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Influence of Ethnicity, Gender and Answering Mode on a Virtual Point-to-Origin Task

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ABSTRACT

The study investigated the turner and non-turner phenomenon reported in [**Klatzky et al.**, 1998], [**Gramann et al.**, 2005], and [**Riecke**, 2008] using a virtual point-to-origin task. There are three main goals of the study: replicate the gender effect found by [**Goeke et al.**, 2013]; extend the effect, found by [**Avraamides et al.**, 2004], of higher turner numbers with spatial language, opposed to pointing, response mode; examine ethnicity influence on turner and non-turner behavior. The experiment was designed as a classroom study with a high number of participants ($n = 498$). We presented participants with four short passages through a virtual star field where, at the end, participants selected the direction pointing back to the origin from four multiple-choice items. There were two different response sheets: pictograms and written language. After the experiment, participants filled out a demographics questionnaire. A majority of participants (44.78%) was classified as non-turners, while 25.3% were turners and 18.88% had no preference. A multinomial regression model with variables, condition, and all interaction terms was fitted. Classification performance reached 49%, and two main factors (Ethnicity and Condition) and two interaction terms (Ethnicity: Condition and Condition: Gender) were significant. Odds ratios showed that written spatial language, compared to pictograms, made the turner strategy more likely. The effect was more pronounced for Chinese subjects and among females, and was not significant for male Caucasians. We extended the findings of [**Avraamides et al.**, 2004], showing higher numbers of turners when using spatial language instead of pointing. Unlike [**Goeke et al.**, 2013], influence of gender was not significant. We found that ethnicity has an influence on turner and non-turner behavior. Caucasians, especially males, are a special subpopulation when it comes to point-to-origin tasks in virtual environments, having a comparably high ratio of turners to non-turners.

Keywords: spatial navigation, reference frames, path integration, navigational strategies, gender differences, ethnicity differences

1 INTRODUCTION

We are able to navigate and orient ourselves effortlessly through the world. Yet, when we put ourselves in a virtual world navigation becomes cognitively demanding. Why the discrepancy? Normally we rely on vision, audition, vestibular, and proprioceptive input to automatically guide us and update our position.

We use two distinct reference frames: egocentric, self-to-object representation, and allocentric, object-to-object representation. We are forced to exclusively use our egocentric reference to navigate in the real world. Forming and maintaining spatial representations is hard to suppress, and ignoring it takes conscious cognitive effort [**Riecke et al.**, 2005]. Yet, when we imagine the same path, we tend to use a mixed strategy to determine where we are. During navigation, spatial representations are not only constantly updated and maintained in parallel but also interact [**Moser et al.**, 2008]. When exactly we use a specific reference frame for a certain task remains a difficult question because individual proclivities come into play [**Gramann**, 2013].

Spatial navigation is a deep rooted and modularized cognitive skill based on spatial representations that are automatically formed and maintained (updated) in specialized brain areas based on multimodal sensory information. Different reference frames for spatial orientations seem to be processed in distinct neural correlates [**Gramann et al.**, 2010; **Zaehle et al.**, 2007]. The sensory information from all senses is automatically combined into a spatial representation in the brain involving a wide network of brain regions (for a review see **Moser et al.** [2008]). However, there are times when spatial updating fails, especially when we receive incomplete or contradicting sensory information. In such cases, we revert to offline strategies where we try to cognitively restore our spatial representations. These offine strategies enable researchers to study the mechanism of spatial updating in more detail: when is spatial updating automatic and obligatory, and when does it brake down? What factors decide which reference frame we use for our spatial representation?

Researchers have discovered a phenomenon involving spatial updating and spatial representations in different reference frames [**Klatzky et al.**, 1998] where, in a point-to-origin paradigm, participants experienced a virtual visual flow environment. Here, the turner group used an egocentric reference frame updated during the trajectory and the non-turner group responded as if they were still facing the original direction they started. However, those using the non-turner strategy solved the task correctly based on their strategy, applying an allocentric reference frame that stays constant throughout the trajectory. The advent of virtual reality (VR) technology gave researchers the opportunity to create experiments where the availability and fidelity of visual, vestibular, proprioceptive and auditive information channels can be controlled separately in a highly controlled way. This enables researchers to systematically dissociate the different influences of the modalities on complex tasks like spatial navigation.

Previous studies have looked at the individual factors that may influence the strategy used for spatial updating in a virtual point-to-origin task, such as gender, video gaming experience, ethnicity, response mode, navigation skills, cardinal direction proficiency, and decision certainty [**Goeke et al.**, 2013; **Avraamides et al.**, 2004; **Riecke**, 2008]. Gramann hypothesized that non-turners respond as if they had not turned and are still facing the original direction. Participants solved the task in a more abstract and disembodied way, applying an allocentric reference frame that stayed constant during the passage. Thus, what was thought to be an error in solving the task turned out to be a different strategy, where the answer is expressed in a different reference frame. [**Avraamides et al.**, 2004] showed that an increased error (corresponding to non-turner behaviour) did not arise when participants performed an imagined triangle completion task and answered using spatial language instead of pointing. The researchers concluded that the non-turner answers in the pointing condition are due to the strong attachment of the pointing gesture to the current perceived body position, that is, aligned with the hypothetical allocentric reference frame.

