial ability individuals are not well supported through those visualizations. However, because most of the studies did not compare static pictures and animations as experimental conditions, knowledge about the *interaction* between spatial ability and type of visualization is limited in this area.

Spatial abilities comprise spatial factors that represent different cognitive facets of spatial information processing. Based on factor-analyses with extensive datasets, Carroll (1993) identified five main factors (1) "spatial visualization" involving complex and multi-step spatial transformations, (2) "spatial relations" requiring mental rotation with simple two-dimensional figures under speeded instruction, (3) "closure speed" requiring quick recognition of incomplete figures, (4) "closure flexibility" involving identification of hidden figures in complex spatial patterns, and (5) "perceptual speed" requiring speeded comparisons of simple figures.

When considering the role of spatial abilities in learning with visualizations, the question arises how a spatial ability measure is related to cognitive requirements of the learning task. It might be noted that a rather small selection of measures is utilized to obtain estimates of spatial ability. The vast majority of measures utilized in the studies included in the meta-analytic review were either representative of the "spatial visualization" factor or of the "spatial relations" factor (Höffler, 2010, p. 259, Table 2). Learning tasks, however, covered a wide range of domains (e.g., mechanical systems, cell biology, spatial layout learning, mathematics, basic electronics, second language learning) and various instructional materials and methods (e.g., multimedia learning with visualizations and with/without verbal narration, learning with/without interactive control, learning by navigating in a virtual environment). Type of measure (i.e., whether the measure was representative of "spatial visualization" or "spatial relations") did not have a moderating effect "although they have been identified previously as two distinguishable facets of spatial ability" (Höffler, 2010, p. 262f). The reason for this finding might be that a measure of spatial ability was not directly related to information-processing requirements of a learning task.

The present study focuses on a narrowly defined task in which an identifiable mental process is required. The task is to understand a visualized three-dimensional spatial structure and to hold this information in working memory for subsequent recognition of a rotated form. It is assumed that mental rotation is involved in this task.

1.3. Mental rotation

Imagining the turning of an object in space is a distinct mental spatial operation. Reaction times of identity judgments between an original object and a rotated comparison object depend almost linearly on the amount of the rotation (Shepard & Cooper, 1982; Shepard & Metzler, 1973). Therefore, mental rotation has been described as an analogous, Gestalt-like cognitive process. The association of mental rotation with motor processes (e.g., Jansen & Heil, 2007; Wexler, Kosslyn, & Berthoz, 1998; Wiedenbauer, Schmid, & Jansen-Osmann, 2007; Wohlschläger & Wohlschläger, 1998) emphasizes the specificity of the mental rotation process and its analogous character. Factor-analytic studies have revealed distinct mental rotation (spatial relations) and spatial visualization factors (Carroll, 1993).

Individuals differ considerably in their ability to mentally rotate objects in space. In the present study, the measure of mental rotation ability is based on reaction times in an identity judgment task with simple two-dimensional figures, i.e., mental rotation is measured chronometrically (Jansen-Osmann & Heil, 2007).

1.4. The present study

The present study examined the effect of animations in a recognition task for rotated spatial structures. Correspondingly, the study focused on the cognitive process of mental rotation and investigated the interaction between visualization (static picture vs. animation) and mental rotation ability. It was hypothesized (1) that animations would facilitate recognition of rotated spatial structures (main effect of visualization) and (2) that mental rotation ability would play a dominant role for recognition with static pictures, but not for recognition with animations (aptitude–treatment-interaction).

The recognition task required assessing the identity of two successively presented simple virtual building models (spatial structures) shown from an external viewpoint. The second, to-be-assessed spatial structure was rotated and showed either the same structure or a different (mirrored) structure. The first spatial structure was either shown as a static picture or as an animation that rotated the spatial structure. A facilitating effect of the animation in comparison to static pictures was expected.

H1. Animations will facilitate recognition of rotated spatial structures.

An aptitude–treatment-interaction was hypothesized because mental rotation would be involved in studying static pictures, whereas it would be involved to a much lesser extent when studying animations. The interaction could be interpreted as compensating low mental rotation ability, because task performance of low ability individuals would be less dependent on their aptitude.

H2. Recognition of rotated spatial structures will be more dependent on mental rotation ability with static pictures than with animations.

2. Method

2.1. Participants

Forty-nine students from a German University took part. They were, on average, 25.0 years old (*SD* = 5.6). Four participants were excluded from the dataset (see below), and 22 participants of the remaining sample were female. Participant's fields of study were foreign languages (16), psychology (9), computer science (7), natural sciences (6), business economics (5), law (1), and musicology (1). They were paid for participation.

2.2. Materials

2.2.1. Chronometric mental rotation task

A mental rotation task was constructed similarly to a task developed by Jansen-Osmann and Heil (2007), using simple two-dimensional primary mental ability (PMA) figures (Thurstone, 1958). Participants