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Editorial: From paper and pencil tasks to virtual reality interventions: improving spatial abilities in girls and women

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Editorial on the Research Topic
From paper and pencil tasks to virtual reality interventions: improving spatial abilities in girls and women

Understanding scientific findings in the context of sex -whether similarities, differences, or complex nuances-is critical to appropriately applying research-derived knowledge to achieve our multiple goals (Clayton, 2016).

When discussing spatial abilities or spatial cognition, it is common to acknowledge that it differs between men and women, as well as in other species, with males frequently outperforming females in various spatial tasks (for reviews see Chamizo and Rodrigo, 2019; Halpern, 2012; Kimura, 1999; Mackintosh, 1998; Voyer et al., 1995). Despite being perceived as "politically incorrect" this assertion is supported by substantial evidence from studies with both human and non-human participants. Geary (2021) has suggested that the difference could be attributed, at least partly, to the fact that males tend to use distant landmarks to orient themselves while navigating towards a goal, whereas females may not employ this strategy with comparable frequency. This statement aligns with the range size hypothesis, which is the best predictor of sex differences with non-human participants, a biological hypothesis that predicts sex differences based on the size of the territory covered throughout life (for humans, see Vashro et al., 2016). This hypothesis connects with our ancestors' past as hunter-gatherers and in other mammals with polygyny, in which promiscuous males mate with multiple females in a breeding session, thereby having a larger home range than females (which is not the case with monogamous males). Despite what has just been said, it is important to note that the differences between men and women in many spatial tasks, such as mental rotation, can sometimes disappear depending on several factors (Jansen-Osmann and Heil, 2007; Hegarty, 2018; Ruthsatz et al., 2019; Álvarez-Vargas et al., 2020; Jost and Jansen, 2023). Future research will have to clarify these apparent inconsistencies.

Spatial abilities (which include a large range of tasks, from paper and pencil tests to real-world navigation) are malleable (Uttal et al., 2013) trough appropriate interventions, as evidenced by numerous studies that have shown significant improvements in a wide variety

of participants, contexts, and ages (for a review with mental rotation tasks in infancy, between 3 and 10 months of age, see Johnson and Moore, 2020). Moreover, the sex gap often observed in multiple spatial tasks can be reduced and even eliminated with such interventions. Examples of successful interventions include a spatial training program delivered within a learning framework in boys and girls from primary schools, (Lowrie et al., 2021); experience with a computerized mental rotation task in 6–8 year old children (Hawes et al., 2015); a physical education program in students of a secondary school (Jansen et al., 2018); a spatial visualization course in first year engineering students (Sorby et al., 2018); and a geometry learning in rats (Aguilar-Latorre et al., this issue). Furthermore, Yang et al., 2020 conducted a meta-analysis with children aged 0–8 years, which showed that various interventions (such as hands-on exploration, visual prompts, and gestural spatial training), could significantly improve young children's spatial abilities. It is important to note that multiple studies have shown that these interventions sometimes benefit women more than men (Provo et al., 2002; Feng et al., 2007; Sorby et al., 2018; Lane and Sorby, 2022).

The impact of Virtual Reality Interventions is demonstrated by the first three contributions of this topic. Cocquyt et al. conducted the first study, which is focused on the ability of university students to create an accurate mental survey representation, or a cognitive map, by means of an immersive virtual task and in a real environment on campus. The results revealed clear differences between men and women, as well as generalization problems between the virtual environment and the real world.

Miola et al. present the second contribution of this topic. It addressed the relationship between the adult participant's mental rotation ability, allocentric orientation, and knowledge of egocentric and spatial beliefs. Following a mental rotation test and several questionnaires, men outperformed women in two specific virtual tasks (an egocentric pointing task and an allocentric pointing task). In addition, only mental rotation ability predicted good performance in the two tasks, although both cognitive abilities and beliefs contributed to support environmental knowledge in men and women.

The third contribution, authored by Dahmani et al. explores the impact of environmental factors, navigation strategies, and age on sex differences in various spatial tasks. More than four hundred and fifty participants took part in this extensive study, while employing virtual radial arm mazes, a virtual wayfinding task, an object location task, a virtual Morris water maze, and a real-life model of the Morris water maze. Significant differences were found between men and women and multiple factors (such as spontaneous navigation strategies: spatial *versus* response—a classification reminiscent of the controversy between Tolman and Hull to explain how rats learn in maze experiments, place learning vs. response learning—, environmental characteristics and age) influenced participants' performance on the different tasks. Importantly, the authors' final discussion concludes by addressing possible implications for the risk of Alzheimer's disease, which particularly affects women.

Finally, the contribution by Aguilar-Latorre et al. addressed geometry learning in rats, in a water maze task in which sex differences in favour of males have been repeatedly found. The study emphasises the importance of possessing extensive prior experience with geometry before performing the target task (in which geometric as well as non-geometric information is involved). The results showed that without such prior experience males outperformed females in a final geometry test, but the difference disappeared with prior geometry experience. These results are discussed in the framework of selective attention.

In summary, this Research Topic serves to unambiguously illustrate the intricate nature of the factors that exert influence on spatial abilities (so important in education, learning and everyday activities, as noted by Ishikawa and Newcombe, 2021), as well as their enormous potential for malleability. While the origin of sex/gender differences in the spatial domain remain to be fully elucidated, the present findings highlight that numerous interventions hold the potential to enhance these abilities. Given the advance and diverse technologies at our disposal, we are optimistic about soon achieving the current goals of reducing or eliminating the sex/gender disparities in various spatial tasks among girls and women compared to men.

Author contributions

VC: Writing–original draft. PB: Writing–review and editing. MM-L: Writing–review and editing. JS: Writing–review and editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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