Avraamides' hypothesis is notably different from the one used by Gramann. While they both agree that participants giving turner answers update their egocentric reference frame according to the given stimulus (i.e., imaginary walking, visual flow, etc.), they have different explanations for the non-turner answers. Gramann explains non-turner behaviour as a different strategy of solving the task using an allocentric reference frame. Avraamides sees non-turner answers as an artifact of the task, namely the conflict between a virtual body orientation and a physical body orientation. Here, non-turner answers are not valid answers in an allocentric reference frame but errors due to an overriding of the virtual egocentric reference frame with a physical egocentric reference frame. However, he found this conflict is not present when spatial language is used to give the answers. Avraamides explains non-turner behaviour with a more abstract and less embodied nature of spatial language compared to bodily pointing; this strategy might be closer to a more cognitive representation of heading. To enable a neutral discussion of the phenomenon, in this study we will use the terms turner and non-turner referring only to behavioural observation - whether participants incorporated the virtual turn in their response or not without making an implicit assumption of which reference frame they use.

Several other studies (see Table 1) have investigated individual factors determining strategy selection, but no coherent picture has emerged. Individual proclivities seem to have a significant influence on strategy selection [**Gramann**, 2013], so we may be able to observe similar influences for automatic spatial updating, e.g., a more prominent use of a turner strategy in studies with naturalistic scenes and vestibular input [**Sigurdarson et al.**, 2012]. The first big cross-sectional study investigating the turner and non-turner phenomenon was an online study conducted by [**Goeke et al.**, 2013]. Their sample contained (after preprocessing) 260 participants from 15 countries, with the majority from Spain and Germany. The task contained left right (yaw) turns as well as up and down turns (pitch). Answers were given via selecting one of four 3D arrows. In their analysis they found the factors gender, cardinal direction proficiency and decision certainty to be significant factors determining turner and non-turner behaviour, though this was not the case for self-estimated general navigation skills or video gaming experience. Overall, it seems that a multitude of known and unknown factors influence strategy use, leading to partially widely varying ratios of turners to non-turners in different studies.

One factor yet to be investigated is potential infuence of ethnicity on virtual navigation strategy. A large body of literature has well established the link between culture and cognitive style [**Kitayama and Cohen**, 2010; **Kitayama et al.**, 2009; **Norenzayan et al.**, 2007; **Varnum et al.**, 2008]. Western cultures, such as the United States, tend to exhibit a more independent and analytic social orientation: emphasizing uniqueness, having relatively low sensitivity to social cues, and encouraging behaviours that affirm autonomy. On the other hand, other cultures such as China tend to exhibit a more interdependent and holistic social orientation: emphasizing harmonious relations with others, promoting sensitivity to social cues, and encouraging behaviours that affirm relatedness to others [**Kitayama and Cohen**, 2010; **Varnum et al.**, 2010]. On the basis of such evidence, the link between social orientation and cognitive style has been widely accepted. [**Goeke et al.**, 2013] suggest looking at cultural background on reference frame proclivity to finally unravel the underlying factors determining human navigation strategies.

Table 1. An overview over turner studies, the used parameters and the percentage of turners ordered by the latter

			context		sensory information						
study	condition	n	answer	scene	visual	proprio-ceptive	vesti-bular	visual	horizontal resolution	FOV	**% of turners**
Klatzky et al. [1998]	blind walking	10	point	blind	no	yes	yes	blind	0	0	**100**
Klatzky et al. [1998]	HMD & Turn	10	point	starfield	yes	no	yes	HMD	800	44x33	**100**
Avraamides et al. [2004]	verbal	20	describe	blind	no	no	no	blind	0	0	**100**
Riecke and Wiener [2007]	standard	20	point	plane	yes	no	no	Projector	1400	84x63	**45**
Sigurdarson et al. [2012]	real turn	12	point	naturalistic	yes	no	no	HMD	800	32x24	**83**
Sigurdarson et al. [2012]	visual turn	12	point	naturalistic	yes	no	yes	HMD	800	32x24	**83**
Riecke [2008]	standard	16	point	ground plane	yes	no	no	Projector	1400	84x63	**62**
Riecke [2008]	angle announced	24	point	ground plane	yes	no	no	Projector	1400	84x63	**54**
Plank et al. [2010]	standard	37	select	tunnel	yes	no	no	Projector	800	41x41	**54**
Gramann et al. [2010]	standard	12	select	tunnel	yes	no	no	Projector	?	41	**52**
Gramann et al. [2012]	Experiment 2	11	select	starfield	yes	no	no	Monitor	?	47x35	**50**
Gramann et al. [2005]	all conditions	43	select	tunnel	yes	no	no	Monitor	?	?	**47**
Goeke et al. [2013]	online	260	select	starfield	yes	no	no	Monitor	1024	?	**37**
Chiu et al. [2012]	standard	20	adjust	tunnel	yes	no	no	Projector	?	206	**35**
Klatzky et al. [1998]	only HMD	10	point	starfield	yes	no	no	HMD	?	44x33	**0**
Avraamides et al. [2004]	Imagine & walk	20	turn	blind / real	yes	no	no	blind / real	0	0	**0**

We have three goals: 1. Replicate the gender bias found in [**Goeke et al.**, 2013]. We hypothesize, based on the literature, females are more likely to be non-turners compared to males. 2. Extend the findings of **Avraamides et al.** [2004], predicting a higher amount of turners when spatial language, opposed to pointing, is used. We will use written spatial language vs. pictograms. 3. Investigate a possible influence of ethnicity on strategy selection.

