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The effect of ostracism on prospective memory in problem solving

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ABSTRACT

Successfully generating plans, while seemingly straightforward, can be riddled with external and internal interferences. One important possible source of interference is ostracism, which has been consistently shown to induce negative psychological effects in various executive functions. Therefore, understanding the impact of unforeseen ostracism on planning is vital to a broad spectrum of the population, from university students, whose self-esteem partly derives from social acceptance, to healthcare professionals, whose performance oftentimes relies on peer feedback. An individual's ability to navigate through intended actions is an evaluation of their prospective memory (PM), which is traditionally divided into three consecutive phases: (1) planning, (2) recall, and (3) performance. This study primarily focused on the impacts of ostracism via Cyberball simulation on the first two phases of PM in the Tower of London (TOL), an assessment of executive functioning designed specifically to test planning ability during problem solving. Using Bayesian analysis, the study found substantial evidence of there being no difference in planning success between social exclusion and inclusion conditions. However, an individual's sex had significant effects on their planning success at baseline (i.e., inclusion condition). Surprisingly, there was no difference in performance between male participants and female participants when excluded, suggesting that ostracism may play an equalizing role. In addition, male participants both listed more moves at planning and recalled more moves, which led to no difference between sexes in terms of recall percentage. This study underscores a need to consider various factors such as sex and differing perceptions of ostracism when analyzing and addressing problem solving performance.

1. Introduction

An integral aspect of everyday life is the ability to efficiently generate plans which can be recalled with satisfactory accuracy. Possessing routinely optimal versus suboptimal planning abilities could mean the difference between reaping the most ideal outcomes from taking a prescribed medication consistently before bedtime or unnecessarily prolonging and worsening a medical condition. Similar to many other cognitive functions, this process can be hindered by external (e.g., environmental distractions) and internal interferences (e.g., mental state), which result in a delayed or unsuccessful execution of prior generated ideas. Ostracism's threat to self-esteem [1], aversion induction [2], and negative psychological effects [3] have been well-established in prior research. Despite its profound effects on an individual's overall mental health and its ingrained presence in the workplace [4], healthcare settings [5], and in education systems [6], ostracism's effects on various executive functions such as planning and recall is understudied. An understanding of the potential impact of unforeseen social exclusion on various aspects of executive control and daily functioning is vital to a

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broad spectrum of the population, from university students to individuals in healthcare professions.

1.1. Prospective memory (PM)

Prospective memory (PM) serves as a representation of the process through which an individual generates an intended action through the moment in time which they execute it [7,8]. In the example outlined above, successful PM would encompass a recognition of the need to do "something" before bedtime and remembering that the "something" is taking medication. While success of the intended action is not the primary focus of PM, an evaluation of specific factors which may impair various phases of PM may be transferable to analyzing its exact effects on cognitive performance and mental health [8]. An ongoing paradigm is outlined in the multiprocess framework, which distinguishes between strategic monitoring and spontaneous retrieval, two potential cognitive heuristics individuals utilize when exercising PM [9].

PM can be divided into three consecutive phases, each of which requires various executive processes: (1) planning (i.e., the formation of an intention); (2) recall (i.e., maintaining the intention); and (3) performance (i.e., combination of intention initiation and execution) [10–12]. In the planning phase, there is first a recognition of the need for specified actions to be executed at some point in the future. Planning could involve setting an alarm, writing down a post-it note, or setting a reminder on a cellular device. At recall, previously planned actions must be accurately remembered when the appropriate cue occurs (e.g., after work, at noon). Acknowledging that the alarm, post-it note, or cellular reminder signaled the need to take medication before bedtime would suggest successful recall. Efficacy of planning and recall is assessed at performance, and overall success can be analyzed via evaluation [10]. If the individual successfully takes their medication before bedtime, they would have achieved optimal performance. Should this ideal outcome occur more often when the individual sets an alarm versus writing down a post-it note, evaluation would entail the realization of this observation, and implementing the alarm system over the post-it note system for future scenarios to ensure a consistent medication schedule. The current study focused on the planning and recall phases, as these are the two phases critical to later manifested success or failure.

1.2. Planning

Planning, whether conscious or unconscious, is vital to the maintenance of control over an individual's daily life. Forming various subgoals to achieve both short-term (e.g., crafting a grocery list) and long-term goals (e.g., organization of a list of errands to blueprint the most effective way to get everything done) allow for the gradual formation of a bridge between an initial and final desired state [13,14]. Perhaps even more important is the ability to adjust initial plans quickly and accurately in the presence of unexpected detours to avoid potentially costly errors. Therefore, having a deeper understanding of the various genetic and environmental factors which influence an individual's planning ability is crucial to the optimization of a plethora of scenarios, from the everyday person's to-do list to a doctor's split-second decisions in an emergency room.

The frontal cortex has been linked to various behaviors surrounding the efficient and successful planning of current and remote goals. Since the mid 1800s, researchers have suspected a link between this area of the brain and planning skill from observations of patients with frontal lobe lesions [15]. This idea was later strengthened, when a loss in the ability to "coordinate the different elements of a complex activity" was observed in primates with large frontal lesions [16]. This became the primary inspiration for the development of the Tower of London (TOL) paradigm, which has since become repeatedly utilized as a measure of executive functions, specifically effective planning ability, in both neurotypical individuals and neuropsychological patients [17–20].

