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Gender differences in visuospatial planning: an eye movements study.

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Title: GENDER DIFFERENCES IN VISUO-SPATIAL PLANNING: AN EYE MOVEMENTS STUDY

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Abstract: Gender studies report a male advantage in several visuospatial abilities. Only few studies however, have evaluated differences in visuospatial planning behavior with regard to gender. This study was aimed at exploring whether gender may affect the choice of cognitive strategies in a visuospatial planning task and, if oculomotor measures could assist in disentangling the cognitive processes involved. A computerized task based on the Travelling Salesperson Problem paradigm, the Maps Test, was used to investigate these issues. Participants were required to optimize time and space of a path travelling among a set of subgoals in a spatially constrained environment. Behavioural results suggest that there are no gender differences in the initial visual processing of the stimuli, but rather during the execution of the plan, with males showing a shorter execution time and a higher path length optimization than females. Males often showed changes of heuristics during the execution while females seemed to prefer a constant strategy. Moreover, a better performance in behavioral and oculomotor measures seemed to suggest that males are more able than females in either the optimization of spatial features or the realization of the planned scheme. Despite inconclusive findings, the results support previous research and provide insight into the level of cognitive processing involved in navigation and planning tasks, with regard to the influence of gender.

Introduction

Literature on spatial cognition often reports gender differences [1, 2]. Males typically perform better in tasks involving mental rotation, three-dimensional figures, spatial orientation and maze navigation [3, 4], whereas females are better at episodic memory tasks such as object location [5]. Many factors have been proposed for the gender differences found in visuospatial processing including behavioural, neuroanatomical substrates, hormonal and environmental [2, 6–9]. Despite these reasons, cognitive processes sensitive to gender are restricted mainly to visuospatial or linguistic features [10].

One aspect of gender differences not yet investigated in detail concerns visuospatial planning. Planning is a fundamental cognitive function frequently employed in common daily activities such as preparing meals, housekeeping, managing financial matters and so on. It requires the cooperation between several cognitive processes including strategy formation, coordination of mental functions, recognition of goal attainment and storage of representations. These guide movement from the “initial state” to the “end state” of a desired goal. When circumstances demand an immediate solution, pressure and speed can be associated with this and can be overcome with rational planning, in which spatial orientation and optimisation strategies are essential for obtaining the best solution. Many studies [11] have shown that flexible coordination between mean-ends analysis and cognitive abilities can favour the emergence of an "opportunistic behavioural" approach, referred to as an "accuracy–effort trade-off" [12] between competing decision-making strategies.

Planning seems to be based on the principle of "cognitive saving", inducing people to employ simple schemes to minimize the cognitive resources required to achieve the result. According to this principle, several studies [11, 13, 14] have shown that human planning is based on cognitive heuristics. These are defined as behavioural schemas that can approximate the correct solution, thereby requiring less cognitive resources than a complete algorithmic process. Planning behaviour, by means of heuristics, generates a strategy, which is a determined series of actions that guides the subject through realisation to the solution of the problem [15]. The application of a heuristic is not intended to be an exclusively automatic process; rather people evaluate the efficiency of an action by comparing the actual and future states of being, as performed by a feed forward process [16]. Visuospatial planning tasks represent a subset of planning problems, in which the items to be organised are described by visuospatial properties such as position, whereas other characteristics (nature, attractiveness, information) are irrelevant to the task. Examples of planning tasks in which the visuospatial component is secondary (or not required at all) for accomplishing the task are meal preparation [17], the towers of Hanoi and London (in which items must be shifted to pass from an initial state to a goal state) [18] and puzzles such as the missionaries and cannibals puzzle [19]. An example of visuospatial planning exists in maze-like tasks, in which people have to organise a path through a series of locations. This is heavily determined by the spatial relationships between the targets.

Previous studies on maze navigation have reported contradictory data on the type of navigation strategy employed by females and males. For example, Saucier and colleagues reported that females rely predominantly on landmark cues, whereas males use both geometric and landmark cues [20]. Lawton and Kallai [21] later found that females show a greater tendency to use landmarks and relative directions, whereas males use more cardinal directions and distances, a pattern that has been replicated cross-culturally. Recently, Mueller and colleagues suggested that women employ a strategy based on memory, whereas males use spatial relationships [22]. Besides these few studies, little attention has been paid to identifying how performance and strategy might be qualitatively different between males and females.

Gender differences in the optimisation and selection of spatial strategies lead to different behavioural performances. The problem lies in finding a suitable task that allows for these processes to be measured. One potential solution might be to evaluate the involvement of visuospatial planning abilities in a simulated environment using the Maps test, which is thought to represent an abstract version of an everyday task. The computerised Maps test [23], which represents an open version of the travelling salesperson problem (TSP) [24], has been used to assess visuospatial planning. Participants are required to minimize the total travel time and distance among a number of locations [25, 26]. The TSP has been considered a reliable tool for investigating planning behaviour because it requires subjects to spontaneously generate a strategy, optimising the order of locations with the aim of extracting a satisfactory path in a modelling space without any spatial constraints [27]. In turn, the Maps task requires a considerable and strong relationship between central and peripheral processes, promoting a fundamental interaction of perceptual, representational and executive components in the achievement of the final goal [28]. These properties allow both genders to adopt, spontaneously (but differently), several cognitive heuristics to optimise the path length. From previous data obtained by visuospatial TSP-based tasks, such as the Maps test and the City Map test [29–31], behavioural data indicated the presence of three distinct spatially-based heuristics generating solving strategies and showed that subjects often change heuristics when executing the plan [29]. The Maps paradigm has also been applied to explore differences between genders. Bisiacchi and colleagues [32], for example, considered only the execution time and pure length of the trajectories, finding that both males and females achieved all sub-goals using a limited number of moves, with males faster in programming and executing the task.

