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One's own country and familiar places in the mind's eye: different topological representations for navigational and non-navigational contents

M. Boccia[1,2*], L. Piccardi[2,3], L. Palermo[2,4], F. Nemmi[2,5], V. Sulpizio[2], G. Galati[1,2] & C. Guariglia[1,2]

[1] Department of Psychology, "Sapienza" University of Rome

[2] Neuropsychology Unit, IRCCS Fondazione Santa Lucia, Rome, Italy

[3] Department of Life, Health and Environmental Sciences, L'Aquila University, L'Aquila, Italy

[4] School of Life and Health Sciences, Aston University, Birmingham, UK

[5] INSERM, U825, Université Paul-Sabatier, Toulouse, France

* *Corresponding author*

Maddalena Boccia

Department of Psychology

Via dei Marsi, 78

00185 Rome (Italy)

maddalena.boccia@gmail.com

tel. +390651501547

fax. +390651501213

Abstract

Visual mental imagery is a process that draws on different cognitive abilities and is affected by the contents of mental images. Several studies have demonstrated that different brain areas subtend the mental imagery of navigational and non-navigational contents. Here, we set out to determine whether there are distinct representations for navigational and geographical images. Specifically, we used a Spatial Compatibility task (SCT) to assess the mental representation of a familiar navigational space (the campus), a familiar geographical space (the map of Italy) and familiar objects (the clock). Twenty-one participants judged whether the vertical or the horizontal arrangement of items was correct. We found that distinct representational strategies were preferred to solve different categories on the SCT, namely, the horizontal perspective for the campus and the vertical perspective for the clock and the map of Italy. Furthermore, we found significant effects due to individual differences in the vividness of mental images and in preferences for verbal versus visual strategies, which selectively affect the contents of mental images. Our results suggest that imagining a familiar navigational space is somewhat different from imagining a familiar geographical space.

Introduction

Visual mental imagery arises when perceptual information is accessed from memory, giving rise to the experience of “seeing with the mind’s eye” [1,2].

This cognitive process draws on many abilities, which rely on different cerebral structures [3] depending on the contents of the image. For example, imagining a face, an object or a place produces activation in different brain areas [4,5,6].

When people have to arrange the parts of a mental image [7,8], they process them using categorical and/or coordinate strategies. In categorical processing judgements have to be made about the relative position of the components of a visual stimulus, and in coordinate processing absolute distances have to be calibrated between the components of a visual stimulus [9]. Palermo et al [10] found that people rely exclusively on categorical processing to generate mental images of common objects, but require both coordinate and categorical processing to generate mental images of landmarks. Furthermore, individuals can be classified as visualizers or verbalizers according to whether they rely on imagery when performing cognitive tasks or on verbal-analytical strategies, respectively [11]. Visualizers mainly process images using coordinate strategies, whereas verbalizers mainly adopt categorical strategies when they have to analyse parts of a mental image [12].

Representational neglect [13], a syndrome which affects the mental representation of space following a cerebral lesion, can selectively affect different imagery domains, that is, patients can show deficits in imagining environments and/or objects [14,15]. Guariglia and Pizzamiglio [16,17] proposed the existence of two different types of mental representations of space: “topological” (navigational) and “non-topological” (non-navigational) images. The first are defined as mental representations of stimuli in which it is possible to navigate, and the latter as representations of objects or visuospatial displays in non-navigational space (i.e., whether or not I can navigate in the space, regardless of its distance). A second reading of cases with representational neglect and a recent group study [15] support this distinction. Ortigue and co-workers [18] reported the case of a patient with representational neglect that selectively compromised the far space of a mental representation. When asked to imagine her near space, the patient made no detectable omissions on the contralesional side of the mental image. By contrast, when asked to bring back memories of a familiar square in Geneva and of the map of France she “forgot” elements that fell on the left side of the mental representation. Grossi and co-workers [19] described another patient who failed when he had to mentally compare two different times on two analogue clocks to decide which clock hands formed the widest angle; thus, he showed a deficit in the mental representation of an object.