The TOL task presents as a specified configuration of three different colored balls placed on three pegs of varying heights (See Fig. 1). Participants are instructed to move the balls from an initial presented state to a goal state in as few moves as possible. As the

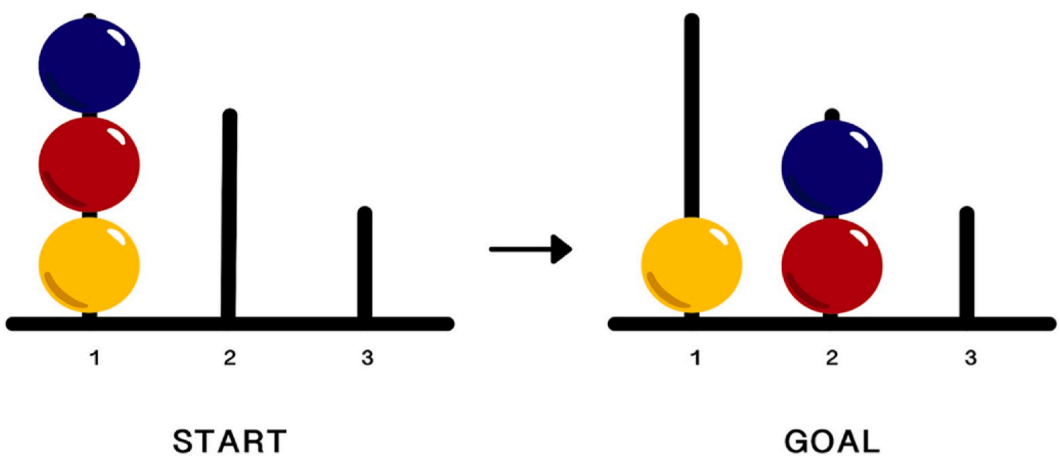

Fig. 1. Illustration of the Tower of London problem setup. Participants were shown an example of the TOL problem in the instruction page, and given a different TOL problem to plan to solve in the planning phase of the experiment.

optimal number of moves increases, the number of sub-goals also increases, hence the demand for planning skill also increases [17,18]. In addition, there is a higher probability that participants would have to mentally retrace any incorrect moves in order to get to the desired state. Certain path constraints were placed, such as (1) only one ball can be moved at a time; (2) if multiple balls are stacked on one another, only the top one can be moved; and (3) a maximum of three balls can be placed on the longest peg, two on the middle, and one on the shortest peg. As participants are asked to mentally plan their pathway before executing the moves, there is ideally an element of mental rehearsal [13].

1.2.1. Tower of London problem

Shallice [17,18] reported that patients with left anterior cortical pathology do poorly on TOL problems, exhibiting longer delays between moves as well as having a larger number of excessive moves compared to their neurotypical peers. Later, Owen et al. [21] assessed TOL performance in neurosurgical patients with either bilateral or unilateral frontal lobe excisions. These patients required more moves to complete the TOL problems and produced fewer optimal solutions after controlling for IQ (intelligence quotient) and age. Other studies have also shown that the ability to suppress unnecessary eye movements during antisaccade tasks is associated with better performance on the TOL problem, suggesting that inhibitory control (a function typically associated with the prefrontal cortex [22]) was a vital element of efficient planning performance [14].

1.3. Recall

No matter how efficient or flawless the planning, these mental preparations prove futile if not recalled at the appropriate point in time. In the planning phase of the TOL paradigm, individuals are indirectly practicing recall via remembering changes in configuration after each move [14]. When an error is made, previous configurations must also be accurately remembered in order for individuals to retrace their moves [13]. Throughout this mental planning, participants rely on their visuo-spatial working memory capacity to recall everchanging intermediate moves [23,24]. Performance in other problem-solving tasks which involved spatial working memory information processing is also significantly correlated with TOL task success [22].

Studies have shown that visuospatial memory, which allows individuals to accurately generate and maintain varying sequences of moves, is a critical predictor of TOL performance in neurotypical children. Furthermore, gaze behaviors provided insight that gaze biases towards task-relevant areas (i.e., the problem setup) and increases in gaze dispersion (i.e., gaze transition entropy) during ideal performance emulated cognitive demands as the TOL difficulty increased. Deficits in information extraction and poor maintenance of spatial information in visuospatial working memory were reflected in sub-optimal gaze behaviors, which tended to occur in the earlier stages of planning [14,25].

Recall was measured more explicitly in this study by directly asking participants to recall the moves they planned to solve the TOL problem at a later point in the experiment. The starting configuration was presented to serve as a cue. Scoring higher on this measure of recall could indicate either (1) optimal utilization of visuospatial working memory via recall of the final configuration and mentally resolving the TOL problem or (2) strong verbal memory via recalling each step previously taken during the planning phase.

While not examined in the current study, it is still important to acknowledge the role that performance plays on a holistically successful PM task. PM performance has been associated with proficient executive functioning across a wide spectrum of prospective paradigms. Furthermore, McFarland & Glisky [26] supported the role of the frontal lobe as a key facet in PM performance. As it is difficult to successfully perform PM tasks without successful recall, the current study underscores the need to examine the inception of PM (i.e., planning and recall), as these potentially predict later performance.

1.4. Factors hindering optimal prospective memory

Given the plethora of complexities surrounding the successful implementation of various phases of prospective memory, there are undoubtedly even more variables involved in its failure. Patients diagnosed with post-traumatic stress disorder (PTSD) have exhibited deteriorating PM performance [8]. A subset of younger children afflicted with prior AIDS-defining diagnosis and comorbid perinatal human immunodeficiency virus (PHIV) have exhibited PM impairment, which impacted necessary daily living skills such as the above-mentioned strict medication adherence [27]. Largely personal choices, such as drug use and abuse (i.e., Ecstasy), has been associated with more errors in both short- and long-term PM. Potential frontal lobe damage resulting from drug use and abuse could explain central executive deficiencies [28], as this area of the brain has been associated with successful planning ability [15,16].

While physical ailments which impact the brain's proper development has been extensively studied respective to their effects on PM, less concrete evidence has been published regarding environmental influences. Acute stress has been suggested to negatively impact time-based PM (e.g., a specific time serving as the PM cue) more than event-based PM (e.g., an occurrence serving as the PM cue), since the former requires more cognitive demand, consuming previously appropriated executive functioning capacity and working memory load [8]. However, studies have also shown that it had mixed impacts on the various phases within PM. In addition, despite its implications on poor health prognosis such as cardiovascular disease [29] and depression [30], little research has been done regarding the effects of ostracism on PM. Furthermore, a plethora of studies have underscored the need to acknowledge sex differences, as male participants and female participants vary in their response to emotions such as stress and ostracism, which can be traced back to neurobiological variations. The current study aimed to address the scarcity of research surrounding the effects of ostracism on PM, and investigated whether mixed results from previous studies could be attributed to sex differences.