Other tests attempting to investigate planning processes are the Multiple Errands [33, 34] and Virtual Errands tests [35]. In these, participants are faced with a list of tasks to be accomplished in a local shopping centre. The task consists of finding an efficient route by considering both spatial and timing constraints. Although these tests examined the impairment of single mechanisms of planning, they were not used to investigate gender differences within the executive functioning context. Our intention was to reduce the gap between gender studies and visuospatial planning analysis by increasing knowledge and improving understanding in both fields of study. Moreover, the investigation of oculomotor variables during the “plan execution” process can provide insight into gender differences in the area of planning behaviour. Eye tracking, for example, allows the investigation of different visual scanning paths when males and females attend to a task by computing vertical and horizontal movements during saccades or during the evaluation of a region of interest within a fixation. It is well known that eye movement behaviour changes according to the level of mental activity in which an individual is engaged [36]. Moreover, eye movements are related to the amount of actively processed material and represent a physiological index of cognitive resource, memory and task demand [37, 38]. A recent study by Mueller and colleagues [22] attempted to specify the visual correlates underlying gender differences in spatial navigation using eye tracking methodology. These researchers examined eye movements and physiological correlates of memory to compare visual scanning of spatial orientation using a virtual analogue of the Morris Water Maze task. Although the behavioural data replicated previous findings of an improved spatial performance for males, they also found that males consistently explored more space earlier than females. These findings were also supported by the fact that for females a significant positive correlation emerged between pupil diameter (indicative of higher working memory load) and performance efficiency despite the longer fixation durations associated with poorer performance in both genders. Combining the Maps Test with an eye movement tracking device while measuring the mental workload required by males and females and disentangling the cognitive strategies used in the accomplishment of the task could contribute to the literature.

This study aimed to explore: (1) the level of cognitive processing at which gender differences in visuospatial navigation occur; (2) whether eye movements add further insight into the explanation of gender differences; and (3) whether gender differences influence the choice of cognitive strategies and the employment of "opportunistic behaviour". The data collected will help describe planning process characteristics for genders, thereby increasing knowledge about the way males and females deal with 2D maps.

Methods

Performance times, qualitative measure of strategies and eye movement behaviour (namely fixation number (NFix) and the fixation ratio (FR)) were used to investigate both behavioural and oculomotor variables. On the basis of Hayes-Roth and Hayes-Roth heterarchical architecture [11], it is reasonable to expect that both genders employ an “opportunistic planning behaviour”, in which they modify their ongoing plans with online adjustments. According to previous research, people produce incomplete plans at the beginning of a route and continuously make decisions along the trajectory of task execution. In turn, with time and length constraints, gender differences in visuospatial planning might be associated with using different cognitive strategies during the task. Moreover, men enjoy a partial advantage over women in performance execution and optimisation ability when priority is given to the length path despite similar preplanning times. This been widely found in literature, but the reasons behind this result are still a matter of debate. The analysis of eye movements can provide significant information on the visual exploration of an environment represented from a survey point of view. If males exhibit an advantage in behavioural performance and strategy selection, they are also expected to produce less eye movements than females. This result implies that males need less information to produce a representation/elaboration of the scene, which also explains why males produce lower execution times than females.

Participants

Thirty subjects (15 males, mean age = 24.40, SD = 3.34), students from the University of Padua, participated in the experiment in return for course credits. Participants were found to be strongly right-handed according to the Edinburgh Handedness Inventory [39]. All had normal or corrected to normal vision with no history of neurological or psychiatric disease. Because of errors in eye movement data collection, three subjects were excluded from analysis, thereby obtaining an overall sample of 27 participants (13 males, mean age = 24.18, SD = 2.89). Informed consent was obtained from all participants. The experiment was approved by the ethics committee of the Department of General Psychology of the University of Padua.

Apparatus

The Maps test

------------------------ Place Figure 1 around here -------------------------------

Each trial of the Maps task presented a fictitious map of a number of buildings blocks set out on a grid of seven vertical and five horizontal roads (see Figure 1). The Maps test was composed of 30 visuospatial problem-solving tasks; each of these situations was composed of seven sub-goals (green-coloured circles placed at different intersections between the roads) plus the final goal. Moreover, a blue square at the top left-hand corner indicated the starting point and a red square at the bottom right-hand corner represented the final goal. Starting at the top-left corner, subjects were asked to move the silhouette (by pressing the arrow keys) to pass over each sub-goal to reach the final goal located at the bottom-right corner. Subjects were instructed to find the shortest route in the shortest time. A blue line showed the step made at every movement of the silhouette, resulting in a feedback of the followed trajectory.