It has, however, been highlighted that both navigational and non-navigational mental images can be defined according to viewer-centred and object-centred coordinates [20]. Viewer-centred coordinates involve the ability to locate objects with reference to one’s own body, whereas object-centred coordinates determine where something lies in the world regardless of one’s position. It can be hypothesized that topological mental images about navigational space rely mainly on a viewer-centred coordinates, whereas mental images of non-navigational objects rely mainly on object-centred coordinates. Indeed, people navigate through the processing of spatial relations among objects by linking them to their own position, thus adopting a viewer-centred perspective. Depending on task requirements, however familiar places might also be represented through an object-centred coordinates. For instance, if an examiner asks a subject to mentally represent the distance between two landmarks, the viewer-centred perspective is not required, even though the individual has already directly experienced the environment in a viewer-centred perspective to make such an estimation. Furthermore, to know what time it is, subjects process the spatial relations between objects using the spatial relations between the hands of the clock, thus adopting an object-centred perspective. Representing the map of one's own country is more similar to object representation, as it is also based on an object-centred perspective. This issue raises some concerns, especially regarding the use of geographical space to assess representational neglect, because geographical and proper navigational space may tap into different mental representation processes. Nevertheless, it is very difficult to establish whether object-centred or viewer-centred coordinate systems make the difference in mentally representing navigational and non-navigational images. This is especially true in the case of geographical maps, which also provide navigational information. Moreover Ortigue and co-workers [18] described a patient who showed a clear deficit in representing both a familiar square in Geneva and the map of France. This suggests that there is a relationship between mental images of geographical and navigational spaces. Differently, Rode and co-workers [21] reported a case in which geographical information had to be spatialised to be neglected. In their study, evocation strategies appeared very different when distances between successively named towns were considered. When the task was to form a visual image of the map, the patient's performance was severely impaired; by contrast, the patient performed without hesitation when he had to list the names of towns in France without imagining placing them on the map.

A study aimed at investigating which strategies healthy participants use in representing different navigational and non-navigational mental images might be useful to better understand the mechanisms underlying the mental representation of space and objects. Furthermore, in light of the disagreement in the current literature over the frequency of representational neglect, with some studies reporting that neglect confined to visual mental imagery is a rare occurrence [22,23] and others reporting higher frequencies for it [15], it might be useful to understand whether its presence was underestimated due to a bias in the tasks used for assessment. Bartolomeo et al [23] hypothesized that a task-dependent bias was present in the "memory after description" condition proposed by Denis et al [24]. In this condition the authors presented patients' visual layouts or verbal descriptions of layouts and then asked them to recall the material. Indeed, in this task healthy participants also showed a tendency to report fewer items on the left than on the right.

As different mental imagery domains exist [16,17], neuropsychological evaluation of representational neglect might fail to find representational deficits because it was not directly assessed. We aimed to determine whether distinct domains exist for different mental images, especially due to the possibility to navigate across them. Other then comparing clearly navigational and non-navigational mental images, we tested for the first time the hypothesis that the mental image of geographical space, which conveys navigational information but cannot be properly navigated, is represented similarly to the mental image used in representing a familiar object. Specifically, we investigated whether processing a navigational mental image of a geographical space (i.e. the map of Italy) corresponds to processing a non-navigational mental image (i.e. the clock) or a navigational mental image (i.e. the campus). Results should be interesting because of the differences reported in neuropsychological case reports and the frequency of representational neglect. For this purpose we developed three different conditions in which we compared navigational vs. non-navigational images using well-defined and comparable tasks. Furthermore, we assessed the presence of individual differences in using strategies to arrange the parts of different mental images. In light of previous findings [10] it is important to better understand whether individual predispositions to use categorical or coordinate spatial relations affect mental imagery domains differently.

Material and method

Participants

Twenty-one healthy right-handed students at the Sapienza University of Rome, very familiar with the campus (i.e. for at least three years)(mean age 27.33±3.97; 12 females) without neurological or psychiatric disorders, participated in the study. Their campus knowledge was assessed by a preliminary questionnaire in which they were asked to locate the campus landmarks on a map (mean *landmark knowledge* of the university campus 81.27%±14.99%). We also assessed participants' geographical knowledge with a preliminary questionnaire in which they had to select the geographical area (i.e. northwest, northeast, southwest or southeast) of a set of 16 Italian cities (mean knowledge about Italian cities 85.71%±16.55%). Geographical knowledge did not differ from knowledge of the campus ($t=1.33$;$p=n.s.$). All participants gave their written informed consent. The study was approved by the local ethics committee of IRCCS Fondazione Santa Lucia of Rome, in agreement with the Declaration of Helsinki.