1.5. Effects of social exclusion

The inherent need to belong, which is undoubtedly exacerbated by societal norms, is apparent in nearly all individuals, to the point where experiences of ostracism are recounted as not only unpleasant, but painful [31]. Williams proposed the Temporal Need Threat model [32] to account for a three stages progression of ostracism's negative effects: (1) reflexive (i.e., the immediate perceived threat of social danger), (2) reflective (i.e., the attempt to cope with the experienced social exclusion), and (3) resignation (i.e., a feeling of helplessness after coping mechanisms are depleted). The experiment reported in this article focused on the first stage of ostracism, namely the reflexive stage. We used the Cyberball simulation created by Williams et al. [33]. This manipulation has been repeatedly utilized as a means to simulate this experience via an online ball-tossing game. Participants believe they are playing with three other players and depending on the condition they are randomly assigned to, have an equal chance to receive the ball as any other player (i.e., inclusion condition) or only get the ball a few times in the beginning of the round (i.e., exclusion condition). In the latter scenario, participants were able to quickly detect that they were being excluded from the activity and feel a threat to their fundamental need for control and belonging. Ostracism has been repeatedly shown to decrease positive mood ratings, threaten self-esteem, and cause aversion and distress among other negative psychological effects [34–36]. Therefore, an understanding of how it affects various aspects of everyday activities is critical to optimization of quality of life.

Currently, there is limited understanding of the effects of social exclusion on planning abilities. Studies examining the effects of ostracism on frontal lobe activity and this region's correlation with formal executive functions have yielded unclear results [29,35]. De Wilde et al. [37] further suggested that positive social relational factors can promote working memory in children. Interestingly, a study of young adolescent girls has shown that there was no significant effect of ostracism on visuospatial working memory after controlling for age [38]. Therefore, the current study investigated whether certain sex effects may mediate the mixed results present in prior studies, which is described more in detail in the subsequent section. The current study aimed to analyze whether impacts of social exclusion on planning mirrored that of visuospatial working memory (i.e., as the TOL paradigm used to assess planning is one that requires visuospatial working memory), hypothesizing that social exclusion would not affect planning abilities.

Similar to planning, there is a lack of research surrounding the effects of ostracism on the recall phase in prospective memory. Rather, many studies utilizing the Cyberball simulation's ostracism effects as a social stressor [39] found that upon exposure to stress, a marked deficit in working memory processing was observed [40]. Furthermore, ostracism has been associated with negatively impacting certain verbal working memory processes (i.e., digit span sequencing) [35,38]. Varying effects of ostracism has also been associated with how individuals recall the social exclusion event. The preoccupation with the negative psychological landslide that comes with ostracism may be obstructing full working memory potential [34]. Therefore, the current study hypothesizes that recall would be negatively impacted by ostracism. However, as practically no studies have explicitly explored the impact ostracism had on the various phases of PM, or even PM in general, the current study primarily aims to address this gap in literature.

1.6. Sex differences

Multiple studies have demonstrated a significant sex difference in response to social exclusion, with female participants being more affected than their male participant counterparts [6,41]. The negative emotions elicited from social exclusion, along with a lack of sense of control, is more pronounced in female participants [42]. While male participants usually acknowledge agentic-type threats, female participants tend to have a stronger focus on communal-type threats [43]. Interestingly, when ostracized, female participants have a stronger tendency to form preventive exclusionary alliances despite being more aware of others' feelings [44]. Taken together, the current study aims to replicate prior findings of female participants being more affected by ostracism than their male participant counterparts, with a specific focus on two phases of prospective memory (i.e., planning and recall).

1.7. Hypotheses

The current study explores the role of sex on social exclusion respective to planning and recall in prospective memory. The current study had not been pre-registered, as the effects of induced social ostracism on prospective memory is largely understudied, and much of the groundwork that must be laid relies on the exploratory nature of this study. As no significant effect of visuospatial memory on planning has been previously determined, it is hypothesized that (1) ostracism would have no effect on planning ability, as the TOL paradigm is a problem which involves the efficient manipulation of objects from an initial to a goal position. Furthermore, prior studies utilizing Cyberball's ostracism manipulation as a social stressor have demonstrated that deficient working memory processing has been associated with the aforementioned measure. Therefore, the current study aims to establish a more concrete relation between ostracism and recall, hypothesizing that (2) recall performance would be negatively impacted by ostracism. To investigate whether prior studies of female participants being more affected by ostracism applied in these contexts, the third hypothesis examined whether (3) sex differences would impact the first two phases of PM along with social exclusion.

2. Materials and methods

2.1. Participants

Participants were 437 undergraduate students (178 female participants, 3 prefer not to disclose) enrolled in an elementary psychology course at Purdue University. To determine the number of participants needed in each condition, a power analysis was conducted using G*power 3.1.9.7 [45] for a 2-way between-subject ANOVA (main effects and interaction) to detect a medium effect size (f = 0.25) with α = 0.05 and β = 0.20. A medium effect size was selected because Cohen noted that a medium effect size would have real-world applicability [46]. Three-hundred twenty undergraduate students (121 female participants; 1 prefer not to disclose) were included in the final data analysis. Participant exclusion and grouping procedures are detailed in the Data Analysis subsection below. Upon agreeing to the consent form, participants were randomly assigned to a social inclusion or exclusion condition for the planning and recall phase of the Tower of London (TOL) problem: (1) Inclusion-Inclusion (II); (2) Inclusion-Exclusion (IE); Exclusion-Inclusion (EI); and Exclusion-Exclusion (EE). An overview of this study is illustrated below in Fig. 2. The study was approved by the Institutional Review Board (IRB) at Purdue University, Main Campus.

