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RESEARCH ARTICLE

Categorical and coordinate spatial task performance in inconsistent-handers versus consistent-right-handers: part II

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Abstract

A previous study reported superior categorical and coordinate spatial task performance in inconsistent-versus consistent-right-handers (ICH versus CRH). Propper et al. used a three-dimensional (3D) computer-based task wherein individuals navigated to 21 locations within a realistic cityscape. During testing, participants were queried on their categorical and coordinate spatial knowledge of the map. In that study, the categorical and coordinate tasks may have inadvertently encouraged language coding of learned spatial information, potentially confounding spatial processing with recall ability for language-based information. Also, that study used a between-subjects design, which precludes examination of relationships between spatial knowledge as a function of handedness. The present study duplicated the learning task in Propper et al. using test stimuli that more faithfully represent spatial, and not language-based, information, as well as a within-subjects design. Results did not significantly replicate the previous study. Possible reasons for this finding are discussed.

Keywords Spatial processing · Handedness · Categorical · Coordinate

Introduction

We recently reported superior spatial task performance in inconsistent- (ICH) versus consistent-right-handers (CRH) (Propper et al. 2018). These results were in line with those reported previously examining handedness effects on spatial ability (Burnett et al. 1982), but somewhat different from the initial hypothesis. Specifically, Kossyln et al. (e.g.: Laeng et al. 2003) have suggested that spatial navigation involves two different types of spatial computations: those that are categorical and those that are coordinate. Categorical information collapses across the distance between two objects while retaining relative information (e.g., two objects may be equivalently "above" or "below" some reference point, though differing in distance from the reference), while coordinate information preserves the precise metric distance between objects (e.g., how far away, in centimeters, for example, two points are). Given suggestions that the neural mechanisms underlying these different types of spatial relationships may be differentially lateralized, with categorical versus coordinate processing relying especially on the left versus right cerebral hemisphere, respectively (e.g.: Baumann et al. 2012; Slotnick et al. 2001), in conjunction with research indicating increased access to, and superior performance of, right hemisphere processes in the ICH relative to the CRH (see Prichard et al. 2013, for review), and it had been suggested that the ICH would outperform the CRH on a coordinate, but not necessarily on a categorical, task. This superior performance would reflect increased access to right hemisphere processes in ICH. Given that both ICH and CRH are presumed to have equivalent access to left hemisphere processes, no differences in categorical performance were predicted. However, in that study, the ICH outperformed the CRH on both forms of spatial processing.

In that between-subjects study, during a Learning Phase, participants navigated to 21 locations within a three-dimensional (3D) maze, thereby coming to learn about the virtual

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environment (see Propper et al. 2018 for full description of task). During the Test Phase, participants either completed a categorical task or a coordinate task. In the categorical task, participants were shown, in the center of the computer screen, the name of a landmark to which they had previously navigated and were asked to click one of four quadrants on the screen indicating the cardinal direction in which they would navigate to get to that landmark, from the bird's eye perspective. In the coordinate task, a landmark name was presented on each of one side of a horizontal line, and participants estimated how far away, as the crow flies, the two landmarks were within the navigated map, by clicking and moving a tab on the line to estimate distance. The ICH outperformed CRH on both these tasks and reported being more confident in their responses.

The current work is a further examination of this effect, with two important changes. First, Propper et al.'s categorical and coordinate tasks were somewhat arbitrary, relatively impoverished, and dissimilar to the stimuli seen during the Learning Phase. For example, although the Learning Phase navigation was designed to be a visual representation of a real-world environment, and included, for example, roads and buildings, the Test Phase tasks were comparatively impoverished, using only landmark names and lines and presenting just two (out of the 21 one) items on each trial. It may have been that in order to complete these tasks, participants re-coded, or supplemented, the spatial information learned with language-based information. Given that the names of locations were provided above each located building to indicate that it had been reached, it is likely that there was at least some language-based labeling during encoding. The possible reliance on language-based labeling at testing is particularly interesting, as the ICH has been shown to have superior episodic memory for language-based information compared to the CRH (see Prichard et al. 2013). It could be that the performance differences between CRH and ICH reflected, in part, between-group differences in recall for the language-based representation of seen items and not spatial abilities per se.

