Gender Differences in a Mental Rotation Task: Examining the Number of Strategies Used and Discovery of Parity Strategy

Stefanie Kabierschke Sotelo

s3672069

Department of Psychology, University of Groningen

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Supervisor: dr. Lisette de Jonge-Hoekstra

Second evaluator: prof. dr. Ernestine Gordijn

In collaboration with: Hannah Hendrikse, Ilse K. van der Meulen, Louise J. Warringa, Luheng Wei, and Paul F. Koelling.

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Abstract

The present study explores the relationship between gender, problem-solving strategies, and the utilisation of the parity strategy in a gear task. The participants (59 females and 9 males) were randomly assigned into two conditions, hand movement allowed condition and hand movement constrained condition, and had to complete six gear mental rotation tasks. During the hand movement-restricted problem-solving tasks, participants were restrained from gesturing to enhance focused engagement with the tasks at hand. The results indicate no significant gender differences in strategy use during problem-solving tasks. However, employing the parity strategy showed a reduction in the number of alternative strategies used during problem-solving. Finally, when exploring if there is an interaction effect between gender and the use of the parity strategy on strategy utilisation, we did not find statistically significant results. *Limitations of this study encompass a major sample imbalance. Nevertheless, the research contributes to the ongoing discourse on gender differences in problem-solving and the effectiveness of abstract strategies in enhancing cognitive performance.*

Keywords: gender differences, gestures, mental rotation task, parity, problem-solving, strategies

Gender Differences in Mental Rotation Tasks: Examining Number of Strategies Used and Discovery of Parity Strategy

The present research study is intended to investigate the relationship between gender differences, the use of different strategies, and problem-solving in the context of mental rotation tasks. Research in this field may yield new insights into the underlying mechanisms of cognitive processes, leading to advances in fields such as psychology and other cognitive sciences. Building upon existing research, the present study delves into the influence of gender on problem-solving performance, particularly focusing on the implementation of strategies. It has been postulated that there is a well-established notion that, on average, males outperform females in tasks involving spatial abilities (Doyle & Voyer, 2013). The current investigation is aimed at examining the impact of gender on problem-solving. Specifically, the utilisation or non-utilisation of diverse strategies throughout different phases of problem-solving tasks will be thoroughly analysed. Consequently, an exploration will be conducted on the connection between strategy usage and cognition, as well as gender disparities in problem-solving tasks. Initial emphasis will be placed on providing a contextual background on previous studies in this field.

The Relationship Between Strategy Usage and Cognition

In recent decades, there has been a growing interest in investigating the relationship between hand movements and cognition. According to Smith (2005), conventional methodologies have been predominantly used to understand cognition and development. In order to differentiate between different concepts and representations for categorising and interpreting the environment, these approaches highlight the significance of cognitive stability and unchanging mental representations, offering a specific framework for comprehending and arranging information (Smith, 2005). Dynamic systems theory, on the other hand, challenges this perspective and proposes an alternative by arguing that cognition is a fluid, adaptive process that evolves through the interaction between an individual and their environment. Cognitive development, from a dynamic systems perspective, can thus be defined as the interplay of behavioural changes and internal processes that change in response to the environment (Smith, 2005). This paper will focus on cognitive development from a dynamic system standpoint. Gestures play a significant role in the acquisition of language and the expression of knowledge, a phenomenon observable in infancy (Iverson & Thelen, 1999; De Jong-Hoekstra, 2021). De Jonge-Hoekstra (2021) suggests that children use hand movements to explore their environment, which facilitates the development of comprehension and cognitive skills. The use of gestures is related to dynamic systems, which include various elements that interact, like speech and hand movements, and self-organize over time (Smith, 2005; De Jonge-Hoekstra, 2021). In spite of the fact that gestures are often overlooked, they go beyond aiding communication and have an important impact on thinking and learning, revealing individuals' unexamined thoughts (Goldin-Meadow, 1999; Novack & Goldin-Meadow, 2015). This study explores the dynamic relationship between strategies, gestures, and cognition, challenging traditional views of cognitive development and emphasising the importance of environmental interactions.