2.2. Materials

In the TOL problem [17], three pegs were presented, with their varying heights representative of the maximum number of balls allowed per peg. Three different colored balls were placed in an arbitrary Start position. The objective was to generate a plan to move the balls from the Start to the designated Goal position in the least number of moves possible. Participants were instructed to follow three rules: (1) only one ball may be moved at a time; (2) if multiple balls were stacked on one peg, only the top one could be moved; and (3) only three balls could be placed on Peg 1, two balls on Peg 2, and one ball on Peg 3, as indicated by Fig. 1. The actual problem participants were given to solve is illustrated in Fig. 3.

2.2.1. Cyberball game

The Cyberball simulation used the original version freely available at http://www.empirisoft.com/cyberball.aspx. In the Cyberball simulation [33], four cartoon characters (i.e., participant + three computer simulations) passed a ball among each other. Upon receiving the ball, the participant would click on one of the three virtual teammates to pass the ball to. Participants were told that the other players in the game were real players. In the inclusion condition, all characters received the ball a relatively equal number of times. In the exclusion condition, the participant received the ball only two times in the beginning. This was intended to induce feelings of ostracism [47,48]. The Cyberball simulation incorporated a total of sixty-five ball tosses.

2.2.2. Distractor task

Participants were asked to select “True” or “False” to a set of arithmetic equations (i.e. 5+2–1 = 6; T or F). There were also visual-spatial tasks intermixed, where two 3 x 3 blocks had certain squares filled in. Participants were asked if the two blocks added up to a final 3 x 3 block when they were superimposed (See Fig. 4). Visuospatial filler tasks were chosen since both the TOL and Cyberball game were visuospatial tasks. This was to maximize potential interference. Furthermore, arithmetic filler tasks were also intermingled as to include participants who may recall information better numerically (i.e., reciting the list of the steps) rather than visuospatially (i.e., reciting how the balls looked as they were moved among the pegs). The filler tasks aimed to introduce adequate time between the

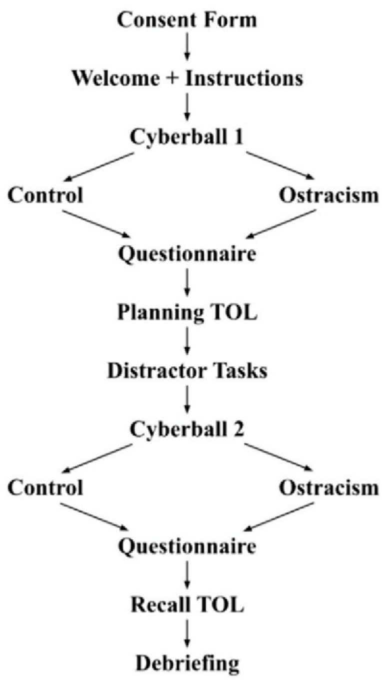

Fig. 2. Overview of Study. Cyberball 1 denotes the initiation of the planning phase while Cyberball 2 marks the beginning of the recall phase.

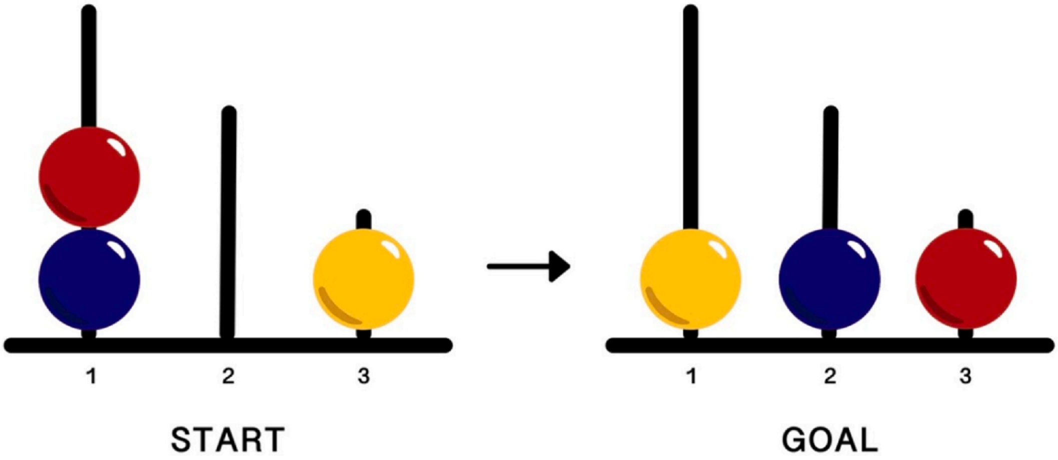

Fig. 3. Illustration of the Tower of London problem presented to participants. The minimum number of moves to solve this problem is: (1) Move the red ball to peg 2; (2) Move the blue ball to peg 2; (3) Move the yellow ball to peg 1; (4) Move the blue ball to peg 1; (5) Move the red ball to peg 3; (6) Move the blue ball to peg 2.

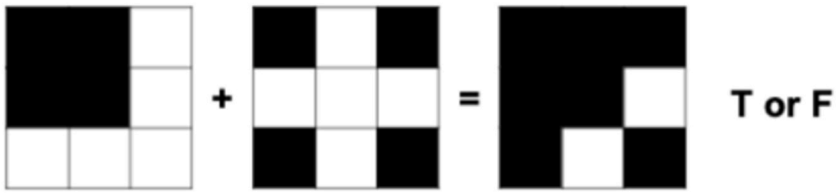

Fig. 4. Example of visual-spatial problem in the distractor task. Participants should select "True" for this specific problem.

planning and recall phases so that the second Cyberball influence was not influenced by residual effects from the first Cyberball task.

2.2.3. *Self-reported questionnaire*

All participants were presented with a seven-item questionnaire which was assessed on a six-point scale (1 = Strongly Disagree, 6 = Strongly Agree), with two items being reverse scored (1 = Strongly Agree, 6 = Strongly Disagree) (See Appendix). While primarily serving as a filler, the questionnaire served as a proxy to promote participants to reflect upon their emotions, and hopefully further solidify feelings of social inclusion or exclusion. All responses were recorded, and a response is required for each question before proceeding to the next page.