Second, Propper et al. examined performance on the spatial tasks using a between-subjects design. There are two issues here: first, it is not clear whether an individual who is superior on categorical processing would also be superior on coordinate processing, given that these two forms of spatial knowledge have been suggested to reflect two different neural circuits (e.g.: Baumann et al. 2012; Slotnick et al. 2001). Second, it cannot be determined whether there is a relationship between categorical and coordinate performance. These issues are particularly interesting in ICH. ICH demonstrates increased symmetry in hemispheric functions, as opposed to the lateralization typically seen in the CRH (see Hellige 2001); these handedness differences in cortical organization may be reflected in differences between groups in the relationship between the two types of spatial computations. For example, it may be that categorical and coordinate processing are 'neuronally enmeshed' in ICH, resulting in positive correlations between performance on these tasks in ICH compared with CRH.

Therefore, in the present study, we replicated the Learning Phase of Propper et al., but changed the Test Phase conditions such that we (1) used stimuli more similar to that of the navigated environment, thereby possibly lessening reliance on language-based labels and potentially decreasing the impact of superior memory for language-based information in ICH versus CRH on task performance and (2) examined measures of categorical and coordinate task performance for each participant.

Method

Participants

Participants were 87 Montclair State University undergraduate male students, who participated for SONA credit in one of their Psychology classes and who were recruited to be between the ages of 18 and 35 years old. All individuals read and signed an Informed Consent form, the research followed all applicable ethical guidelines according to the Declaration of Helsinki and any subsequent modifications, and the protocol was approved by the appropriate IRB. The sample was restricted to men in order to replicate Propper et al. (2018) and to reduce between-subject variability in cortical organization (e.g., Tian et al. 2011). Twenty individuals dropped out/were removed prior to completion of the experiment due to computer/technical problems (e.g., $n=5$), dizziness/motion sickness ($n=5$), not following instructions/lack of attention ($n=10$). Total N completing the experiment $=67$.

Materials

Participants completed the experiment in individual testing rooms, using Dell OptiPlex 7020 i7 computers with Intel HD graphics cards and Dell P2014H 17in screen monitors. The navigation Learning Phase (see below) was presented via Unity software (Unity Technologies 2015), and questionnaires were presented via Qualtrics, Version 2015 (Provo, UT, Copyright 2017). See Propper et al. for a detailed description of the Learning Phase and Questionnaires used. Categorical and coordinate knowledge was examined via the Gardony Map Drawing Analyzer (GMDA; Gardony et al. 2016, see below).

Procedures

Participants were tested individually in separate rooms with up to 10 individuals for a single testing session. After reading and signing the consent form, individuals practiced navigating within the virtual environment by completing a five landmark-to-landmark navigation practice. Participants navigated by using the mouse to look in the direction they wanted to move and the upper arrow key on the right side of the keyboard to move forward in that direction.

Next, participants performed the Learning Phase. During the Learning Phase, individuals navigated through a 3D, first-person perspective in an urban virtual environment. In this landmark-to-landmark learning task, participants were instructed to navigate between successive landmarks in an unknown environment (e.g., "You have reached the MARKET, now head to the HOSPITAL"); in doing so, they learn about the environment's landmarks and layout (e.g., Brunye et al. 2012). Landmarks were clearly marked with their names (e.g., HOSPITAL). Participants navigated to 21 landmarks during this Learning Phase. After arriving at each landmark, participants rated how "Time Pressured" they felt, using a Likert rating scale of 1–7, with one indicating feeling no time pressure and seven indicating feeling the most time pressure.

After finishing the Learning Phase, individuals completed the Edinburgh Handedness Inventory (EHI; Oldfield 1971) and two distractor questionnaires (not reported here, see Propper et al. 2018) the order of presentation of which was randomized. As per Propper et al., we used the EHI version as recommended by Edlin et al. (2015), using the five-point response scale and the modified items endorsed by Christman et al. (2015).