The use of strategies can help cognitive processes while solving tasks, positively influencing reasoning and problem-solving skills (Popescu & Wexler, 2012; De Koning & van der Schoot, 2022). Specifically, gestures are indicative of the embodied nature of cognition, providing insights into thinking processes and facilitating abstract reasoning and logical thinking. Variability in strategy usage highlights cognitive growth, with gestures enhancing spatial problem-solving performance and improving spatial working memory (Siegler, 2006). Particularly in mental rotation tasks, gender differences in spatial abilities have been widely observed, with men often outperforming women (Doyle & Voyer, 2013; Voyer et al., 2016). Furthermore, recent research suggests the involvement of motor processes and visual-spatial working memory in mental rotation, indicating distinct processing mechanisms between genders (Voyer et al., 2016; Di Tore et al., 2017)

Exploring the correlation between gestures and cognition is a critical area of study. Current research, such as that by Pouw et al. (2014), delves into the complex relationship between gestures and internal cognitive processes. It posits that gestures serve as external representations of the cognitive system, supporting and replacing otherwise purely internal mental processes. This perspective emphasises the overlap between how the human mind interacts with its environment and the role of gestures as beneficial tools in cognitive tasks. By clarifying the embodied nature of cognition, gestures offer valuable insights into the embodiment of cognitive processes (Pouw et al., 2014).

Gestures, Strategies and Problem-Solving

Gestures are characterised as hand and body movements and have the potential to impact reasoning and problem-solving positively (Goldin-Meadow, 1999). These bodily movements can help to effectively express ideas that are challenging to articulate verbally, consequently leading to insights and facilitating conceptual development, as noted by Novack and Goldin-Meadow (2015). The act of gesturing while explaining not only provides valuable feedback but also influences learners' comprehension and cognitive processes (Novack & Goldin-Meadow, 2015). The production of gestures in response to perceived or simulated actions activates specific brain regions associated with motor and premotor functions (Alibali, 2014). These represent components of mental simulations of activities and sensations, which extend to abstract notions (Iverson & Thelen, 1999; Alibali et al., 2011).

Hand gestures may also influence problem-solving processes by increasing the activation of perceptual and motor information in the brain (Alibali et al., 2014). Individuals who exhibit discrepancies between their gestures and speech, indicating that their gestures and speech are not in agreement, tend to have more than one idea or notion about a single problem

(Goldin-Meadow, 1999). This observation indicates that they display variability in their responses (Siegler, 2006). In contrast, individuals who demonstrate mismatches and therefore present more than one different approach to each explanation of their math problems exert more effort in arriving at solutions when compared to individuals who align their gestures and speech, articulating a single method per explanation (Goldin-Meadow, 1999).

Goldin-Meadow (1999) conducted a study to test this prediction by asking children to solve math problems and explain their solutions. They found that mismatchers underperformed when recalling words compared to matchers after solving hard math problems (Goldin-Meadow, 1999). According to Siegler (2006), when solving cognitively demanding tasks, individuals implement multiple methods, showing a wide range of variability in the ideas leading to fluctuation in their strategy utilisation from one trial to another, often reverting to less sophisticated approaches even when solving identical tasks within a single experiment. additionally, The term “cognitive variability” refers to the inherent variation in thought processes and approaches to problem-solving between and within individuals (Siegler, 2006). It comprises the different techniques, strategies, representations, and ideas individuals can employ to solve problems. In light of this, variability can be analysed in relation to the acquisition of new strategies, increased utilisation of existing strategies, efficient implementation of strategies, and enhanced decision-making among strategies (Siegler, 2006).

According to Chu and Kita (2012) when individuals are motivated to use hand gestures, it has been observed that this practice can significantly enhance their performance in spatial problem-solving tasks as well as improve their spatial working memory capacity. Their research findings suggest that gestures can serve as a beneficial tool for individuals of all ages when addressing spatial problem-solving tasks. Furthermore, Chu and Kita's (2012) study highlights the potential benefits of integrating hand gestures into the problem-solving process, thereby emphasising the significant role that non-verbal communication can play in enhancing cognitive abilities

Prohibiting participants from gesturing can also result in the adoption of abstract strategies, like the parity strategy, which can facilitate the derivation of solutions (Alibali et al., 2011). In tasks involving mental rotation, the parity strategy refers to the identification that odd-numbered gears turn in the same direction as the initial gear and even-numbered gears turn in the opposite direction (Alibali et al., 2011; Alibali, 2014). This variability is observed across different levels of cognition, ranging from neuronal and associative processes to higher-level cognitive functions (Alibali et al., 2011; Siegler, 2006). The parity strategy involves using abstract reasoning and logical thinking to determine the movement of gears in mental rotation tasks (Alibali et al., 2011). Instead of physically simulating the movements of the gears, individuals using the parity strategy rely on their understanding of the concept of the gears (Alibali et al., 2011).