2.3. *Procedure*

Data collection took place online at the time and place of the participants' choosing to minimize additional stress of time constraints or experimenter effects. After electronically signing the consent form, participants completed a one question questionnaire regarding their Sex to collect demographic information for subsequent analyses. All participants then proceeded to the next page after completing the questionnaire, where they were presented with a welcome message along with instructions and rules regarding how to solve the TOL problem.

2.3.1. *Planning phase*

Participants were asked to engage with the first Cyberball game simulation, the condition (exclusion vs. inclusion) of which depended on the first half of condition (II, IE = inclusion; EI, EE = exclusion) participants were randomly assigned to at the beginning of the experiment. After completing the simulation, participants were prompted to complete a seven-item self-report questionnaire.

In the planning phase, participants were then shown the TOL problem they would plan to solve. Each participant was asked to indicate the least number of moves they believe would solve the problem. On the following page, the participant was asked to list all the moves necessary to solve the problem. Participants were given 3 min to complete both these tasks.

2.3.2. *Distractor task*

Next, a distractor task was presented. Participants solved as many problems as they could until 5 min was up, at which time they were auto-advanced to the next section of the study.

2.3.3. Recall phase

All participants then moved on to the second Cyberball manipulation, where they were randomly assigned to either the exclusion or inclusion version depending on their randomly assigned condition (II, EI = inclusion; IE, EE = exclusion).

After the Cyberball game, participants were prompted to complete a questionnaire. This questionnaire asked the same questions as the first, with two different items reverse scored to serve as attention checks. All participants were then given 3 min to recall their moves to solve the TOL problem from the beginning of the experiment while only being presented with an image of the Start configuration.

2.3.4. Check

Next, participants answered a two-item questionnaire regarding whether they have seen or encountered the Tower of London problem or the Cyberball game.

Each session lasted approximately 30 min, and participants received credit for their elementary psychology course. The experimenter did not play an active role in this experiment, as everything was conducted virtually over Qualtrics. An electronic debriefing form was included at the end of the experiment along with the researchers' names and emails in case they wish to contact them.

2.4. Data analysis

Bayesian statistics were analyzed using Package BayesFactor [49] in R Project. We report BF_{10} (evidence in favor of an effect) in cases where the frequentist analysis showed a statistically significant difference ($p < 0.05$) and BF_{01} (evidence in favor of a null effect) when the frequentist analysis did not show a statistically significant difference. As a result, all reported Bayes factor are larger than one and interpreted using Kass & Raftery's [50] K table (available at https://en.wikipedia.org/wiki/Bayes_factor). Frequentist statistics were computed with IBM SPSS Statistics Data Editor Version 28.0.0.0.

2.4.1. Initial participant exclusion procedure

Of the 437 participants, those under the age of 18 (n = 4) and those who did not complete the entire study (n = 46) (i.e., exited the Qualtrics survey prior to the debriefing page) were removed. When coding participants' list of moves in the planning phase, all participants who misinterpreted the questions (e.g., indicated a number rather than listing out moves, did not attempt the problem) were excluded (n = 14). In addition, participants who indicated an exorbitant number of moves to solve the TOL (e.g., $x > 50$), or those who did not list at least one valid move in the planning phase were also removed (n = 8).

2.4.2. Attention check – final participant exclusion procedure

Participants were excluded on the basis of spending too much or too little time on the self-report questionnaires. Spending too little time would imply that the participant did not take the time to thoroughly read each question, and that their response may not be indicative of their true mental state. Spending too much time could lead to the Cyberball simulation's intended ostracism effects being worn off. Using the whole data set from the 365 participants remaining after the initial participant exclusion procedure, an outlier calculation was performed ((Q3 + 1.5 (Q3 – Q1) and Q1 - 1.5 (Q3 – Q1)). Nineteen participants were removed using this method on the first questionnaire, followed by the removal of 26 participants in the second questionnaire. With a final sample size of 320 participants (121 female participants; 1 prefer not to disclose), a power of 0.994 to detect the expected effects was achieved. While a potential issue may be that the thresholds for spending too little or too much time is based on the times of other participants, these boundaries can also be validated from a more objective view. Even accounting for transitional (i.e., scrolling or clicking) and average reading time, as outlined in the study by Trauzettel-Klonsinski et al. [51], the boundaries initially set by the outlier calculations adequately encompasses the amount of time that should have been spent on each section to test social ostracism induction effect.

3. Results

3.1. Planning phase

To analyze planning data, participants were grouped based on their planning cyberball condition. Two groups were formed: planning inclusion [PI = II (n = 77; 33 female participants, 1 prefer not to disclose) and IE (n = 80; 26 female participants)] and planning exclusion [PE = EI (n = 82; 32 female participants) and EE (n = 81; 30 female participants)]. Performance in planning was assessed using two measures: (1) proportion of participants who listed the correct moves to solve the TOL problem and (2) participants' deviation from optimal (DFO) scores.

3.1.1. Proportion solved

To determine whether there was a difference in the proportion of participants who successfully planned how to solve the TOL in each of the two conditions, a one-way ANOVA was conducted. Any series of moves that led to the final configuration, regardless of whether it was the optimal strategy, was considered successful. There was substantial evidence [$F(1, 315) = 0.076$, $p = 0.783$] ($BF_{01} = 7.84$) suggesting that participants in the exclusion planning conditions did not have a different proportion of participants who successfully planned how to solve the TOL problem in comparison to participants from the inclusion planning conditions.

3.1.2. Deviation from optimal scores

The DFO measure was calculated to determine how close the participants were to the ideal number of planning moves (i.e., 6). There was substantial evidence [F (1, 315) = 2.567, p = 0.110] (BF_{01} = 3.38) suggesting that participants in the exclusion planning condition did not have a different deviation from optimal scores in comparison to participants from the inclusion planning condition. These results suggest that exclusion did not impact participants' ability to accurately list moves to solve the TOL problem or their determination of the ideal number of moves to solve the TOL.