Next, participants completed the Test Phase using the GMDA (Gardony et al. 2016). During the Test Phase, participants were presented with an accurate over-head view of the map through which they had previously navigated, and a list of the 21 locations they visited. They were asked to place the location names on the map, by dragging-and-dropping them with the mouse, in the location they believed they belonged. If they did not recall having navigated to a location, they were told not to include it on the map. On the displayed map, all location names and labels were absent, and this bird's eye perspective retained both categorical and coordinate spatial information about the locations.

Note that by placing the locations on the map, we are able to extract both categorical and coordinate information from the locations (see Gardony et al. 2016). Furthermore, the measures analyzed (see below) are not impacted by the number of items recalled; that is, by having participants only place items that they recalled having seen previously, we (1) have a measure of recall (e.g., the absolute number of items placed on the map out of the 21 total) and (2) can examine categorical and coordinate performance in the absence of the impact of recall ability. To further explain, recall ability does not differentially affect categorical or coordinate performance estimates since these measures are only derived from data pertaining to landmarks that were recalled and are relative to each other. We examined absolute recall for the landmarks as a function of Handedness in a different analysis (see below).

Completion of the Test Phase was followed by, in a randomly presented order, the Game Engagement Questionnaire (GEQ; Brockmyer et al. 2009), the Santa-Barbara Sense of Direction Scale (SBSDS; Hegarty et al. 2002), a Landmark Confidence Scale (LCS), and a Strategy Questionnaire (SQ). See Propper et al. (2018) for detailed description of these questionnaires.

Participants were then given the opportunity to have questions answered, thanked, and dismissed.

Data analyses

Handedness

To replicate Propper et al. (2018), CRH was defined as + 85 and above on the EHI, and ICH as + 80 to − 80.

Spatial task performance

To score map drawings, we used the Gardony Map Drawing Analyzer (GMDA) (Gardony et al. 2016) as described above. We used this software to provide a rapid, standardized analysis of landmark locations. Three measures of map drawing accuracy were considered. First, because participants tend to omit landmarks from drawings, we assessed the number of landmarks that was never placed on the map, providing a simple measure of landmark recall as a function of Handedness. Second, we assessed the canonical accuracy of landmarks placed on the map, which provides information regarding the accuracy of relative landmark positions (e.g., Landmark A is north of Landmark B). Because it is not possible to assess the positional accuracy of undrawn landmarks, this measure only assesses the relative positional accuracy of drawn landmarks (i.e., it is output-bound), a measure of categorical knowledge. Third, we complement the canonical accuracy measure by calculating distance accuracy of landmarks placed on the map, which provides information regarding the absolute positional accuracy of each landmark relative to its originally learned location (e.g., Landmark A is 57 pixels from its originally learned location), a measure of coordinate spatial knowledge. For a more detailed description of these measures and their calculations, see Gardony et al. (2016).

Given the results of Propper et al. (2018), we performed one-tailed t tests to assess whether ICH outperform CRH on categorical and coordinate performance, using canonical accuracy and distance accuracy, respectively. We also conducted an unpaired *t* test as a function of Handedness examining number of locations placed on the map, a measure of recall. In addition, correlation analyses were conducted to examine the relationship between canonical accuracy and distance accuracy and whether there were differences in the strength/direction of this relationship based on Handedness.

Questionnaires

The SBSDS, GEQ, the amount of time pressure felt, and the LCS were examined via one-tailed, unpaired *t* tests, with Handedness as the independent variable. Performance on the GEQ and SQ was analyzed using chi-square analyses where appropriate.

Results

Handedness

Three individuals scoring −85 or below, and therefore classified as consistent-left-handers (CLH), were removed prior to analyses, replicating Propper et al. (2018). Four individuals' total number of recalled landmarks (the number of items placed on the map during the Test Phase) fell two standard deviations below the sample mean ($\bar{X}$ = 17.16, sd = 4.66) and were excluded. Final N = 60 (CRH n = 18, EHI $\bar{X}$ = 94.72; ICH = 42, EHI $\bar{X}$ = 45.60).