Gender Differences Across Problem-Solving Tasks

This research is centred around the examination of gender disparities in spatial abilities, with a specific emphasis on the impact of employing strategies such as gesturing and parity strategy. Interest in this topic has grown considerably in recent years, revealing gender differences in spatial orientation with a male advantage dominating (Doyle & Voyer, 2013; Voyer et al., 2016). Research has consistently observed gender differences in this specific domain in numerous studies (Di Tore et al., 2017).

A closer examination of this topic reveals that gender disparities may vary depending on the tests and item properties utilised, as these factors may entail distinct cognitive demands that may favour men's performance on specific items compared to women's (Alexander & Evardone, 2008; Doyle & Voyer, 2013). Notably, mental rotation tasks exhibit the most pronounced sex differences in cognitive performance (Linn & Petersen, 1985; Voyer et al., 2016). While initial perspectives exclusively emphasised visuospatial perception, current research suggests the involvement of motor processes as well (Iverson & Thelen, 1999; Seepanomwan et al., 2013). Empirical research indicates that motor processes can interfere with mental rotation, particularly when directions are incongruent (Seepanomwan et al., 2013). Mental rotation includes a wide range of cognitive processes, including sensory processing, formation of mental representations, planning and execution of rotation, and comparison of rotated stimuli (Seepanomwan et al., 2013). Additionally, in terms of gender differences, visual-spatial working memory appears to play an important role in mental rotation and sex differences (Voyer et al., 2016), indicating that men and women process spatial information in different ways (Di Tore et al., 2017).

Understanding the dynamic link between strategies, such as gestures and parity, problem-solving, and gender is the primary objective of the present study. Dynamic systems theories claim that cognition is a dynamic and adaptive process shaped by environmental interactions (De Jonge-Hoekstra et al., 2020). From early infancy, gestures are essential for the acquisition of words, the expression of knowledge, and the expansion of one's vocabulary, serving as examples of the embodied characteristics of cognition and facilitating learning and thinking by providing insights into unexplored ideas (Novack & Goldin-Meadow, 2015). Gestures serve as external tools of the cognitive system, influencing internal cognitive processes and supporting problem-solving (Goldin-Meadow, 1999). According to Doyle and Voyer (2013), the use of gestures enhances reasoning, problem-solving skills, and spatial working memory. Specifically, the discovery of abstract strategies, such as the parity strategy in mental rotation tasks, can lead to more efficient problem-solving by reducing reliance on physical simulations (Alibali et al., 2011). Gender differences in spatial abilities, particularly in tasks like mental rotation, have been consistently observed, with men often outperforming women (Doyle & Voyer, 2013).

Purpose of the Present Paper

Building on prior research in this field, the goal of the current study is to further explore the complex relationship between gender, the implementation of different strategies, and problem-solving in the context of mental rotation tasks. Our study aims to identify the degree to which gender affects problem-solving ability throughout different task phases, in light of the literature that currently exists that suggests men have an advantage in spatial tasks (Doyle & Voyer, 2013). Additionally, analysing gender differences in mental rotation tasks may help identify and address differences to promote gender equity. Furthermore, it may offer valuable insights for educational practices and the development of curricula in order to tailor teaching approaches to better meet the different learning styles and preferences of both genders. Moreover, it serves to enhance the body of scientific knowledge, contributing to a more comprehensive understanding of human cognition and behaviour.

In particular, we will look at how certain strategies are applied or not applied and how that could affect how well problems are solved. We developed a number of research questions and hypotheses to help guide this exploration. By examining the intricate links between gender, cognitive functions, and problem-solving strategies, these investigations hope to advance our knowledge of human cognition and behaviour. The present study aims to address the following research questions: First, does gender have a statistically significant influence on the number of strategies used during problem-solving tasks? Second, does the discovery of the parity strategy have an influence on the number of strategies used during problem-solving tasks? Third, is there an interaction between gender and the use or non-use of the parity strategy on the number of overall strategies used during the gear problem-solving tasks? Therefore, the following hypotheses were defined:

1. We hypothesise that male participants use fewer strategies during the gear problem-solving tasks

2. We hypothesise that the implementation of the parity strategy leads to the use of fewer strategies during the gear problem-solving tasks
3. We hypothesise that there is an interaction between gender and the use or non-use of the parity strategy on the number of overall strategies used during the gear problem-solving tasks

Method

Participants

A total of 120 participants originally participated in the study. After exclusion, which will be explained in the next paragraph, the data of 68 participants (59 females, 9 males, M_{age} = 20.73, SD_{age} = 1.52) was used. The participants were divided among two conditions, with 35 participants in the hand movement allowed condition and 33 participants in the hand movement constrained condition. All participants were Dutch and followed a bachelor or pre-master program at the faculty of Behavioural and Social Sciences. The Ethics Committee of Psychology department of the Faculty of Behavioural and Social Sciences, University of Groningen approved the study, Codes: PSY-1819-S-0037 & 17209-O.

In total 52 participants were excluded from the sample. An overview of reasons for exclusion can be found in Table 1. Our methodology differed from the protocol by Alibali et al. (2011) as we opted not to exclude participants who were not given an opportunity to correct their answer if they were incorrect, but were told the correct answer instead. We believe this deviation is unlikely to significantly impact the discovery and usage of the parity strategy.

Table 1

Reasons for exclusion

Reason for Exclusion	Number of participants excluded

Protocol was not followed	16
Participant was in the hands constrained condition, but still moved their hands	3
Participant did not understand the gear task	1
Not all gear tasks were properly documented	1
The coding was not available for this participant	18
There was an ELAN error found	2

Materials

The experiment was carried out in an assigned room equipped with the necessary equipment which included a laptop, two cameras, a screen, a chair, a pair of Velcro gloves, a wooden board with cans attached to it, and a wooden board with Velcro straps. During the hand movement-restricted problem-solving tasks, Velcro gloves, a wooden board affixed with cans, and another wooden board featuring Velcro straps were utilized; These tools served to restrain participants from gesturing, facilitating focused engagement with the tasks at hand. The laptop was used for the participants to fill out a short questionnaire in Qualtrics. The primary role of the cameras was to record the trials and, more importantly, the strategies employed by participants during the data collection process. In order to prevent the experiment leader's behaviors from influencing the participant's behavior, a screen was placed between them.

Additionally to the use of different materials, we used software to process the data for our study. The software used included VLC media player 3.0.20 Vetinari, OpenShot 3.0.0, Audacity 3.4.2, R studio 4.3.2, Matlab R2020b, and ELAN 6.4. The VLC media player is a program used for playing a variety of audio and video file formats. OpenShot is a video editing tool and Audacity is a digital audio editor and recording application software. R studio is software used for statistical computing and graphics and is used for data analysis, statistical modeling, and visualization. Matlab is a programming software used for numerical computing, data analysis, and visualization. Finally, ELAN is a computer program designed for the annotation and analysis of audio and video recordings.

Procedure

The experiment was carried out in Dutch by student researchers within the second year Research Practicum course. Each student researcher was assigned to collect data from two participants. The first participant was randomly assigned to either the gesture-prohibited condition or the gesture-allowed condition, by flipping a coin. The second participant was automatically assigned to the other condition.

Prior to the experiment, participants were informed about the aim of the experiment, given informed consent, and completed a questionnaire. This questionnaire solicited information pertaining to their age (in years), gender (elicited through an open-ended query), field of study, and nationality. After filling out the informed consent form, the experiment leader announces the start of the experiment, with the cameras being turned on and brought into position to capture the hands of the participants. In contrast to the study by Alibali et al. (2011), the cameras were visible to the participants instead of hidden. Depending on the condition, participants' hands or feet were constrained. In the gesture-prohibited condition, participants had to wear Velcro gloves and hold two cans attached to a board, while in the gesture-allowed condition, participants’ feet were attached to a board with Velcro straps. The foot restriction served as a control to the strangeness of the hand restriction. In addition, a screen separated the experimenter and the participant.

The experimenter explained to the participant that six gear problems would be presented and that the participant should think aloud while solving them. An example of a gear problem is: “Imagine four gears connected in a horizontal line. If you turn the gear on the left clockwise, what would the gear on the right do?”. The gear problems involved four, seven, nine, five, eight, and six gears respectively. Following the completion of these tasks, the experimenter concluded the experiment and asked the participants about their overall thoughts and experiences.