3.1.3. Sex effects

To investigate whether sex or an interaction between sex and condition had an impact on planning performance, two-way ANOVAs were conducted for both measures of planning. As sex differences respective to female participants versus male participants were being examined, any participant who did not indicate one of the two sexes was removed from subsequent analyses (n = 1). Corroborating the results above, no differences were observed between inclusion and exclusion conditions for proportion of participants who successfully solved the TOL problem [F (1, 315) = 0.076, p = 0.783] (BF_{01} = 7.40, substantial evidence) or their DFO scores [F (1, 315) = 2.567, p = 0.110] (BF_{01} = 2.18, not worth more than a bare mention).

Respective to the first measure of planning performance, significant differences were observed between male participants and female participants [F (1, 315) = 5.724, p = 0.017] (BF_{10} = 1.88, not worth more than a bare mention). There were a higher proportion of male participants (x_M = 0.444, SD = 0.498) who solved the TOL problem than female participants (x_F = 0.314, SD = 0.466). An interaction between sex and condition was also observed [F (1, 315) = 5.806, p = 0.017] (BF_{10} = 2.53, not worth more than a bare mention). In the planning inclusion condition, male participants outperformed female participants in listing the moves necessary to solve the TOL problem [t (154) = 3.407, p < 0.001] (BF_{10} = 32.27, strong evidence). However, no significant difference was observed between female participant and male participant's planning performance when excluded [t (161) = −0.012, p = 0.990] (BF_{01} = 5.75, substantial evidence), suggesting that exclusion may exert an equalizing role between the two sexes (See Fig. 5). Overall, the Bayesian analysis suggests that while the statistically significant main effect of sex and the statistically significant interaction between the factors provide only weak evidence of an effect, the decomposition of the interaction provides strong evidence of a male participant advantage in the inclusion condition and substantial evidence for the absence of a sex difference in the exclusion condition.

A further analysis was conducted to examine the deviation of planned number of moves from the ideal number which would yield the requested formation in the TOL in the fewest moves possible. Significant differences were present between male participants and female participants [F (1, 315) = 6.316, p = 0.012] (BF_{10} = 2.87, not worth more than a bare mention); however, there was no interaction between sex and condition [F (1, 315) = 1.366, p = 0.243] (BF_{01} = 2.83, not worth more than a bare mention). Male participants (x_M = 0.228, SD = 0.220) had lower DFO scores than their female participant counterparts (x_F = 0.329, SD = 0.501) [t (317) = −2.479, p = 0.007] (BF_{10} = 2.87, not worth more than a bare mention), suggesting better performance on this measure of planning. Male participants' better performance on both measures of planning (See Fig. 6) could be due to their higher visuospatial problem-solving abilities.

3.2. Recall phase

Recall performance was assessed using two measures: (1) recall percentage and (2) total number of moves recalled. Due to the fact that participants were randomly assigned to inclusion or exclusion at both planning and recall, participants were regrouped into a recall inclusion [RI = II (n = 77; 33 female participants, 1 prefer not to disclose) and EI (n = 82; 32 female participants)] or recall exclusion [RE = IE (n = 80; 26 female participants) and EE (n = 81; 30 female participants)] for the analyses below.

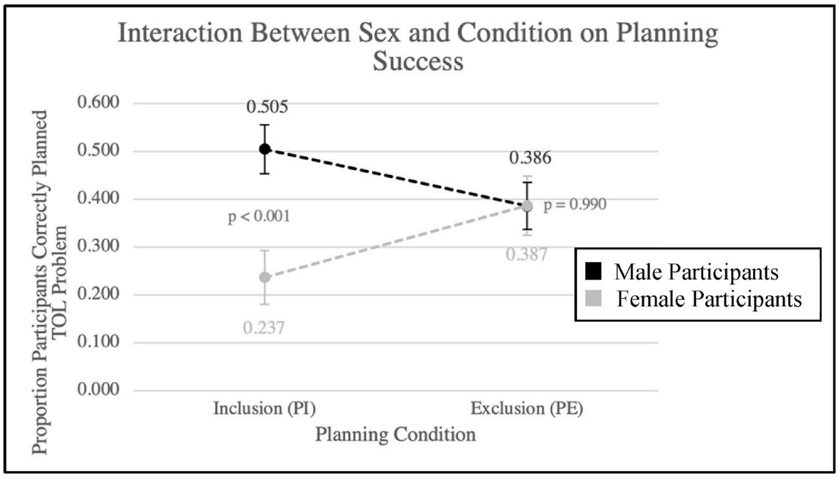

Fig. 5. Differences between male participants and female participants and the interaction between sex and condition on proportion of participants who correctly solved TOL problem.

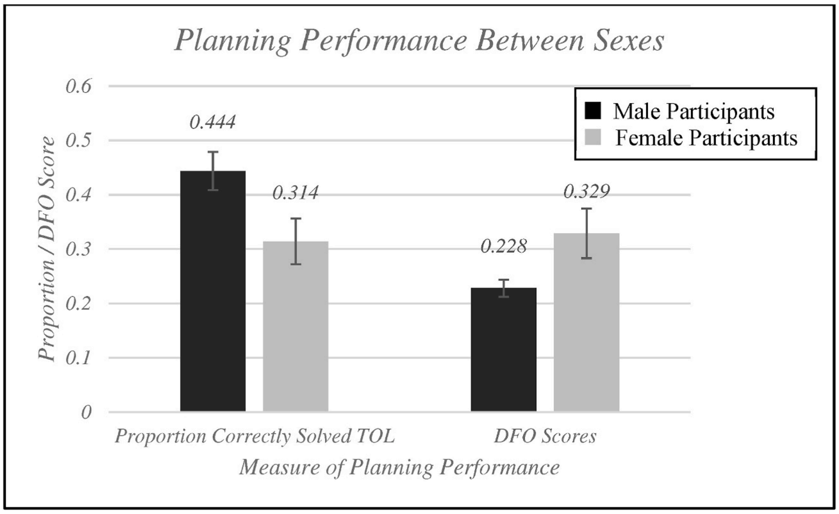

Fig. 6. Planning performance (proportion participants who could solve TOL; DFO scores) between male participants and female participants.