Stimuli

To investigate whether different domains of visual-mental imagery exist, we built set of stimuli following three main dimensions: *images* of a familiar environment (the campus); *images* of a familiar object (a clock); and *geographical images* to investigate how a familiar geographical space is processed (a map of Italy)(Figure1A). For the familiar environment *images* we made a set of 120 stimuli, which included 15 campus landmarks. For the familiar object *image*, we collected a set of 120 stimuli by using them 12 times (i.e. 01:00; 02:00; 03:00 etc.). Finally, for the *familiar geographical images* we collected a set of 120 stimuli by using 16 Italian cities. Within each category, stimuli consisted of two words or times (e.g., Geology–Chemistry; 01:00–06:00; Trieste–Salerno) indicating two items from the same category, which could be displayed *horizontally* (50%) or *vertically* (50%)(Figure 1B) and represented the correct or incorrect spatial position of the items in real space (50% correct).

---Insert figure 1 here---

Procedure

Participants performed a *Spatial Compatibility Task* (SCT). SCT requires making a decision about the spatial position of the stimulus items, which are presented vertically or horizontally. Each stimulus represented either the correct or the incorrect spatial position of the two items relative to their current spatial location on the map of Italy, the campus or the clock face (Figure1B). Participants had to indicate whether the spatial location of the two items was correct or incorrect by mentally recalling their spatial representation and pressing one of two buttons on a keypad with their right index and middle finger. In the case of the campus, we asked participants to imagine themselves standing in front of the statue of Minerva, which is located at the centre of the campus. Stimuli were presented in a randomized sequence. Each stimulus remained on the screen for 3000 msec and was followed by an inter-trial interval of 500 msec, during which a fixation point appeared (Figure1B). For each category (i.e., the campus, Italy and the clock) and orientation (i.e., horizontal or vertical) we computed accuracy and response time (RT). The experiment was implemented in Matlab, using Cogent 2000.

Each participant completed also a *Vividness Task* (VT;[25]) and the *Verbalizer-Visualizer Questionnaire* (VVQ;[11]). The *VT* tests the vividness of mental images by asking participants to imagine a common object. The VVQ investigates consistencies and preferences in processing visual versus verbal information and classifies individuals as either Visualizers (also called Imagers), who rely primarily on imagery when performing cognitive tasks, or Verbalizers, who rely primarily on verbal-analytical strategies.

Statistical analysis

Statistical analysis was performed using SPSS. We performed two repeated measures ANOVAs to test for significant effects of category (i.e., the campus, Italy and the clock) and orientation (horizontal and vertical) and a possible interaction effect between the two factors.

Then we performed two factorial ANOVAs to test the effect of the vividness of mental images on accuracy and RTs across different categories and orientations. We calculated the median of the participants' scores on the *VT* and divided our sample into two groups: *good* (above median) and *poor imagers* (below median).

The last two factorial ANOVAs were aimed at testing the effect of preferences in processing visual versus verbal information on accuracy and RTs across different categories and orientations. We calculated the median of the participants' scores on the VVQ and divided them into *Visualizers* (above median) and *Verbalizers* (below median).

Finally, we performed a linear regression analysis on the accuracy in different categories to determine whether accuracy on the campus or the clock significantly predicted accuracy on Italy. We also performed three multiple regression analyses using distances between items (campus: distances were expressed in metres; Italy:

distances were expressed in kilometres; clock: distances were expressed as discrete positions of hours) as predictors and RTs as dependent variable.

Results

---Insert figure 2 here---

We observed significant differences in participants' accuracy due to a main effect of category ($F_{2,40}=6.59;p=0.003$) and orientation ($F_{1,20}=10.61;p=0.004$), but also due to an interaction between the two ($F_{2,40}=19.79;p=0.000$)(Figure2A). A Duncan's post hoc analysis showed that mean accuracy was higher on Italy (mean=51.29±7.73) than on the campus (mean=47.36±7.19) and the clock (mean=45.79±9.79)($p<0.05$). Participants' accuracy was higher in the vertical (mean=49.54±8.29) than in the horizontal (mean=46.75±8.68) orientation. The interaction effect suggests that the effect of orientation was not the same in the three categories. In fact, Duncan's post-hoc analysis showed a different pattern of accuracy for horizontal and vertical orientations across categories (Figure2A). Regarding the campus, participants were more accurate on the horizontal than the vertical orientation. The pattern of accuracy on Italy and the clock was the same, and opposite to that of the campus. For both Italy and the clock, participants were more accurate on the vertical than the horizontal orientation.