Data Processing

The video data was processed according to an instruction manual (De Jonge-Hoekstra, 2023), which can be found in the Research package. Using VLC media player, the raw data was checked for whether the experiment protocol was followed, and subsequently data that violated the protocol or fulfilled other exclusion criteria was excluded. Afterwards, each video was trimmed with OpenShot to the length of the actual experiment. From the trimmed videos a video file, audio file and an image sequence (at 30 Hz) was extracted. Further, background noise was removed from the audio file using Audacity. These steps were repeated for every video.

For the audio files a script for R, developed by Pouw and Trojillo (2019) was used to extract amplitude envelopes. Amplitude envelopes allow for detecting the intensity of speech over time by measuring the smoothed amplitude of sound across time. Next the body movements were extracted from the image sequences using the frame differencing method in MatLab (script: Paxton & Dale, 2013). The frame differencing method tracks how the pixels’ colors change from one frame to another in a video file making it possible to track movements in front of a static background. Afterwards, R was used again to automatically detect when speech starts and stops within each video (script: De Jonge-Hoekstra, 2023).

Next, the videos were coded in ELAN. After the start and stop of speech had been automatically detected in the previous step it was manually coded whether the participant or the experimenter was talking for each section of speech. Furthermore, the start and stop of the six trials within each video were coded. In the next step the problem-solving strategies participants used were coded on the trial level, respectively "Depict all", "Depict chain", "Parity", "Incorrect rule", "Guessing" or "No strategy". A complete overview of the different problem-solving strategies, including examples, can be found in Table 2. On this trial-level, regardless of whether a participant used more than one strategy, only one strategy was coded, following a number of decision rules": 1) if the participant used parity, the trial was always coded "parity", and 2) when the participant used "depict chain" and "depict all", the trial was always coded "depict all". Last, the problem-solving strategies were coded on the within trial level, which entailed coding every strategy that was used within a trial. To ensure interrater-reliability of the coding a Google Space was created that allowed all Bachelor's students involved in the analysis to consult the supervisor when in doubt about the coding of the strategies. Lastly, the audio, movement and coded data were combined using a custom R-script and coded time series (100 Hz). From these time series new variables were calculated for the final analysis.

Table 2

Strategy Codes, Definitions, and Examples

	Strategy	Definition	Example
Perceptual motor strategies	Depict all	The participant represents the actions of each individual gear with words and/or gestures. When coding this strategy, it is therefore important to see whether the actions of all gears are actually displayed. If the actions of only part of the gears are displayed, then the following strategy is encoded: Depict Chain.	"The first one goes clockwise, the next_ one goes counterclockwise, clockwise, counterclockwise".
	Depict chain	The participant represents the actions of some of the individual gears with words and/or gestures. The difference between the Depict Chain and Depict All strategies is that Depict All is only coded if the actions of all the gears are actually displayed, while displaying the actions of some of the gears always leads to the coding of Depict Chain.	"With four gears it went counterclockwise, so five clockwise, six counterclockwise, seven clockwise".

Abstract Strategies	Parity	The participant states in words that the chain of gears contains an even or odd number of gears.	"It is an odd number so it goes clockwise just like the first".
	Incorrect rule	The participant states in words a wrong rule with which he/she predicts the direction of the last gear.	"All gears rotate in the same direction".
Other strategies	Guessing	The participant indicates that he or she has guessed the solution, without showing a solution strategy in verbal expressions and/or gestures.	"I guessed".
	No strategy	The participant only answers the question, without showing a solution strategy in verbal expressions and/or gestures.	"Clockwise".

Results

We examined the impact of gender on strategy utilisation and problem-solving. For the initial hypothesis, that male participants will use fewer strategies than female participants on the within-trial level while solving the six gear problems, an analysis of variance (ANOVA) was employed. We found that men on average use 3 strategies (*SD* = 1.118) and women on average use 2.5 strategies (*SD* = 0.868). The outcomes of the ANOVA suggest the absence of a statistically significant effect of gender on the number of different strategies used ($F(1,64) = 2.639$, $p = .109$). This finding is contrary to our first hypothesis. However, it is crucial to note that there is a considerable gender imbalance in the sample, with 59 females and 9 males, which will be further discussed in the Discussion.

