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Sex differences in neural efficiency: Are they due to the stereotype threat effect? ☆

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ABSTRACT

The neural efficiency hypothesis postulates a more efficient use of brain resources in more intelligent people as compared to less intelligent ones. However, this relationship was found to be moderated by sex and task content. While the phenomenon of neural efficiency was previously supported for men when performing visuo-spatial tasks it occurred for women only when performing verbal tasks. One possible explanation for this finding could be provided by the well-studied phenomenon called stereotype threat. Stereotype threat arises when a negative stereotype of one's own group is made salient and can result in behavior that confirms the stereotype. Overall, 32 boys and 31 girls of varying intellectual ability were tested with a mental rotation task, either under a stereotype exposure or a no-stereotype exposure condition while measuring their EEG. The behavioral results show that an activated negative stereotype not necessarily hampers the performance of girls. Physiologically, a confirmation of the neural efficiency phenomenon was only obtained for boys working under a no-stereotype exposure condition. This result pattern replicates previous findings without threat and thus suggests that sex differences in neural efficiency during visuo-spatial tasks may not be due to the stereotype threat effect.

1. Introduction

Individual differences in cognitive performance can be elucidated from different perspectives. The personality based approach takes an ability perspective in attributing performance differences to stable traits. This point of view differs from the social psychological approach, which acknowledges that cognitive performance can be affected by various state factors. As trait and state effects can be reflected in test scores (Wicherts, Dolan, & Hessen, 2005; cf. Cronbach, 1957) we will conjoin both perspectives when investigating sex differences in neural efficiency (negative IQ-brain activation relationship; e.g., Haier et al., 1992).

According to the individual differences/trait perspective, sex differences in neural efficiency would be attributed to sex differences in the underlying ability domain (women typically show higher verbal ability, men show higher spatial ability). The neural efficiency hypothesis is represented by an IQ-brain activation correlation, which can be moderated by sex and task content (Jaušovec & Jaušovec, 2008; Lipp et al., 2012; Neubauer, Fink, & Schrausser, 2002; Neubauer, Grabner, Fink, & Neuper, 2005): Males and females showed the expected inverse IQ-brain activation relationship primarily in those tasks in which they usually perform better, i.e. males in visuo-spatial tasks and females in verbal and emotional intelligence tasks. This certainly holds true for the visuo-spatial domain where considerable evidence demonstrates that men usually outperform women (for a review cf. Halpern et al., 2007). However, with respect to the verbal domain it is more complex. While women stereotypically think to perform better in verbal tasks evidence for an actual performance difference is rather mixed (Halpern, 2004).

Sex differences in task performance can be explained by ability factors as well as by situational factors. Moreover, ability differences can have genetic causes but also long-term environmental causes (Halpern et al., 2007; Steele, 2010). In particular, performance can be influenced by implicitly activated stereotypes. A stereotype threat arises in a situation in which the stereotype is relevant and the situation strikes one as a test of stereotype-relevant qualities. Steele (1997) proposed that a negative stereotype about a group to which one belongs leads to fear, self-doubt, which in turn may impair working memory and hamper cognitive performance. Empirical evidence demonstrates for instance that, White males underperform in athletics (Stone, 2002) and women underperform in math and science domains (Good, Aronson, & Harder, 2008; Spencer, Steele, & Quinn, 1999). According to Steele

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(2010), negative stereotypes can have long term consequences, leading to a loss of interest and eventually diminishing math or spatial ability in the long run.

Although research has shown that activated negative stereotypes may impair performance and lead to fear and self-doubt, little is understood about the mechanism that accounts for these effects. Stereotype threat effects have been explained within different frameworks such as the mere effort account (Jamieson & Harkins, 2007), the disruptive mental load (Croizet et al., 2004), the attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) or the arousal-based theory (O'Brien & Crandall, 2003).

The integrated process model (Schmader, Johns, & Forbes, 2008) attempted to integrate existing frameworks for explaining stereotype threat effects. It assumes that interrelated cognitive, physiological and affective processes can impair executive resources thus hampering efficient processing. In an fMRI study by Wraga, Helt, Jacobs, and Sullivan (2007), the confrontation with a negative stereotype about one's own group resulted in impaired performance and in raised activation of amygdala as well as in reduced activity in brain regions associated with high performance in spatial ability (e.g., ventral and medial portions of anterior prefrontal cortex). Additionally, increased activation in the rostral-ventral anterior cingulate cortex (a region associated with emotional self-regulation) and the right orbital gyrus (a region associated with social knowledge) were found. Similar results were found by Krendl, Richeson, Kelley, and Heatherton (2008). These results largely support behavioral research showing that coping with negative stereotype related emotions seize cognitive resources that could otherwise be used for cognitive tasks (Schmader & Johns, 2003; Schmader et al., 2008). In other words, women may underperform under stereotype threat because valuable cognitive resources are spent on emotional regulation and thereby reducing working memory capacity.