Similar to the previous ANOVA, the one on participants' RTs showed a significant main effect of category ($F_{2,40}=11.73;p=0.000$), orientation ($F_{1,20}=35.49;p=0.000$), and an interaction effect between category and orientation ($F_{2,40}=19.19;p=0.000$)(Figure2B).Duncan's post-hoc analysis showed that mean RTs on Italy (mean=2755.42±430.67) were faster than those on the other categories (campus mean=3033.71±337.89; clock mean=3021.32±455.24)($p<0.05$). Participants' RTs were faster on the vertical (mean=2854.65±406.46) than on the horizontal orientation (mean=3018.98±435.62). In any case, as mentioned above, the interaction effect suggests that the effect of orientation was different in the three categories. Duncan's post hoc analysis showed that, although there was no difference between RTs on the vertical and horizontal level of the campus category, participants' RTs on Italy and the clock categories were faster for the vertical than the horizontal orientation (Figure2B).

When we tested the effect of the vividness of mental images on accuracy and RTs, we found an interaction between vividness and orientation on participants' accuracy ($F_{2,18}$=5.16;p=0.02)(Figure2C). Duncan's post hoc analysis showed that good and poor imagers differed in processing the vertical orientation of the campus items (p<0.01): good imagers performed better than poor imagers (Figure2C). No effect of vividness was found in RTs.

Then we tested the effect of preferences in processing visual versus verbal information on accuracy and RTs. Also in this case, we found an interaction effect between preferences in processing visual versus verbal information and orientation on participants' accuracy ($F_{1,19}$=4.61;p=0.05)(Figure2D). Duncan's Test showed that visualizers and verbalizers differed in processing the horizontal orientation of Italy and the clock (p<0.01): verbalizers performed better than visualizers (Figure2D). No effect of preference in processing visual versus verbal information was found in RTs.

A linear regression analysis showed that participants' accuracy on the clock (unlike the campus) significantly predicted their accuracy on Italy (Beta=0.72;T=4.11;p=0.00), with a positive correlation (r=0.74).

Finally, distance between items significantly predicted RTs on Italy and the clock (*Italy* Beta=-0.06;T=-2.90;p=0.00; *clock* Beta=-0.08;T=-4.16;p=0.00), with a negative correlation in both conditions (*Italy* r=-0.21 and clock r=-0.76).

Discussion

Our results confirm that different representations subtend the mental imagery of navigational and non-navigational contents. This suggests that imagining a familiar navigational space is somewhat different from imagining a familiar geographical space. Rather than indicating a difference across categories, our results suggest that different representational strategies exist within each category. Indeed, we found that to solve the SCT a particular orientation seemed to be preferred in each category: a horizontal perspective for the campus and a vertical one for the clock and Italy. This could be because a clear preference for the vertical orientation was shown for the Italy and the clock as both of them were learned with a marked north-south/above-below orientation. The data also suggest that these classes of mental images are preferentially processed with an object-centred perspective (i.e., Northern Italy or Above on the clock face). Otherwise, horizontal orientation seems to be preferred in representing a familiar navigational space. This could be because the campus is mainly represented by a viewer-centred perspective, which facilitates seeing what is in front of the imagers. Further, an *alignment effect* could explain this result. This effect is a facilitation in judging relative locations when participants are aligned with respect to the environment than when they are contra-aligned (rotated by 180°), because this judgment is more cognitively demanding [26]. The difference we found in vertical and horizontal orientation of the campus could be due to this effect, as participants were required to imagine themselves in a specific orientation. Furthermore, individual differences in the vividness of the mental images selectively affected one of the three contents of the mental images, that is, the navigational space. We found that good imagers were more able to solve the SCT with the vertical orientation of a familiar navigational space than poor imagers; this roughly corresponds to imaging what is beyond and behind their visualization with respect to their position. Good imagers are probably also more able to access and retrieve a survey representation of a familiar navigational space than poor imagers [27,28,29]. However, the size of the high and low imagers' groups was too small to allow drawing definitive conclusions about the differences observed in solving the SCT. Individual preference in processing visual versus verbal information selectively affected the non-navigational mental images of familiar objects (the clock) and geographical images (the map of Italy). Indeed, we found that when verbalizers performed the cognitive tasks they were more able to solve the horizontal perspective of the SCT on the clock and Italy than visualizers. The horizontal perspective is unusual for both Italy and the clock, because they are usually represented vertically. In both of these cases, verbalizers can take advantage of a verbal-analytical strategy to perform the SCT in the unusual horizontal perspective of Italy and the clock. On the other hand, visualizers who primarily relied on imagery found no advantage in retrieving the usual vertical perspective of these contents. Other explanations can be provided by referring to the evidence that categorical and/or coordinate spatial relations can be used to arrange the parts of a mental image [7,8]. As stated above, people rely exclusively on categorical processing to generate a mental image of a common object, but require both coordinate and categorical spatial relations processing to generate a mental image of a building [10]. This could be in line with our results, which suggest that Italy and the clock were mainly processed as common objects (by categorical strategies) and that the campus was processed as a familiar navigational object (by coordinate strategies). Considering the importance of category formation in many aspects of language, if verbalizers perform the horizontal perspective of the clock and Italy better, it can be assumed that the mental images of the clock and Italy, like other objects, are mainly generated according to the categorical spatial relations between items.