A reaction time task was administered as an additional task of the Maps test to calculate the planning index (PI; see further details on behavioural testing section). A sequence of 25 stimuli measured the individual ability in the pressing of the four possible arrow keys (4-choice RT). A sound with a duration of 150 ms and frequency of 432 Hz was followed by a pre-stimulus consisting of a human silhouette that appeared in the middle of the screen within an interval between 200 and 1000 ms. A green circle would then appear in one of four positions (up, down, left or right), displaced five ocular degrees with respect to the silhouette. Subjects had to press the arrow key as fast as possible to move the silhouette to get to the circle.

Eye movement tracking

Eye position and movements were measured in real time using an infrared video-based system (Viewpoint™ Eye Tracker, Arrington Research, Inc).

Gaze position was determined by analysing eye position (collected at a sampling frequency of 30 Hz). The system recorded horizontal (*x*) and vertical (*y*) pupil positions with a monocular eye tracker camera. Calibration and drift correction of the position signal were defined before starting the experimental session and repeated during the experiment as necessary.

Procedure

The study was performed in a quiet and windowless room with the lights off during behavioural testing. Subjects sat on a comfortable chair in front of a PC screen positioned at 45 cm from their eyes. Subjects were tested in one session lasting approximately 30 minutes. First, the sequence of 4-choice RT was presented. Task instructions for the Maps test were then displayed on the screen, and two practice maps were presented to let participants familiarise themselves with the task. Participants were then prompted to begin, and a randomised sequence of 30 Maps was presented separated by a 10 s inter-trial interval.

Behavioural testing

The computerised test automatically recorded information about the timing and the sequence of errands achieved by the subject. For each trial of the Maps test, the following measures were collected: preplanning time, execution time, each intermediate time and number of key presses between every couple of sub-goals (eight couples, originating the independent variable location) and sub-goals achievement order.

Preplanning time is the time between the appearance of the sub-goals and the subject's first movement. It can be considered the time that subjects use to collect information on the situation and begin solving the task by preparing a provisional plan. Execution time is the time taken for the subject to execute the task, that is, between the first movement made and the attainment of the final sub-goal (execution time excludes preplanning time).

Given that movements in the Maps test are segmented into steps (where each step corresponds to an arrow key press), a modification of the optimisation index proposed by Graham and collaborators [40] was used. Accordingly, StepPAO indicates the percentage of steps made by the subjects that are above the minimum number of steps required to execute the tour [29]. In the Maps test, StepPAO is a measure based on the total number of steps needed to complete the tour rather than the total tour length. For each solution X_i made by a participant i of a map X, StepPAO is calculated as follows:

$$StepPAO(X) = [Total\ Steps\ (X_i) - Optimal\ Steps(X)] / Optimal\ Steps(X)$$

The optimal steps were calculated with an exhaustive search algorithm for each map. The more the StepPAO of a tour X_i approximates to 0, the more the corresponding trajectory is close to the optimal solution. This measure was considered a reliable index of quality of the performance on a TSP-based task in spatial terms (completing the time measures), and has been repeatedly found as very low in humans [41, 42].

Furthermore, the PI was considered an estimate of the cognitive effort devoted by the subjects to plan the route step-by-step [28]. This index was created to obtain a succession of measures, each one filtered by the relative distance of the sub-goals in the situation and the subjects' skills in key pressing. It consisted of an array of eight measures calculated as follows. The intermediate time between each sub-goal of the trajectory was divided by the corresponding intermediate number of moves, and was then divided by the 4-choice RT obtained by each subject.

The sub-goals achievement order was analysed using a procedure based on the detection of heuristics and strategies (which emerged from the combination of heuristics).

To detect the presence of a heuristic, four algorithms were run, each one corresponding to a heuristic. As in a previous study by Basso et al. [29], the analysed heuristics were: (1) a cluster heuristic (all the locations are separated into distinct clusters, then afterwards all locations within the same cluster are achieved before proceeding with the next cluster [43]); (2) a nearest neighbour heuristic (the next location to achieve is the closest one from the actual location [44]); and (3) two directional heuristics corresponding to the vertical and horizontal directions (starting from a border position, the next locations are achieved following an orientation (horizontal or vertical) and a direction (up or down for vertical direction, left or right for horizontal direction) [23]. Other kinds of heuristics could have described the performance of the participants; however, given the spatial constraints of this task (i.e., the regular grid, the limited number of streets) this list was sufficiently appropriate [25] and feasible [23] to represent human performance on the open version of the TSP.

For each sub-goal of each path, each algorithm detected whether the criteria for its attribution were satisfied (for a complete description of the algorithms see [28]). If this check returned a positive value for at least three successive sub-goals within the path, then the corresponding heuristic was attributed to that section of the path. Thus, each heuristic could result in one of the three following patterns: (1) attributed to the *whole* path, (2) attributed to only a *part* of it; or (3) *not* attributed at all in that path. All the heuristics could be attributed either to the whole path, or to a part of it, except the cluster heuristic; given that it divides the whole space into sectors, it can only be used for the whole path. A certain part of the path could be representative of more than one heuristic at a time, a case that cannot be avoided because it is usually present in real life.

At the end of the mechanism of heuristic attribution, the resulting pattern for each path generated one of these three types of strategy: (1) one or more heuristics were attributed to the whole path (from the beginning to the end of the path: constant strategy); (2) heuristics were used for only a part of the path but covered the whole path when taken together (strategy with changes of heuristic, also named flexible strategy); or (3) the four algorithms did not indicate any heuristic or combination of heuristics which could cover the whole path (no strategy).