3.2.1. Testing potential carryover effects

To ensure that effects of exclusion are not carried over from Cyberball at planning, the two measures of recall were first compared between same conditions at recall (II vs. EI and IE vs. EE). No significant differences were observed between the two recall inclusion conditions ($x_{II} = 0.503$, SD = 0.447; $_{EI} = 0.575$, SD = 0.454) or the two recall exclusion conditions ($x_{IE} = 0.599$, SD = 0.443; $x_{EE} = 0.540$, SD = 0.458) respective to recall percentage [$t\ (156)_I = -1.003$, $p = 0.318$ ($BF_{01} = 3.67$, substantial evidence); $t\ (159)_E = 0.835$, $p = 0.405$ ($BF_{01} = 4.26$, substantial evidence)].

Likewise, there were no significant differences between the two recall inclusion conditions ($x_{II} = 2.675$, SD = 2.577; $x_{EI} = 3.037$, SD = 2.622) or the two recall exclusion conditions ($x_{IE} = 3.413$, SD = 2.722; $x_{EE} = 2.790$, SD = 2.611) in regard to number of moves correctly recalled [$t\ (157)_I = -0.875$, $p = 0.383$ ($BF_{01} = 4.28$, substantial evidence); $t\ (159)_E = 1.481$, $p = 0.141$ ($BF_{01} = 2.14$, not worth more than a bare mention)]. Therefore, it was safe to regroup the four conditions into the two recall conditions as expressed above.

3.2.2. Recall percentage

Recall percentage was measured by the ratio of the number of moves correctly chronologically recalled by the number of moves listed at planning, regardless of whether these moves solved the problem (or not). To analyze whether recall percentage was affected by exclusion, a two-way ANOVA (Sex x Condition) was conducted. Contrary to the second hypothesis, there were no significant differences between the exclusion and inclusion conditions [$F\ (1, 315) = 0.094$, $p = 0.760$] ($BF_{01} = 7.61$, substantial evidence) respective to recall percentage, nor was an interaction present [$F\ (1, 315) = 0.759$, $p = 0.384$] ($BF_{01} = 4.21$, substantial evidence). Furthermore, sex effects were not present for recall percentage [$F\ (1, 315) = 0.461$, $p = 0.498$] ($BF_{01} = 6.51$, substantial evidence).

3.2.3. Number of moves correctly recalled

Total number of moves recalled was measured by the number of moves participants accurately recalled chronologically from their generated list at planning, regardless of whether these moves solved the problem (or not). To test whether exclusion impacted the

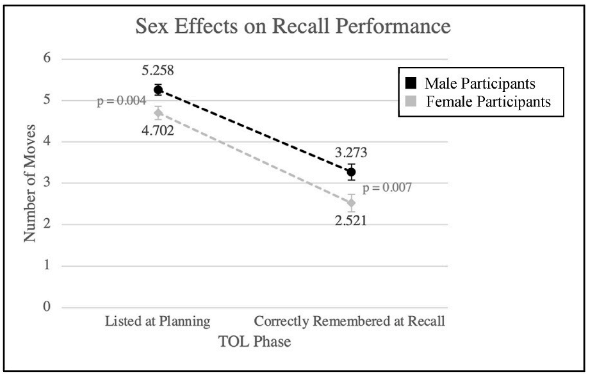

Fig. 7. Difference in number of moves planned and recalled for TOL problem for each sex.

number of moves participants could recall in each condition, a two-way ANOVA (Sex x Condition) was conducted. Similar to the first measure of recall performance, participants' condition did not affect the number of moves accurately recalled [$F (1, 315) = 0.166$, $p = 0.684$] ($BF_{01} = 7.61$, substantial evidence), nor was there an interaction [$F (1, 315) = 0.568$, $p = 0.452$] ($BF_{01} = 4.47$, substantial evidence). However, a significant sex effect was observed [$F (1, 315) = 6.040$, $p = 0.015$] ($BF_{10} = 2.19$, not worth more than a bare mention), which will be explored below.

3.2.4. Sex effects

The main effect of Sex in the two-way ANOVA showed that male participants ($x_M = 3.273$, $SD = 2.803$) significantly outperformed female participants ($x_F = 2.521$, $SD = 2.281$) in total number of moves recalled. An exploratory analysis revealed that male participants ($x_M = 5.258$, $SD = 1.788$) also listed significantly more moves at planning than female participants ($x_F = 4.702$, $SD = 1.754$) [$t (317) = 2.710$, $p = 0.004$] ($BF_{10} = 4.12$, substantial evidence), suggesting that male participants both listed more moves at planning and accurately remembered more moves at recall (See Fig. 7), which explains why there was no difference in recall percentage between the two sexes.

4. Discussion

The current study - for the first time - aimed to address gaps in literature regarding the effects of ostracism on the first two phases of PM while also examining the role of sex. Consistent with the first hypothesis, no effects were observed between ostracism and either measure of planning performance: (1) proportion of participants who solved the TOL problem; (2) DFO scores. Conversely, recall performance [i.e., (1) recall percentage; (2) total number of moves correctly recalled] was also not affected by ostracism, which was inconsistent with the second hypothesis. Upon further examination of data respective to the first two phases of PM, the third hypothesis was supported - sex differences played a significant role in the lack of effects between social inclusion and exclusion conditions.

4.1. Effects of exclusion on prospective memory phases

No significant difference was observed between inclusion and exclusion conditions for planning performance, respective to either proportion of participants who solved the TOL problem or DFO scores, supporting the first hypothesis. As the TOL paradigm is predominately a visuospatial task, these results added to prior studies which concluded that visuospatial working memory was not affected by ostracism [38,52]. Similarly, exclusion did not seem to affect recall performance in regard to recall percentage or number of moves recalled. This contradicts the second hypothesis, as exclusion was thought to negatively affect recall performance. Without examining potential latent and confounding variables, this would suggest that being socially excluded did not predict individuals' ability to remember moves involved in solving a problem. Sex differences, which are examined below, appear to give a deeper insight into the null effects of ostracism on planning, and the contradictory data present at recall.