Spatial task performance

CRH did not differ significantly from ICH in either canonical accuracy [CRH $\bar{X}$ = .56, sd = .18, ICH $\bar{X}$ = .61, sd = .14; t(58) = −1.21, one-tailed p = .12, Cohen's d = .32] or distance accuracy [CRH $\bar{X}$ = .80, sd = .03, ICH $\bar{X}$ = .80, sd = .04; t(58) = .46, one-tailed p = .33, Cohen's d = .13]. CRH ($\bar{X}$ = 17.44, sd = 3.60) did not significantly differ from ICH ($\bar{X}$ = 18.38, sd = 2.58) on number of landmarks recalled; t(58) = −1.14, one-tailed p = .17, Cohen's d = .30. Additionally, CRH ($\bar{X}$ = 3.22, sd = 1.41) did not differ from ICH ($\bar{X}$ = 3.05, sd = 1.02) in feelings of time pressure [t(58) = .52, one-tailed p = .31, Cohen's d = .13].

Regarding correlations between canonical and distance accuracy, a significant positive correlation was found (r = .78, p < .001; see Fig. 1). In separate correlation analyses, the CRH and ICH groups' canonical and distance accuracy scores were significantly positively correlated (CRH r = .80, p < .001; ICH r = .82, p < .001). These correlations did not significantly differ from each other (p = .42).

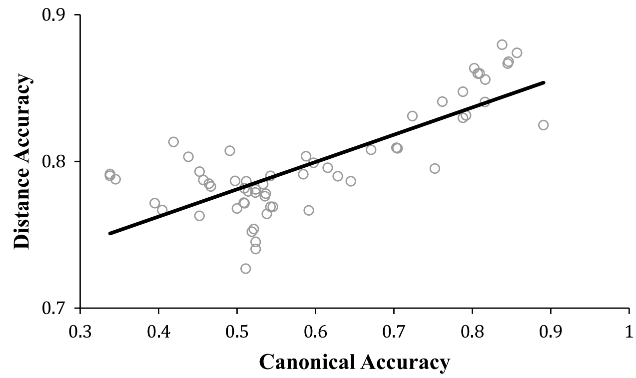

Fig. 1 Relationship between canonical accuracy and distance accuracy. There is a significant, positive correlation between canonical accuracy and distance accuracy (r = .78, p < .001). The graph above depicts this relationship for the entire sample; N = 60

Questionnaires

SBSDS scores were not significantly different between CRH ($\bar{X}$ = 4.04, sd = 1.31) and ICH ($\bar{X}$ = 4.32, sd = 1.21); t(58) = −.78, one-tailed p = .22, Cohen's d = .22. Eight participants had at least one missing LCS rating; these participants were removed from the sample prior to LCS score analysis. LCS scores were also not significantly different between CRH ($\bar{X}$ = 1.14, sd = .45) and ICH ($\bar{X}$ = 1.12, sd = .41); t(50) = .16, one-tailed p = .44, Cohen's d = .05). On the SQ, no differences were found between the Handedness Groups on whether a strategy was used, how often a compass was used, or how often the compass was used as a navigation aid (χ^2, p > .10 for all comparisons, Cramer's V = .03, .20, and .06, respectively). CRH ($\bar{X}$ = 1.74, sd = .76) and ICH ($\bar{X}$ = 2.12, sd = .92) groups did not significantly differ on the GEQ [t(58) = −1.55, one-tailed p = .07, Cohen's d = .45]. Additionally, participants in the ICH and CRH groups did not differ in whether they considered themselves to be a video game player [χ^2(1) = .26, p = .61, Cramer's V = .07]. See Table 1 for all means and standard deviations as a function of Handedness.