Eye tracking testing

Data from the eye tracker was analysed through a custom-made code written in Matlab (Version 7.0). As for the PI, eight measures of NFix, one for each sub-goal, were obtained. An eye movement was considered a fixation when the gaze resided inside a 1.5 degree field for a time greater than 170 msec. First, we evaluated the relative vertical and horizontal gaze movement vectors for each sampling point by selecting x and y positions at $time = n$ and $time = n + 1$. By summing eye position vectors, we obtained the eye shift between each sampling point. To avoid eye movement effects related to speed in visuospatial processing, we calculated the FR. As for the PI, the FR was calculated for each sub-goal and was the ratio between the time spent on fixations divided by the steps needed to move between a sub-goal and the next one. Compared with NFix, the FR was not influenced by individual differences in either the quality of execution or optimisation level. Trials, containing either blinking or eye movements, occurring off screen [45] as well as data 60 ms before and 60 ms after such an artefact were also discarded (overall mean = 15%).

Data analysis

The following variables were used for the analysis. The array of values included the PI (behavioural measures calculated for each sub-goal of each path), NFix (frequencies of eye movements, obtained for each sub-goal of each path) and FR (values of eye movements, calculated for each sub-goal of each path). Single behavioural measures included preplanning time, execution time, StepPAO (the value calculated from comparing to the norm), strategy (given by the combination of heuristics) and four heuristics: direction right (r), direction down (d), cluster (c) and nearest neighbour (n). Given their structure, in analysing the PI, NFix and FR the variable 'location' was used to separate the effects of each segment of the path. To test the hypothesis that males and females differ in the use of cognitive strategies, differences in 'gender' were first investigated using a chi-square analysis on the frequency of paths attributed to each 'strategy'. The no-strategy was excluded because it was expected to provide too little data to perform a reliable analysis. Differences in gender in the preference of heuristics were assessed through a series of chi-square tests comparing gender on the frequencies of the values of heuristics (used for the whole path or only for a part of it), either separated for the four heuristics or

comparing them. Preplanning time, execution time and StepPAO underwent a mixed ANOVA with gender as a between-subjects variable and type of strategy (two levels: constant and with-changes strategy) as a within-subjects variable. Because the choice of a particular strategy can produce differences in the performance, the PI and eye tracking data were split according to the strategy factor. Thus, a mixed ANOVA analysis was performed with gender as a between-subjects factor (two levels) and strategy and location (2 × 8 levels) as within-subjects factors on the three dependent measures the PI, NFix and FR. To specifically evaluate the impact of gender and strategy on each measure, we performed additional post-hoc analysis (Bonferroni corrections with the alpha error threshold set at 0.05) on the PI, NFix and FR for each location. Given that these measures are composed of an array of values, a general evaluation was unsuitable for catching the presence of single differences in specific items.
According to recent APA norms, partial eta-squared values (indicated with the symbol η^2) were added to each F-value, whereas standard error means were provided for each mean value.

Results

Behavioural tests

The chi-square test showed a relationship between gender and type of strategy ($\chi^2(2) = 14.105$, $p < 0.001$; see Figure 2). Males employed roughly the same number of constant (51%) and with-changes (46%) strategies despite females prominently using constant strategies (64%) over strategies with changes (33%).

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The analysis of the heuristics evidenced that the two genders have different preferences in the use of heuristics. Males were likely to choose direction right heuristic ($\chi^2(3) = 51.897$; $p < 0.001$), whereas females preferred both directional heuristics ($\chi^2(3) = 71.809$; $p < 0.001$).

Chi-square analysis was also applied to evidence distinctions in gender for each heuristic, split for the two strategies. Differences because of gender were noticed only when people used a constant strategy (restricted to cluster and direction right heuristics; see Table 1).

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The mixed ANOVA analysis revealed that preplanning time was not significantly different between males and females ($F_{1,26} = 0.011$; $\eta^2 < 0.01$; Figure 3a). Conversely, a significant effect of the strategy factor was found on preplanning time ($F_{1,26} = 5.140$; $p < 0.01$; $\eta^2 = 0.17$) and showed that the time spent to plan a constant strategy was significantly shorter than the amount of time needed when a subject used a strategy with changes (Table 2). No interaction was found between the gender and strategy factors on preplanning time ($F_{2,26} = 3.081$; n.s.; $\eta^2 = 0.11$). Considering the execution time, a main effect because of both gender ($F_{1,26} = 53.260$; $p < 0.001$; $\eta^2 =$

0.68) and strategies ($F_{2,26} = 29.400$; $p < 0.001$; $\eta^2 = 0.54$) was found, showing significantly lower values for males than females in the execution of the paths. However, execution time was lower when subjects employed constant strategies. No interaction was found between gender and strategy factors on execution time ($F_{2,26} = 2.031$; n.s; $\eta^2 = 0.08$.).

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The analyses of StepPAO showed significant differences in both gender ($F_{1,26} = 8.294$; $p < 0.01$; $\eta^2 = 0.25$) and strategies ($F_{2,26} = 5.555$; $p < .05$; $\eta^2 = 0.18$) factors (Figure 3b). Males produced shorter paths, whereas females employed a higher number of steps. Moreover, a higher optimisation performance resulted when participants implemented a strategy with changes rather than a constant strategy. A marginally different interaction was found between gender and strategy on StepPAO ($F_{2,26} = 3.913$; $p = 0.06$; $\eta^2 = 0.16$). The pairwise post-hoc analysis (Bonferroni corrected for multiple comparisons, alpha threshold = 0.01) revealed a significant difference for females in the optimisation performance when a constant strategy was implemented.