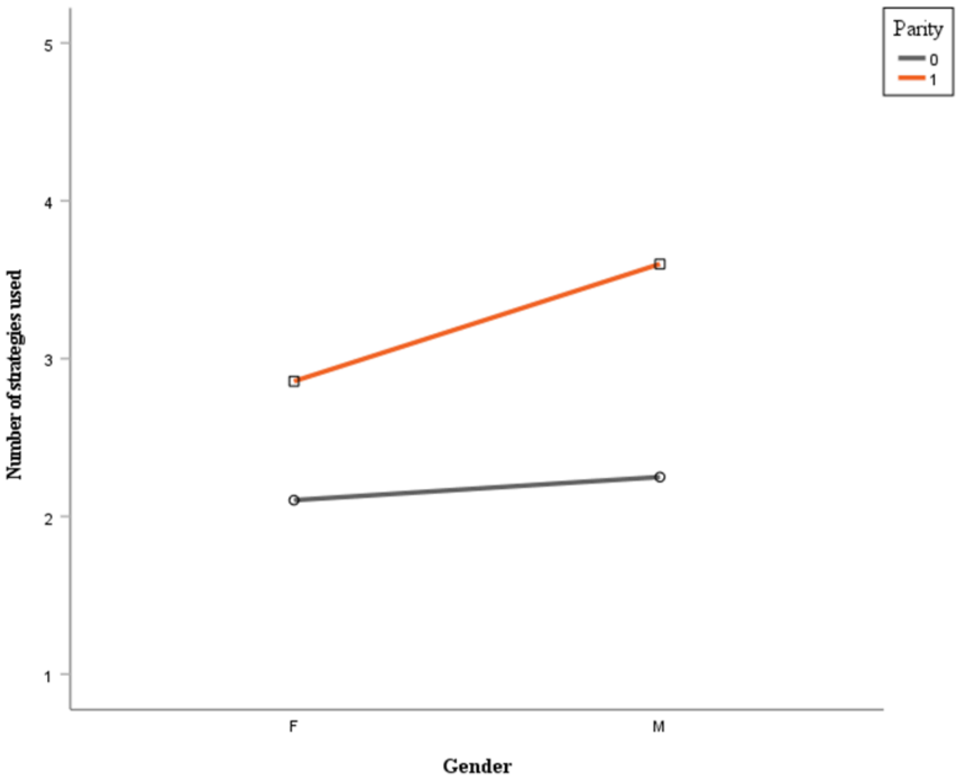
The second hypothesis examines that participants who use the parity strategy at least once use fewer alternative strategies when solving the six-gear problem.

We found that people who use the parity strategy at least once on average use 2.1 strategies (*SD* =.893), and people who do not use the parity strategy on average use 2.9 strategies (*SD* =.728). Analysing this hypothesis revealed a significant effect of the use of the parity strategy on the overall use of strategies ($F(1,64) = 17.894$, $p < .001$). Indicating an interaction effect on the number of strategies used when the parity strategy is used or not.

Finally, we analysed if there is an interaction between gender and the use of the parity strategy on the overall number of strategies used during the gear problem-solving tasks. We found the interaction effect between gender and the use of the parity strategy on the number of strategies used to be non-significant, $F(1,62) = 1.058$, $p = .308$. Figure 1 displays an interaction plot, which shows that contrary to our expectations, there is no interaction effect between gender and the use of parity on the number of strategies employed. This implies that, within the confines of our study, there is insufficient evidence to support the presence of an interaction effect, refuting this hypothesis.

Figure 1

Interaction Between Gender and Parity Strategy Use on Overall Number of Strategies



Discussion

Does Gender Influence the Number of Strategies Used During Problem-Solving?

