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Motor expertise and performance in spatial tasks: A meta-analysis

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ABSTRACT

The present study aimed to provide a summary of findings relevant to the influence of motor expertise on performance in spatial tasks and to examine potential moderators of this effect. Studies of relevance were those in which individuals involved in activities presumed to require motor expertise were compared to non-experts in such activities. A final set of 62 effect sizes from 33 samples was included in a multilevel meta-analysis. The results showed an overall advantage in favor of motor experts in spatial tasks ($d = 0.38$). However, the magnitude of that effect was moderated by expert type (athlete, open skills/ball sports, runner/cyclist, gymnast/dancers, musicians), stimulus type (2D, blocks, bodies, others), test category (mental rotation, spatial perception, spatial visualization), specific test (Mental Rotations Test, generic mental rotation, disembedding, rod-and-frame test, other), and publication status. These findings are discussed in the context of embodied cognition and the potential role of activities requiring motor expertise in promoting good spatial performance.

1. Introduction

According to the embodiment approach in cognitive science, simple sensory motor interaction with the environment plays an important role in the development of higher cognitive skills (Wheeler & Clark, 2008). From this perspective, cognitive processes are deeply rooted in the body's interaction with the world, and sensory and motor resources are used for cognitive activity such as reasoning.

Mental rotation, the hypothesized process one performs when attempting to discriminate stimuli presented at different orientations (Shepard & Metzler, 1971) has received much attention in the context of embodied cognition. In fact, many studies have demonstrated that mental rotation performance is facilitated when human bodies are used as stimuli (Amorim, Isableu, & Jarraya, 2006) and that anatomical restraints hinder the mental rotation of body parts (e.g. Pellizzer & Georgopoulos, 1993; Sekiyama, 1982).

Another way in which the role of embodiment has been shown in mental rotation and other spatial tasks has been through demonstrations that these tasks involve a significant motor component (Moreau, Mansy-Dannay, Clerc, & Guerrien, 2011). In this context, activities that require mental manipulation of motor movements would promote good spatial abilities through their shared requirement to process objects in space. In an example of research using this premise as a starting point, Moreau et al. (2011) showed that athletes involved at the elite level in activities that involve complex motor skills (i.e., mental manipulation of motor processes), such as combat sports, performed better than individuals not involved in such activities (runners) or individual with little expertise in such activities (novices).

Findings similar to those reported by Moreau et al. (2011) have been extended to other activities in several studies (e.g., Heppe,

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Kohler, Fleddermann, & Zentgraf, 2016; Steggemann, Engbert, & Weigelt, 2011). In fact, this fledgling area of research seemingly provides solid support for so-called motor experts demonstrating better spatial abilities than non-experts. However, findings in this area have yet to be considered as a whole so their actual magnitude and the role of critical factors have yet to be explored. Accordingly, the present meta-analysis quantified the potential advantage of motor experts over non-experts in spatial tasks and examined variables that might moderate it.

1.1. Defining spatial tasks

Although there have been many definitions of spatial tasks (see for example, McGee, 1979), we chose to focus on the definition of categories of tests presented by Linn and Petersen (1985). These authors classified measures of visual-spatial abilities into three categories: spatial visualization, mental rotation, and spatial perception. According to Linn and Petersen, spatial visualization refers to the ability to manipulate spatial information when several stages are needed for solving the task. Mental rotation is a specific visual-spatial ability that involves the process of imagining how a two- or three-dimensional object would look like if rotated away from its original upright position (Shepard & Metzler, 1971). Finally, spatial perception requires determining horizontality or verticality despite distracting information. Accordingly, our analysis relied on these definitions to classify tests of spatial abilities.

1.2. Potential moderator variables

A crucial part of any meta-analysis requires the identification of potential moderators of the effect sizes. This selection has to be guided by a theoretical or empirical rationale as a simple use of any and all possible moderators increases the risk of Type 1 errors in the meta-analytic results (Lipsey & Wilson, 2001). Accordingly, in describing possible moderating variables, we focus on variables identified in past research.

1.2.1. Type of experts

It would appear from the existing literature that the specific expertise can affect group differences in spatial tasks. For example, Pietsch and Jansen (2012a) reported that music and sport students show a better mental rotation performance than education students, most likely as a result of the motor activity involved in the practice of sports and musical instruments. Similarly, Moreau et al. (2011) reported that elite participants in combat sports performed better than novices in such sports in a mental rotation task, whereas no significant elite vs novice difference was found for runners. Such findings can be interpreted as reflecting the fact that expertise in motor movements required in combat sports facilitates motor processing in mental rotation. These few examples justify coding the type of experts as a potential moderator of effect sizes.

1.2.2. Specific tests and stimuli

The categorization of spatial tests proposed by Linn and Petersen (1985) that we discussed earlier suggests the possibility that expertise effects could vary as a function of the categories, as has been found in the case of sex differences. In that context, Linn and Petersen found the largest sex differences in mental rotation, followed by spatial perception, and finally by spatial visualization, with the last category producing no significant effect. Assuming that this categorization reflects different processes that produce individual differences varying in magnitude, we coded test category as a moderator to determine whether the observation made by Linn and Petersen (and replicated by Voyer, Voyer, & Bryden, 1995) for sex differences would extend to motor expertise.

In terms of specific tests found in the Linn and Petersen (1985) categories, spatial visualization is often investigated with *the Embedded Figure Test*, the *Block Design,* or the *Differential Aptitude Test – Spatial Relations* subtest. In spatial perception, the *Water Level task* and the *Rod and Frame Test* are representative measures. Finally, mental rotation is the category that has received the most attention in the context of motor expertise, possibly because it has also received much attention in the context of embodied cognition. In fact, Wexler, Kosslyn, and Berthoz (1998) and Wohlschlaeger (2001) both implied that mental rotation involves covert motor rotation. Specifically, these authors showed that performance on such a task is negatively affected when individuals are required to complete a motor task incompatible with the required mental rotation.

Specific test and stimulus type are inseparable to some extent as the specific tests in the spatial visualization and spatial perception categories always use the same stimuli within test. In contrast, mental rotation can vary in terms of how it is administered and in terms of the specific stimuli that are used. Specifically, administration can be psychometric, in the form of tests where participants have to solve mental rotation items requiring comparison of a target stimulus with two or more alternatives. These tasks typically only used response accuracy to assess performance. Administration can also be chronometric, where participants sit in front of a computer screen and stimuli are presented as pairs or as single mental rotation object. These tasks usually record response time in addition to accuracy as measures of performance.

Regardless of the administration procedure, different types of stimuli have been used in mental rotation tasks, with the most popular variations involving either block figures or human bodies/body parts (Amorim et al., 2006; Parsons, 1987). Considering the particularities of mental rotation, stimulus type will be examined as a potential moderator both for the overall sample as well as in a subset analysis considering only mental rotation tasks.

1.2.3. Sex composition of the sample

In view of the well-documented sex differences in spatial abilities, often producing a male advantage (Voyer et al., 1995), it would be remiss to ignore the potential influence of sex on the relation between motor expertise and spatial test performance. However, as