The mixed ANOVA with gender, strategy and location as factors revealed a main effect of gender on the PI ($F_{1,26} = 6.649$; $p < 0.05$; $\eta^2 = 0.21$). Specifically, the amount of cognitive resources that females needed to execute the paths was higher than that of males. Moreover, a main effect of both strategy and location on the PI was found ($F_{1,26} = 18.892$; $p < 0.01$; $\eta^2 =$

0.43 and $F_{7,26} = 19.494$; $p < 0.01$; $\eta^2 = 0.44$ respectively). PI values were higher for the strategy with changes, whereas both first and last values were lower than the central ones, which were constant. A gender × strategy interaction was marginally significant ($F_{7,26} = 4.145$; $p = 0.05$; $\eta^2 = 0.14$), whereas gender × location ($F_{7,26} = 0.364$; $\eta^2 = 0.01$) and three-way gender × strategy × location ($F_{7,26} = 0.644$; $\eta^2 = 0.03$) interactions were not. The post-hoc analysis evidenced that gender differences were present only in the second half of the path (Figure 3a).

Eye movement results

The mixed ANOVA revealed the significant effect of gender on NFix ($F_{1,26} = 22.570$; $p < 0.01$, $\eta^2 = 0.47$). Post-hoc analysis showed that females needed a significantly higher number of fixations than males (1.504 ± 0.050 vs. males 1.163 ± 0.052. A main effect of both strategy ($F_{1,26} = 5.534$; $p < .05$) and location on NFix ($F_{7,26} = 3.130$; $p < 0.01$) was found, but the low eta-squared values ($\eta^2 = 0.18$ and $\eta^2 = 0.11$ respectively) indicated that the effects were weak. Post-hoc comparisons showed that participants made a higher number of fixations using a strategy with changes rather than a constant strategy (1.283 ± 0.032 vs. 1.383 ± 0.050).

The strategy × location interaction reported a significant effect ($F_{1,26} = 3.730$; $p < 0.05$, $\eta^2 = 0.13$). The post-hoc comparison showed that, within the constant strategy, only the sixth value was significantly higher than the others, whereas the fifth and sixth values were higher than the last one in the strategy with changes. Interactions between gender and strategy ($F_{1,26}$ = 3.125; η^2 = 0.11), gender and location ($F_{7,26}$ = 0.320; η^2 = 0.01) and gender × strategy × location ($F_{1,26}$ = 1.209; η^2 = 0.06) were not significant.

However, planned post-hoc comparisons showed that, in the females sample only, NFix was higher for the strategy with changes (Figure 3b).

The results on the FR revealed a main effect because of gender ($F_{1,26}$ = 9.735; $p < 0.01$, η^2 = 0.28). Females (mean = 0.474 ± 0.023) showed higher FR values than males (mean = 0.371 ± 0.024). Moreover, a main effect of location ($F_{7,26}$ = 27.052; $p < 0.01$; η^2 = 0.52) but not strategy ($F_{1,26}$ = 0.006; $\eta^2 < 0.01$) was observed. The post-hoc comparison on location replicated the pattern shown for the PI, with the first and last values lower than the central ones. Although the other interactions failed to achieve a significant value, the planned post-hoc comparisons showed interesting significant effects. Genders were significantly different in locations 1, 2, 5, 6 and 8 (Figure 3c).

Discussion

The results of this study have supported previous findings that males tend to have an advantage over women with regard to visuospatial skills [1, 46]. Moreover, new insights have been achieved using the several measures collected with the Maps test. The analysis of heuristics and strategies suggests that the difference between genders exists because of the considerable use of flexible strategies by males compared with females, who often employ strategies based on a heuristic that is constantly used throughout the pathway. The general preference for directional heuristics, substantially replicated in both genders, is characterised by the constraint of the 2D environment of the Maps task, which was made of horizontal and vertical streets. Because no statistical gender difference was found in preplanning time, it might be suggested that the difference in strategy selection is unrelated to this phase. The initial processing stage (including representation of the environment and the first sketch of the plan) is unlikely to be different between genders. By contrast, the faster execution times and higher optimisation levels achieved by males strongly imply that the differences found occurred during the execution of the task rather than in the preplanning phase. This pattern of behavioural data points towards a difference between genders because of their differences in the control and management of strategies.

Previous literature [29] has suggested that the choice to use more flexible strategies is preferable because it allows a greater number of possibilities in the determination of the trajectory, although the selection and execution of a constant strategy still allows the attainment of a satisfactory solution. According to our results, males seem to be capable of reconsidering and managing their previous choices and, consequently, can change their heuristic when the current one is no longer suitable for achieving the desired goal. Conversely, females tend not to change the initial plan. They instead apply a schema of a resolution chosen from a set of candidates – the one which best fits from a perceptual basis. We might consider female navigation as egocentric navigation [47, 48], which is probably based on the detection of anchor points (i.e., landmarks), as suggested by Sandstrom and colleagues [49]. In the case of the Maps task, the concept of “egocentric perspective” should not be intended as the correspondence between the position of the actor in the real space and his/her representation on a map. However, according to Witkin [50], a continuum exists between egocentric and heterocentric perspectives. An egocentric strategy concerns the assumption of an internal reference, minimizing the attention to external stimuli. By contrast, a heterocentred strategy is based on an interaction between internal aims and elements retrieved from the environment. Females' general preference for egocentric strategies has recently been found by Chen and colleagues [51] using a terrestrial/2D task (similar to the one used in this study) where participants had to find a specific object located at the bottom of a virtual aquarium. The performance of the female sample in the you-are-here (YAH) condition was poor compared with males in the same condition, and compared with their own performance in the guide sign condition.