As outlined in the introduction, this study aimed to understand the relationship between the use of different strategies and investigate whether male participants use fewer strategies compared to female participants while problem-solving. Analysing the first hypothesis, our results showed that, contrary to initial expectations, gender does not exert a significant influence on the number of strategies applied. These unexpected results suggest that, within the scope of this study, gender does not play a discernible role in shaping the variety of strategies individuals employ during problem-solving tasks. However, the substantial gender imbalance in the sample, with 59 females and 9 males, calls for caution in generalising these findings, especially for males. Furthermore, it is critical to note that the discrepancies in the gender distribution of our sample indicate that the power of this study is insufficient. Hence, there is a high risk of a type 2 error and reaching conclusions about gender differences is not possible. Contrary to our findings, prior research has consistently reported gender differences in spatial abilities and performance, particularly in tasks involving mental rotation (Linn & Peterson, 1985; Alexander & Evardone, 2008; Doley & Voyer, 2013; Voyer et al., 2016). Examining gender disparities, research has found that the complexity level of a task influences how gender differences vary and become more evident depending on the test content and item properties (Doley & Voyer, 2013; Alexander & Evardone, 2008). In the current study, participants engaged in solving gear problems under conditions where hand movements were either restricted or allowed. Notably, the mental rotation tasks presented in our study were relatively straightforward in terms of difficulty. Previous research by Doyle and Voyer (2013) suggests that task structure, particularly the difficulty level, significantly influences problem-solving performance and highlights gender differences in spatial abilities. To test this, they manipulated task difficulty by changing the items participants had to mentally rotate. Additionally, they implemented varying degrees of occlusion. Their findings revealed pronounced gender differences in performance, particularly in tasks involving rotating block items under occlusion conditions, with females underperforming compared to males. However, these differences were only observed when rotating block items and not in tasks involving rotating human figures (Doley & Voyer, 2013). This, in the context of our study, emphasises the importance of how task complexity can influence performance on mental rotation tasks due to different cognitive demands and reveal certain gender differences that would not become apparent with simpler tasks (Doley & Voyer, 2013; Voyer et al., 2016).

Does the Discovery of the Parity Strategy Have an Influence on the Number of Strategies Used During Problem-Solving?

Problem-solving skills are fundamental for individuals as they enhance comprehension and analytical abilities, necessitating the application of Higher Order Thinking Skills (Hadiprayitno et al., 2022). Examining the findings of the second hypothesis presented in this study, it was posited that the identification and use of the abstract strategy, parity, would lead to the implementation of fewer strategies in gear problem-solving tasks. In agreement with this assumption, our analysis revealed a statistically significant difference in the variety of strategies used between participants who applied the parity strategy and those who did not. As previously discussed, employing strategies, including hand movements, in problem-solving tasks provides valuable insights into the cognitive processes involved. The connection between cognition and motor functions, mediated by different brain regions, highlights the potential benefits of integrating gestures into problem-solving, particularly during early development (Schaefer, 2018). Incorporating these into spatial tasks enhances cognition by directly influencing thought processes and reducing the cognitive load (Alibali et al., 2014; Popescu & Wexler, 2012; Pouw et al., 2014; Schaefer, 2018). Alibali et al. (2011) observed that gestures play a critical role in problem-solving and that individuals employ various strategies to arrive at solutions. Gestures that align with subsequent actions, termed compatible or matching gestures, have been shown to enhance problem-solving performance in terms of time (Alibali et al., 2011; De Koning & van der Schoot, 2022). Conversely, incompatible or mismatched gestures occur when individuals attempt to convey new understanding through gestures while preserving former knowledge in words, leading to greater variability in their responses (De Jonge-Hoekstra et al., 2021; Goldin-Meadow, 1999). Using incompatible gestures, however, does not interfere with solving tasks successfully (De Koning & van der Schoot, 2022). Variability in an individual's strategy use further emphasises the dynamic nature of strategy development, suggesting a progression towards more efficient strategies over time, facilitating the identification and application of more conceptual strategies as more effective strategies evolve (De Borders et al., 2019). Hand movements are then translated into mental representations, allowing to determine gear movement and demonstrating an evolution of strategy use from less sophisticated simulation-based to more abstract (Alibali et al., 2011; Alibali et al., 2014; Siegler, 2006). Shifting focus on the use of the abstract strategy, parity, the results of our study align with the findings of previous research. It shows that discovering the parity strategy may have a positive influence on the number of strategies used while problem-solving, resulting in the use of fewer alternative strategies. While the overall results of the second hypothesis suggest differences, caution is warranted in generalising these findings, particularly for males, given their smaller representation in the sample. This highlights the complex relationship between cognitive processes, embodied cognition, and problem-solving strategies, emphasising the need for further research into how these factors interact and influence task performance and cognitive development. Future investigations with a more balanced representation are recommended to validate and extend these findings, offering insights into the potential gender-specific implications of the parity strategy on problem-solving approaches.

Is There an Interaction Between Gender and the Use of Parity Strategy Influencing the Number of Alternative Strategies Used?