Both the differences in the orientation of representations of the campus, Italy and the clock and the specific effects of individual differences on imagery abilities suggest that images of navigational and geographical spaces are somewhat different. We found that the pattern of accuracy for mental images of the Italy is quite similar to that of the clock and different from that of the campus. Finally, the distance between items significantly predicted RTs on Italy and the clock but not on the campus, with shorter distances associated with slower RTs and vice versa. This trend suggests that for both Italy and the clock, the SCT is more difficult for short than for long distances. Thus, we can assume that the mental images of the clock and Italy, which were retrieved to solve the SCT, are similar.

The finding that mental images of a familiar geographical space are processed similarly to that of a familiar object raises some question about the use of geographical images to assess representational neglect. Recently, Guariglia and co-workers [15] provided evidence that representational neglect is more frequent than previously reported [22,23]. These differences are probably due to a task-dependent bias [23,24,30] in detecting it. Moreover, if a patient suffers from a selective deficit in representing navigational space that seems more diffuse than the other type[15], this deficit will be undetected if assessed by the map or the clock tasks, because the representation of navigational space differed from that of geographical space and non-navigational objects.

Overall our results suggest that direct experience of the environment compared with the acquisition of abstract geographical information could affect the strategies we use to mentally represent the space around us. These results support the distinction made by Guariglia and Pizzamiglio [16,17] between two different types of mental representations of space and shed more light on the mental representation of geographical space, which is often used to assess the presence of representational neglect. At the same time, they suggest the need for further investigations. First, the hypothesis should be tested that good imagers are more able than poor imagers to solve the vertical perspective on the campus because they are facilitated in retrieving a map-like representation of space. Second, the contingent dissociations between navigational and geographical images in patients with representational neglect should be investigated. Third, neuroimaging techniques should be used to discover the distinct neural circuits of geographical and navigational images.

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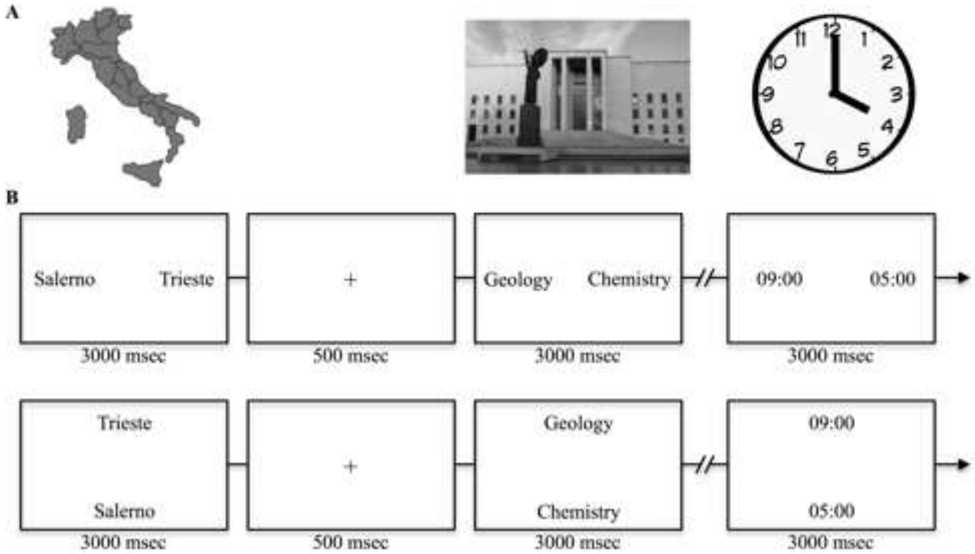
Figure captions