1.1. Research question

The main aim of this study was to examine whether sex differences in neural efficiency could be attributed to the stereotype threat effect. In this study a visuo-spatial task is selected, since there exist robust sex differences and stereotypes regarding visuo-spatial performance, especially in mental rotation (for a review cf. Halpern et al., 2007). Furthermore, visuo-spatial skills are a fundamental element in STEM (Science, Technology, Engineering, and Mathematics) which indicates the practical significance (Lubinski, 2010) of this study. Lubinski (2010) even suggested that selecting students for advanced learning opportunities in STEM without considering spatial ability might be unprogressive. Therefore, several attempts have been made to discover the origins of sex differences in spatial ability. Women working on visuo-spatial tasks might be affected by implicitly activated stereotypes resulting in higher arousal (cf. O'Brien & Crandall, 2003). Moreover, higher arousal could lead to higher and more diffuse brain activation which then would oppose efficient processing.

We assume that the stereotype threat may affect brain activation differentially in women according to their individual level of intellectual ability. It can be hypothesized that high IQ women (who sense the task easier than low IQ women generally show lower brain activation according to the neural efficiency hypothesis) confronted with the stereotype show increased brain activation because they feel challenged to disprove this stereotype (cf. Jaušovec & Jaušovec, 2008). Low IQ women may also strive to disprove the stereotype, but their already high level of arousal (due to their perception of increased task difficulty) may limit a further increase of activation. As a consequence IQ and brain activation would be no longer correlated in women under stereotype threat, which would explain why neural efficiency in visuo-spatial tasks has only been found for men but not for women. Therefore, this study aims at testing whether stereotype threat is partly responsible for sex differences in neural efficiency. To this end, neural efficiency during visuo-spatial processing shall be investigated under two experimental conditions, either involving an explicit stereotype threat or involving no stereotype threat. If behaviorally a stereotype threat can be elicited and if the above described sex difference in neural efficiency can be found only in the threat condition then it might be concluded that the particular threat is responsible for sex differences in neural efficiency.

2. Method

2.1. Participants

Out of a pool of 929 participants, 63 healthy Austrian adolescents (31 girls and 32 boys aged between 15 and 18 years) were selected to represent a large variability in figural intelligence participated in the study. All participants were IQ-matched between experimental groups in order to avoid a confounding. The sample showed an average IQ of 100.50 (SD = 15.52), and there were no differences in figural IQ, neither between sex groups ($F(1,54) = 0.04$, $p = .84$; $M_{girls} = 101.11$, $SD_{girls} = 17.59$; $M_{boys} = 100.26$, $SD_{boys} = 13.89$) nor between stereotype exposure conditions (stereotype exposure vs. no-stereotype exposure) ($F(1,54) = 0.17$, $p = .68$; $M_{non\_st} = 99.83$, $SD_{non\_st} = 17.55$; $M_{st} = 101.54$, $SD_{st} = 13.21$). Prior to the study, participants provided written informed consent (for underage students it was provided by their parents). Participation was voluntary and students received €20 for participation. The data of 5 persons were excluded from the analysis either because of excessive EEG artefacts or because they disagreed to one of the two following statements: (1) "I am good at math" and (2) "It is important to me that I am good at math", leaving a total of 58 participants (26 girls and 32 boys).

2.2. Experimental task

A mental rotation task was employed, in which participants were presented 48 pairs of Shepard-Metzler (SM) figures. Participants' task was to judge whether the figures were congruent or incongruent. In order to come to the correct solution, SM figures have to be rotated mentally until the main axis points in the same direction, before it can be decided whether the pair of figures is identical or not (i.e., mirror images). All SM-figures were presented in a 3D presentation mode. The 3D presentation mode was employed because a mental rotation task in a 3D presentation mode seems to create fair conditions for both sexes (Neubauer, Bergner, & Schatz, 2010).

2.3. Experimental design

A 2×2 design was employed using the between-subject factor SEX and STEREOTYPE EXPOSURE (stereotype exposure vs. no-stereotype exposure). Participants of both sexes were randomly assigned to one of the two experimental conditions. The experimental manipulation was part of the written task instruction, which was presented prior to working on the task. In the stereotype exposure condition, students received the message that boys perform better. ("This test measures your visuo-spatial ability. Recent studies demonstrated that in this task boys usually perform better than girls. That means that girls solve fewer items than boys.") This information reflects a stereotype threat for girls and a stereotype lift for boys. Participants working under the no-stereotype exposure condition were informed that in the particular task no sex differences exist. ("This test measures your vi-