The final question posited in this study examines whether there exists an interaction between gender and the utilisation of the parity strategy, impacting the variety of strategies employed during problem-solving tasks at the within-trial level. Previous research has demonstrated the significant role of gestures in bridging body language with conceptual comprehension (Harisman et al., 2017). Gestures play a functional role in problem-solving as they shape strategy choices, by structuring perceptual-motor information and developing more efficient abstract strategies, such as the parity strategy, which facilitates solving tasks (Alibali et al., 2011). The diversity and complexity of hand movements have been linked to alterations in spatiotemporal regions, thus exerting influence on cognitive development to some extent (De Jonge-Hoekstra et al., 2020). Additionally, research suggests that gesturing during problem-solving serves as a cognitive tool, fostering higher levels of reasoning and problem-solving skills (Goldin-Meadow, 1999; De Jonge-Hoekstra, 2021). Our findings regarding the influence of gender during problem-solving tasks indicate no statistically significant difference in strategy usage between genders. However, this lack of distinction may stem from the considerable gender imbalance within our sample. However, other studies propose gender disparities in problem-solving strategies (Harisman et al., 2017). For instance, women tend to use more analytical strategies, whereas men prefer a holistic approach, suggesting divergent processing of spatial information between genders during spatial orientation tasks (Di Tore et al., 2017). In this study, we did not find an interaction effect between gender and parity use on the number of different strategies that participants used. Consequently, the relationship between gender and the number of strategies employed appears to remain relatively consistent, irrespective of the use or non-use of the parity strategy. This highlights the need for further research to delve deeper into potential moderating factors or nuances that may influence this relationship, providing a more comprehensive understanding of the dynamics at play. Congruent with the findings in this study and previous studies, this does not yield any statistically significant differences between genders in the use of strategies. The number of strategies used in relation to gender differences has not been explored sufficiently in past research. This raises the question of the generalizability of our findings. There may be gender differences when it comes to the discovery of parity and the number of strategies used, but we were not able to uncover them due to an imbalance in the distribution of gender in our sample, indicating the possibility of a type 2 error. Other research has documented findings indicating that there are certain gender differences when solving spatial tasks. These become apparent on a different level than the amount of use of different strategies utilized. Especially when it comes to gender, research has observed that in mental rotation tasks, gender differences become apparent (Linn & Petersen, 1985; Voyer et al., 2016) in the way of processing spatial information. Men show more efficient joint neural activations among brain regions while solving spatial problems than women (Di Tore et al., 2017; Kim et al., 2023). However, this merely indicates that there is a difference in neural activation and does not interfere with successfully completing tasks (Kim et al., 2023). Furthermore, the characteristics of the problem-solving task may impact the effects of strategies on problem-solving performance (Alexander & Evardone, 2008; Doyle & Voyer, 2013). According to Schaefer (2018), the use of embodied techniques did not benefit females and males equally. Male individuals benefited more from embodiment than females, indicating potential gender differences. This highlights the importance of considering gender-specific approaches when implementing embodied learning strategies (Schaefer, 2018).

Further investigation is required in this field to expand our understanding. Conducting additional studies with larger and more diverse samples could provide clearer insights into the relationship between gender and the number of strategies used. Moreover, longitudinal studies tracking individuals' problem-solving strategies over time could offer valuable data on the long-term effects of gesture use. By exploring these domains, researchers can gain a more comprehensive understanding of the role of abstract strategies and gender in problem-solving and the factors influencing their effectiveness.

Limitations

There are limitations that should be addressed. Firstly, there appears to be a lack of exploration in the literature regarding the impact of gender on the number of strategies used, in combination with the effect of gender on the use of the parity strategy. Additionally, while there may be an effect, our sample has a substantial gender imbalance to detect it. This was caused by a significant loss of data during collection.

Conclusion

The discussion of our results sheds light on the intricate relationship between gender, problem-solving strategies, and the discovery of the parity strategy. Contrary to initial hypotheses, gender did not significantly influence the number of strategies used during problem-solving tasks in our study. However, we observed a significant difference in the number of strategies used between participants who applied the parity strategy and those who did not. This implies that discovering the parity strategy may lead to a more efficient problem-solving approach, reducing the reliance on alternative strategies. While unexpected, the lack of an interaction effect between gender and parity use on strategy utilisation suggests a consistent relationship between gender and strategy employment, regardless of the presence of the parity strategy. Nevertheless, the substantial gender imbalance in our sample, primarily comprised of female participants, raises concerns about the generalisability of our findings, particularly for males. Hence, future research with a more balanced gender representation is needed to validate and extend these results, offering deeper insights into gender-specific implications when using problem-solving strategies.

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