Fig. 1 Stimuli and task. A. Mental image contents required during the SCT: from left to right, Italy, campus and clock. **B.** Experimental stimuli and timeline.

Fig. 2 Effect of category and orientation. A. Mean accuracy. **B.** Mean response time (RT). **C.** Mean accuracy according to individual differences in vividness of mental images. **D.** Mean accuracy according to individual preferences in processing visual versus verbal information (Vs=*Visualizers*;Vb=*Verbalizers*).

Figure 1


A
B
Salerno
Trieste
3000 msec
+
500 msec
Geology
Chemistry
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09:00
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Salerno
3000 msec
+
500 msec
Geology
Chemistry
3000 msec
09:00
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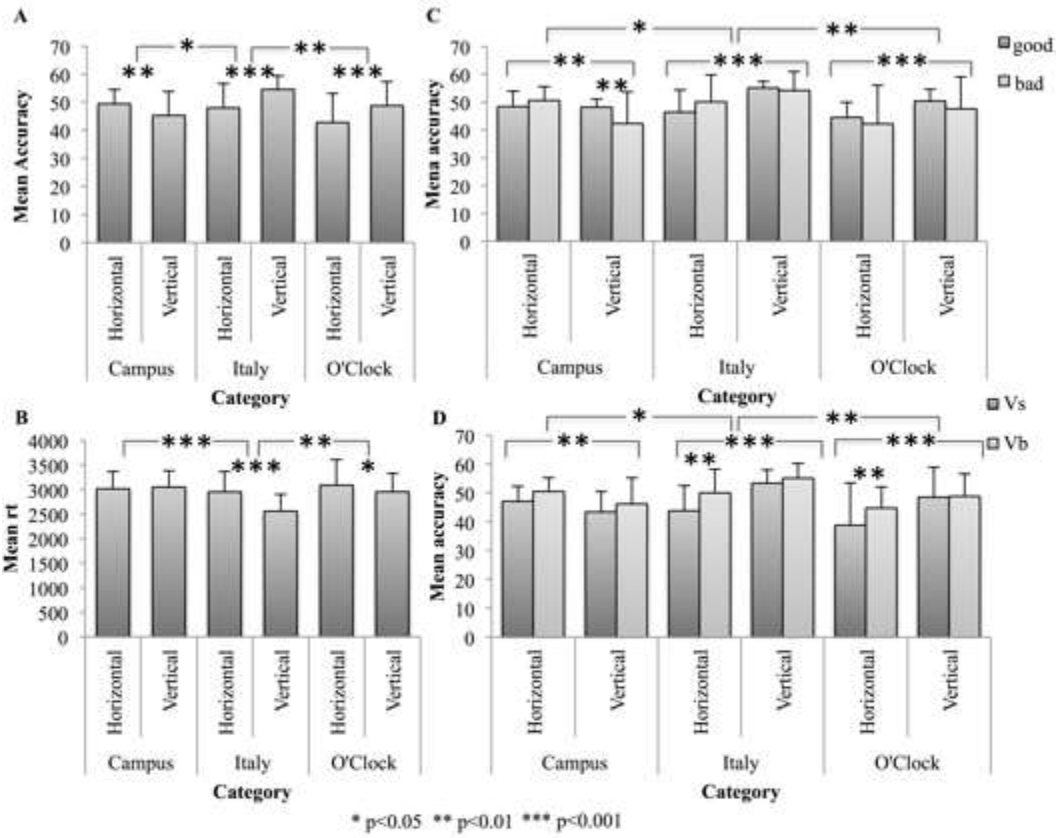
Figure 2


A
Mean Accuracy
Horizontal
Vertical
Campus
Italy
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* p<0.05 ** p<0.01 *** p<0.001