On the basis of these findings, it can be hypothesised that females are likely to perform worse than males in spatial orientation because they tend not to prefer configurational strategies, or because they cannot easily switch their strategy according to the information retrieved from the environment. These differences might concern components such as the “actual navigation or imagined map scanning”, which Coluccia and Louse state are “less efficient during an orientation task” [2].

We further hypothesised that gender differences in the PI and eye movements could be explained by the different planning methods employed by the two genders. The results obtained from the PI and FR supported this hypothesis. The two measures (which are higher in women for most of the pathway) suggest that gender differences influence the whole path implementation until the final goal is achieved. The examination of eye movements evidenced a reciprocal confirmation: the number of fixations follows the same trend as the PI. Furthermore, the FR result provides substantial proof of the reliability of the PI. Given that the PI and the ocular measures are considered indices of cognitive effort, higher values in each measure for females strongly suggest they need more cognitive resources to solve the task.

The higher NFix in females could be because of poorer performance during execution. Thus, it is reasonable to expect on average more fixations in females than in males. Even though this might be a plausible assumption, analysis of the FR denies this possibility. Because the FR was specifically developed to be insensitive to the intermediate steps the difference between genders is likely to be caused by different planning abilities.

Although the optimisation level is different for the two genders, females' StepPAO values demonstrate they are capable of performing well. Furthermore, when females used strategies with switches between heuristics there were no gender differences in the optimisation level. This result suggests that the difference in female performance completely exclude explanations based on a lack of knowledge or use of heuristics. The low performance of females might be because of either a lower ability to create optimised plans (including switches and combinations of heuristics) or realise the plan, as compared to males. However, this experiment did not distinguish between the contribution of planning and more general executive processes and it remains an area in need of further exploration. Nonetheless, considering the trade-off between performance and cost, females appear to be more conservative (aiming to reduce costs), whereas males tend to maximize gain in both areas.

This proposes another possibility when considering gender differences in risk-taking behaviour [52]. Males of various ages have been generally found to take more risks than females in several activities. In particular, females are less confident in assuming risks, and this led them to show higher results in the Iowa Gambling task and the Betting task, as assessed by d’Acremont and Van der Linden [53]. Given that the preference for a constant strategy can be indicative of conservative behaviour (because the change of heuristics implies abandoning the previous plan for a new one) a common process might underlie both risk-taking behaviour and strategy choice. The assumption could seem speculative, but the similarities between the two aspects of decision-making behaviour have been hypothesised to originate from an evolutionary system of self-protection [54] or a stronger psychophysiological reaction to emotional stimuli [55].

Confusion remains as to whether gender differences occur in risk-taking behaviour or because of a lower tendency to create complex plans (as well as in the motor implementation or in the processing of visual stimuli). A deeper exploration of both the perceptual properties of the environment and the instructions of the task would be helpful to disentangle what "cognitive effort" means in this case, that is, whether gender differences during the execution of the plan are because of different representations of the environment/task, the efficacy of the control process or the inhibitory process that allows switching between heuristics. In fact, the strong route-perspective provided by the Maps task might have strengthened the notion that the difference is down to gender. The level of abstraction required to take the first-person perspective [56], adopting the human silhouette as the "me" moving into an environment, is strictly related to the means of representing the locations into the egocentric/allocentric continuum [57].

Research using the YAH maps has shown how the presence of landmarks can be modulated by the alignment of the map to the observer [58]. Thus, genders can manipulate differently the perceptual data provided by the 2D representation of the environment and the ability to easily control the frame of reference. This could be a crucial factor in the emergence of a difference in performance between males and females. This hypothesis has been recently verified by Chen and collaborators [51] in their research investigating way-finding tasks. Males (using more allocentric strategies) showed better navigational performances than females (who used more egocentric strategies). But when females were supplied with the appropriate support (i.e., guide signs), gender differences were eliminated.

In conclusion, this research is the first attempt to explore gender differences in the field of errand-planning behaviour by using the Maps test in conjunction with oculomotor measures. Our findings confirm that a trade-off between execution time and optimisation exists because of the human tendency towards an opportunistic planning approach. Gender differences modulate this concept. Our results confirm that a continuous planning process is spontaneously implemented by both genders, but males are more able to make adjustments to the initial plan. According to Mueller and colleagues [22], the investigation of oculometric correlates underlying differential male and female performances in spatial tasks has provided substantial confirmation of the hypotheses on gender peculiarities in the field of errand-planning behaviour. Although the origins of these differences remain partially unknown, this paper provides additional evidence for the peculiarities of genders in planning behaviour. People dynamically adapt their choices to the environment, but within this visuospatial task males are more skilful in adjusting previously made decisions.

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Captions

Table 1.