Discussion

Although categorical and coordinate spatial processing here were not significantly different between Handedness groups, there are several potential explanations for this finding. From a practical perspective, in order to attempt replication of Propper et al., here ICH and CRH were categorized based on that study's median EHI score. In the present study, however, the median was considerably lower (+75). It is therefore possible that the very different 'n's per handedness group (ICH being twice as numerous and CRH) contributed to the lack of significance. We would like to point out that we did

Table 1 Mean, standard deviations, and effect sizes, for dependent measures as a function of handedness

Comparison	CRH $n=18$ Mean (*sd*)	ICH $n=42$ Mean (*sd*)	Cohen's *d*
Canonical accuracy	.56 (*.18*)	.61 (*.14*)	.32
Distance accuracy	.80 (*.03*)	.80 (*.04*)	.13
Landmarks recalled	17.44 (*3.60*)	18.38 (*2.58*)	.30
Time pressure	3.22 (*1.41*)	3.05 (*1.02*)	.13
SBSDS	4.04 (*1.31*)	4.32 (*1.21*)	.22
LCS[a]	1.14 (*.45*)	1.12 (*.41*)	.05
GEQ	1.74 (*.76*)	2.12 (*.92*)	.45

[a]Note that ns for LCS were CRH = 15 and ICH = 37. See text

indeed examine all the dependent measures using the present study's median as the categorization point, and in all cases the results maintained non-significance ($p > .1$). However, it may be that underlying cortical differences between handedness groups, and subsequent cognitive differences, exist when handedness dichotomization occurs above + 80 (see Prichard et al. 2013). Furthermore, post hoc analyses on achieved power in *t* test analyses ranged from .07 to .47, suggesting that the present study was considerably underpowered, thereby reducing the likelihood of obtaining significance.

It is important to note that the effect sizes were small, but suggestive, of meaningful differences, for measures of spatial processing, with $d = .30$ for number of landmarks recalled and $d = .32$ for coordinate processing. Also of note is that these results were numerically in the predicted direction for both these measures (see Table 1). These findings suggest that handedness differences in spatial processing may in fact exist, and such a hypothesis can be examined in the future by increasing sample size. We did not replicate the previous finding of increased confidence in ICH compared with CRH, nor did we replicate superior coordinate processing in ICH compared with CRH. This may reflect the underpowering of our analyses and/or the lower median here, though this is not clear.

From a theoretical perspective, the testing procedures used here minimized language coding of spatial information, whereas in Propper et al. (2018), testing conditions may have inadvertently encouraged language-based coding of the previously learned spatial information. Given the substantial literature demonstrating superior memory for language-based information in ICH relative to CRH (see Prichard et al. 2013, for review), the former study may have inadvertently biased testing procedures such that individuals with superior recall for language-based information, or for transforming spatial information into language, would outperform other individuals. Future work could directly examine this hypothesis.

There were no differences between groups, or overall, in the relationship between categorical and coordinate task performance. Performance on one measure was strongly correlated with performance on the other. Although certainly not definitive, this finding suggests that categorical and coordinate processing may in some instances share a common neurological process or structure, and that this process/structure is not one that is different as a function of Handedness. In fact, there is some evidence that categorical processing may be necessary for the formation of coordinate information (Niebauer 2001). In a series of experiments, Niebauer (2001) reported facilitation of coordinate information with prior exposure to categorical information, but not vice versa. Results were interpreted as suggesting the possibility that coordinate information is a subset of categorical information. If so, then it is likely that there are indeed shared neurological processes or structures between these two types of spatial processing.

In sum, caution is suggested in interpreting the results in relation to previous work. Note that this is a cross-experiment comparison; participants were not randomly distributed between this and the previous research, and so there is the possibility that there are subject differences between these studies. We also did not explicitly manipulate language coding as a factor here; future work might do so to examine the hypothesis that language coding mediated the superior spatial performance of the ICH in the previous research. Although not significant, the results are in the same direction as those reported in our previous study, suggesting that the current work may be underpowered, thereby increasing the possibility of a Type II error.

Finally, given the potential replication crisis in Psychology (see Pashler and Wagenmakers 2012, for a brief overview of the issues involved), we believe it is important to acknowledge and publish findings that are not directly supportive of previously published research, even if that research is our own. Such an orientation can only enhance our understanding of Psychology principles and of science generally.

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Compliance with ethical standards

Conflict of interest All authors declare that there are no conflicts of interests.

Ethical approval This article does not contain any studies with animals performed by any of the authors.

Human and animal rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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