4.2. Effects of exclusion on sex in planning

Variations in neural responses between male participants and female participants regarding planning have been shown in previous studies. This suggests the existence of specified sex-dependent processing and recruitment, which may translate to varying strategies between the two sexes [53]. In the inclusion condition, male participants consistently outperformed female participants on either measure of planning. There were a higher proportion of male participants who solved the TOL problem, and male participants had lower DFO scores, indicating that they were closer to listing the optimal number of moves to solve the TOL problem. Due to the fact that the TOL problem was a visuospatial problem, male participants' better performance in general could be attributed to their relatively higher visuospatial problem-solving abilities [54]. If the task were switched to a verbal fluency task, perhaps female participants would have outperformed on either measure of planning [24,55,56]; however, this conjecture should be addressed in future research.

Previous research has shown that social exclusion led to threats to perceived self-control [57,58]. Magnetoencephalography (MEG) results suggested that social exclusion interferes with attention, which led to a negative impact on self-control [59]. When excluded, the difference in proportion of individuals who solved the TOL problem was negated. This could be due to the cognitive depletion theory, in which a certain proportion of cognitive resources which would have been set apart for attention was instead allocated to self-regulation of social exclusion. Male participants' higher performance between the two sexes in the inclusion condition may have been negatively impacted due to a trade-off between planning performance and self-regulation resources in the exclusion condition [60]. A similar trend was not present in female participants, which may be explained by Gottfredon and Hirschi (1990, p. 149) [61], who suggested that female participants have higher levels of self-control than their male participant counterparts. A plethora of other studies have also backed this finding [62–64]. The results suggest that the negative impact on self-control that ostracism had on male participants may not have been as prominent, or perhaps even negligible, in the case of female participants. While female participants are more affected by ostracism [6], their higher self-control may negate the need to consume extra cognitive resources on regulating social exclusion. This could explain why their planning abilities were not affected.

4.3. Effects of exclusion on sex in recall

Overall, male participants listed more moves at planning and correctly remembered more moves at recall compared to their female participant counterparts. However, there were no observable differences in recall percentage between the two sexes. Prior studies have shown that longer movement execution initiation times could be attributed to differences in cognitive processing between male participants and female participants [65,66]. Male participants' shorter execution initiation time (i.e., attempting the problem, regardless of accuracy, sooner) may have allowed them to list more moves at planning, regardless of accuracy, therefore giving them a larger verbal bank from which to extract moves at recall. With male participants listing more moves initially at planning, even if both sexes were to recall each move perfectly, male participants would seemingly have better recall than their female participant counterparts when in reality, they had more to work with.

Male participants correctly remembering more moves at recall appears to contradict prior research, which points to female participants having higher episodic and cued verbal memory [55]. However, female participants' initial lower planning success may have limited their potential episodic memory advantages at the recall phase.

4.4. Limitations

First and foremost, we acknowledge that this study was a first of its kind and exploratory in nature. It should thus be replicated – both online and in a lab setting. The current study was conducted online via Qualtrics, allowing participants to do the experiment wherever and whenever they wished. This introduced a multitude of confounding variables (e.g., writing TOL moves on paper, distractors in the environment), which could have impacted planning and recall performance. One important limitation introduced by allowing participants to do the experiment anytime is that some participants may not have believed that they were playing cyberball with other human players. Zadro et al. [67] found significant negative effects of ostracism induction even when participants were led to believe they were playing with the computer rather than real-life online players. As a result, we believe that the effect of ostracism was likely still being experienced by participants. Nevertheless, future studies should endeavor to replicate this experiment in a more controlled environment.

Furthermore, a time limit was placed on planning and recall measures to ensure that the Cyberball's manipulation did not wear off, and that participants had less time to potentially search for any answers. However, this could have posed an innate disadvantage to female participants, who had been shown to have slower execution initiation times compared to their male participant counterparts [65,66]. Given enough time, perhaps female participants could have listed more moves at planning, had higher TOL solve rates, and correctly remembered more moves at recall. These speculations should be examined in future studies.

4.5. Summary and conclusion

In conclusion, ostracism induced via Cyberball did not impact planning or recall phases within prospective memory. Male participants' higher performance during planning in the control condition could be a manifestation of their greater visuospatial problem-solving abilities. No sex difference was observed in the exclusion condition during planning. Social exclusion presents threats to perceived self-control, which takes up cognitive load originally allocated for executive controls such as attention, which optimize planning performance. Advantages that male participants had were potentially negated via this cognitive depletion theory. At recall, there was no difference between sexes respective to recall percentage; however, male participants listed more moves at planning and remembered more moves at recall than female participants. Acknowledging the role which sex differences play in executive functions within PM such as planning and recall underscores the importance of inclusivity in all situations, from primary schooling to the workforce. Addressing concerns surrounding ostracism would not only maximize a firm's overall performance – it could also increase worker satisfaction via optimization of mental health, which could significantly reduce the risk for potentially debilitating health implications which surround neglected mental wellbeing.

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Additional information

This study was reviewed and approved by Purdue University Human Research Protection Program System, with the approval number: IRB-2022-206. All participants/patients (or their proxies/legal guardians) provided informed consent for the publication of their anonymised case details and images.

Data availability statement

The experiment material and data is available in the OSF public repository: https://osf.io/7sf35/?view_only=99ede4feccf6487b9ab89642b0cd6797.

CRediT authorship contribution statement

Stella Yao: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Sébastien Hélie:** Writing – review & editing, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Self-Report Stress Questionnaire.
Please rate the extent to which the following statements are applicable to you currently:
I feel stressed.
Please rate the extent to which the following statements are applicable to you currently:

I feel like I am under pressure.

*Please rate the extent to which the following statements are applicable to you currently:

I feel anxious.

**Please rate the extent to which the following statements are applicable to you currently:

I feel frustrated.

Please rate the extent to which the following statements are applicable to you currently:

I feel that I do well in problem solving.

**Please rate the extent to which the following statements are applicable to you currently:

I feel confident.

*Please rate the extent to which the following statements are applicable to you currently:
I feel included in group activities.

Note. * = reverse-scored in the first questionnaire; ** = reverse-scored in the second quest

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