Number of used heuristics, separated for Strategy (K=constant strategy; wC=strategy with changes) and Gender. On rows are represented the 4 types of heuristics (R=direction right, D=direction down, C=cluster, N=nearest neighbor), while in columns frequencies are separated for the heuristic use in the whole path or only for a part of it. The Chi-square analysis represents the differences between the two genders: asterisks indicate a $p<0.01$, while plus signs indicate a $p<0.05$. Cluster heuristic is not present within the flexible strategies, since it can be attributed only to the whole path.

Table 2.

Means (+ S.E.M. in brackets) are represented separately for both genders during Preplanning Time (sec.), Execution Time (sec.) and StepPAO (steps), depending on the two kinds of strategies used by subjects.

Figure 1.

An example taken from the Maps task. The square in the upper left corner represents the starting point, the square in the lower right corner represents the end point, and the light circles represent the subgoals.

Figure 2.

Percentage of each type of strategy used by subjects on the total number of paths presented. The percentages represent the amount of strategies used by the subjects based on the absence of a strategy (light grey bars), based on a constant heuristic (grey bars) and based on changes between heuristics (black bars), with respect to the total number of paths performed by the participants.

Figure 3.

In each of the graphs, data from the male group is represented by light lines and data from the female group by dark lines. Mean values (+S.E.M.) are separated for Gender (males: black colored lines; females: grey colored lines) and for Strategy (constant strategy: solid lines; flexible strategy: dotted lines), representing the three following measures:
a) Planning Index (PI); b) Number of fixations (Nfix); and c) Fixation Ratio (FR).

Keywords: Gender differences; Visuo-spatial planning, Navigation; Strategy; Optimization; Eye movements

Acknowledgements

Click here to download Supplementary Material: Acknowledgements.doc

Table 1

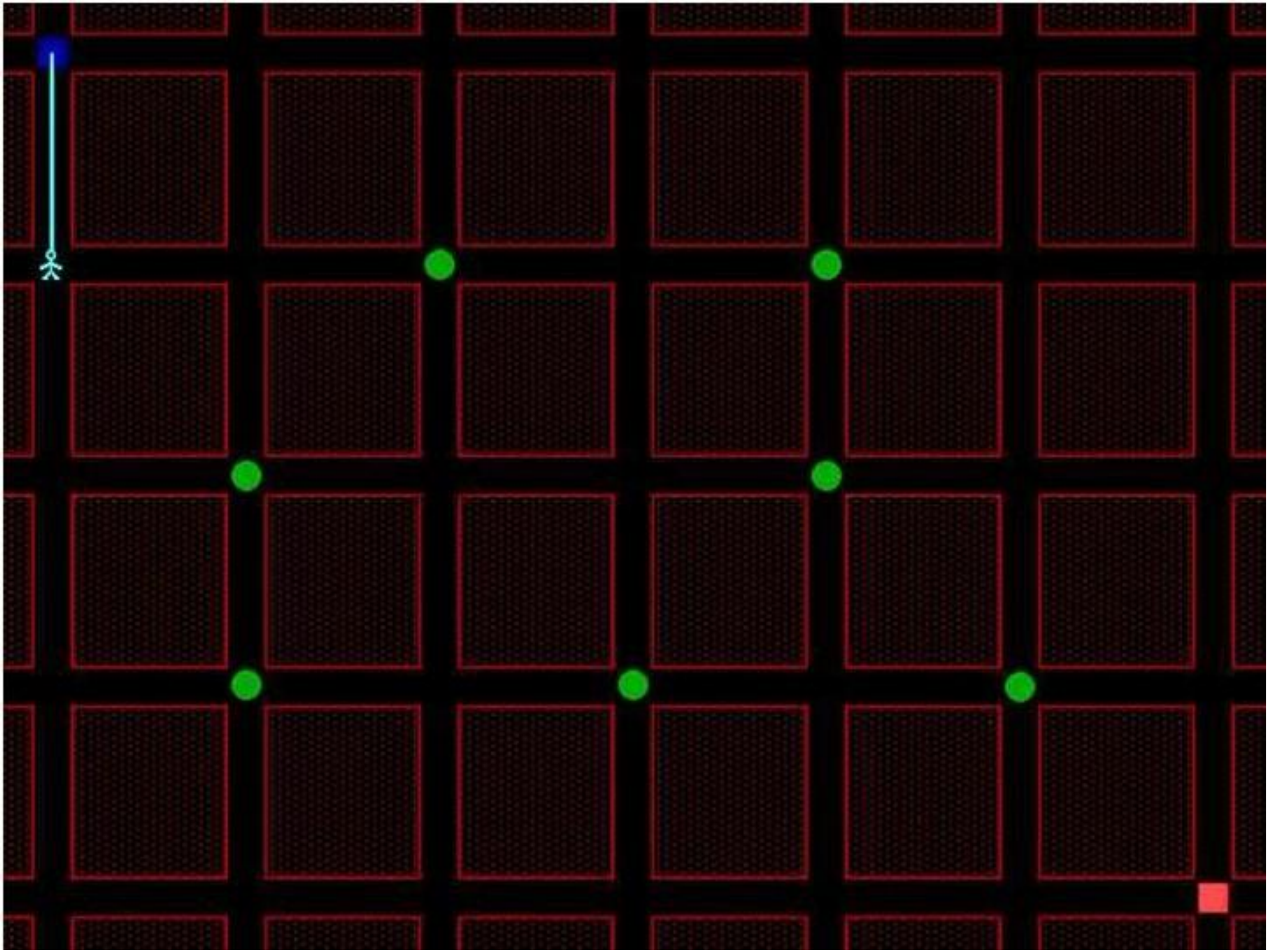
	Used for the whole path					Used for a part of the path				
	males		females			males		females		
	K	wC	K	wC	χ^2	K	wC	K	wC	χ^2
R	153	21	125	14	.310	26	150	21	125	.010
D	20	4	128	0	21.910^{*}	31	165	27	137	.028
C	133	90	127	56	4.156^{+}	/	/	/	/	/
N	43	10	40	5	1.130	75	85	54	65	.062
Total	349	125	420	75		132	400	102	327	

Table 2

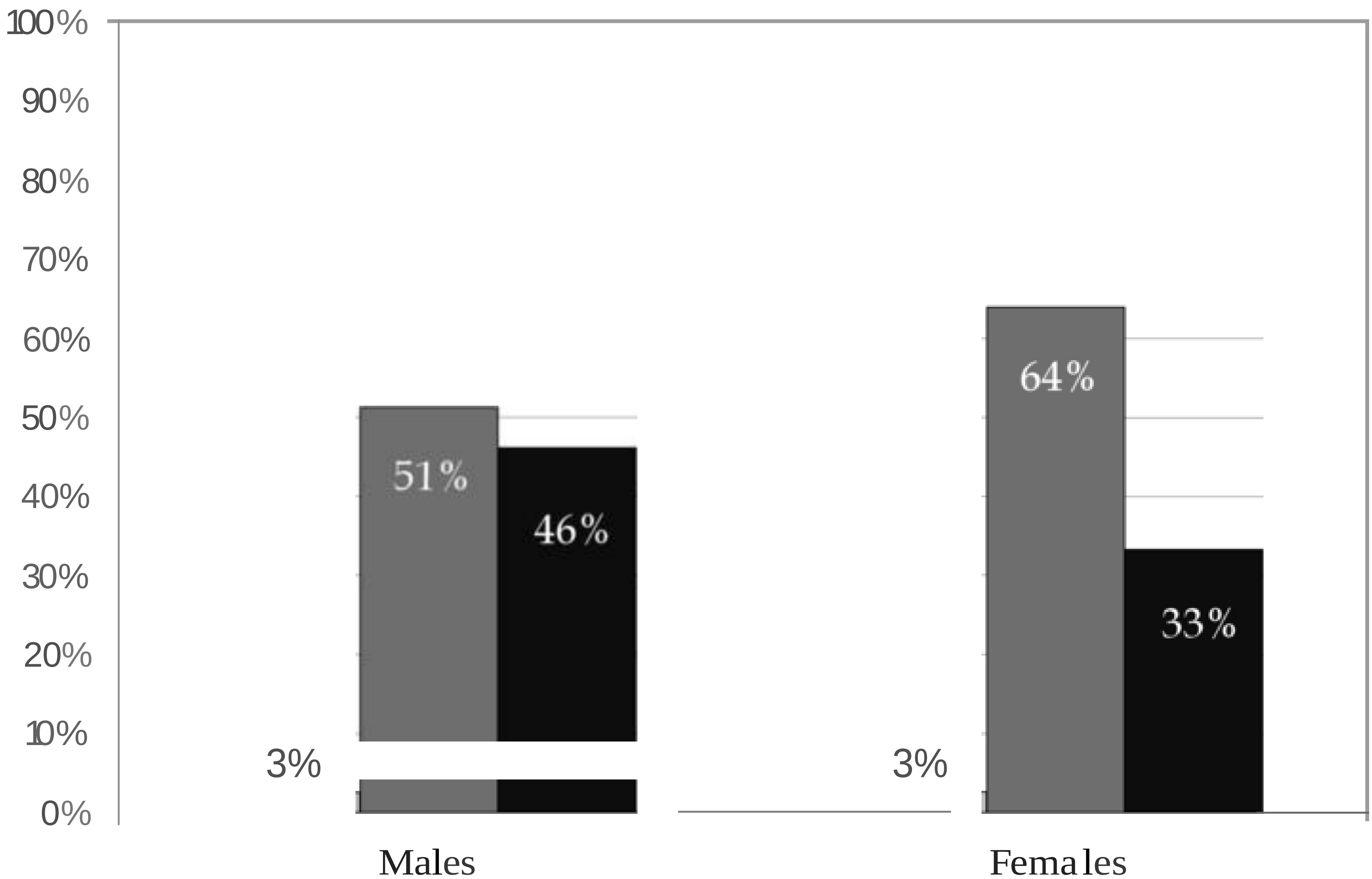
	Males		Females	
	Constant	**With changes**	**Constant**	**With changes**
Preplanning Time	1.21 (0.15)	1.24 (0.19)	1.07 (0.14)	1.33 (0.19)
Execution Time	5.65 (0.23)	6.18 (0.27)	7.80 (0.22)	8.71 (0.26)
StepPAO	0.08 (0.01)	0.07 (0.01)	0.14 (0.01)	0.10 (0.01)

Agure1

Click here to do\vnloOO high resolution imsge



Agure2
Click here to do\vnloOO high resolution imsge



Agure3
Click here to do\vnloOO lighresolution1msge