To answer these three questions, we designed our study with the idea of having a very large sample size to cope with intrinsically noisy strategy classification data and high individual differences. We used a design that could be executed with many participants simultaneously, showing the stimulus on a projector and recording the answers via a paper questionnaire. This way, we were able to perform the experiment in lecture halls at the beginning of regular courses. We chose a small number of trials, since earlier studies have shown that strategies are relatively stable over time [**Goeke et al.**, 2013]. As a consequence of the study design, we could not directly employ the same answering modes as in **Avraamides et al.** [2004]. Instead, we used pictograms for the more embodied version and written spatial language for the equivalent of description on spatial language. We are aware that these answering modes are somewhat more abstract that the ones used by Avraamides and, thus, expect weaker effects.

2 MATERIAL & METHODS

2.1 PARTICIPANTS

A total of 507 participants took part in the study: 228 female, 273 male, and 6 NA. Participants with missing gender or ethnicity data were cut out (n = 6). The average age was 20.5 years (SD = 3.2). We recruited a diverse spectrum of participants from 3 universities: Simon Fraser University (244 participants) and the University of British Columbia (183 participants) both in Vancouver, Canada, and the University of Osnabrück in Germany (104 participants). An effort was made to recruit a sample with high ethnic diversity (see Fig. 1). Participants were not reimbursed.

2.2 STIMULUS & APPARATUS

Participants were shown a passage through a virtual starfield, providing optical flow without any landmarks. Trajectories consisted of an initial straight path, followed by a curve and a second straight path at the end. Curve angles used for the four trials were $60°\ left$, $90°\ right$, $90°\ right$ and $60°\ left$, respectfully (paths are illustrated in Fig. 2). The velocity profile was smoothed to make the stimulus less artificial and prevent nausea. The first linear part included a $1s$ linear acceleration phase with $10\frac{m}{s^2}$, followed by a constant movement with $10\frac{m}{s}$ for $2s$. The turn was divided into an accelerating half and a decelerating half, the constant acceleration being $15\frac{°}{s^2}$, resulting in an overall turn time of $4s$ for $60°$ and $5s$ for $90°$. The second linear part consisted of a $3s$ constant linear movement and $1s$ deceleration - slightly longer than the first part.

Velocities and distances are abstract in a starfield environment and subjective perception highly depends on the starfield parameters chosen (star size, area and visibility range). Passages were programmed using *Vizard 4.0*. Code for the pre-study can be found online (`http://github.com/leftbigtoe/starfield`) and can be executed with the free trial version of *Vizard 4.0*.

Answers were given via a multiple choice questionnaire (see supplemental material). For each trial of the point-to-origin task, the same four possible answers could be selected: front left, front right, back left, and back right for both the textual condition and the pictorial condition. For each trial, the sequence of items was randomized to avoid answering tendencies. The response form was folded and sealed with tape, with the demographic information questionnaire inside to prevent possible task performance bias. The stimulus was shown on classroom projectors and lights were dimmed where possible. Participants were asked to group as closely as possible around the projector to minimize extreme viewing angles.

2.3 PROCEDURE

The experiment took place either at the beginning or at the end of the classes. The lecturer introduced the experimenter, followed by distribution of informed consent forms. All students volunteering to participate signed the consent form and were randomly handed a pictorial or text condition response form. The experimenter then explained the task until no subject had further questions. Participants were asked to select the answers as quickly and intuitively as possible. They were also asked not to copy from their neighbours or discuss their answers until after the experiment. Trials were shown to the class, pausing after each trial until everyone finished. No questions were answered that could provide feedback. After completing the task, the room was illuminated again and participants were asked to open their forms and fill out the demographics questionnaire. In total, the experiment took approximately 10 minutes.

2.4 PREPROCESSING

Before the analysis, preprocessing was performed on the collected data. Only participants who provided data for ethnicity and gender, and had no missing answers for the navigation task were used ($n = 6$ participants excluded). For each trial, strategy was classified (turner, non-turner, frontal pointing 1 or frontal pointing 2), in accordance with previous studies (e.g., **Goeke et al.** [2013]), where participants were classified as users of the respective strategy based on consistent strategy use in 75% of the trials. All others were classified with no preference. Frontal pointing 1 occurs when participants choose a response in the direction of the turn, and frontal pointing 2 occurs when participants choose a response in the opposite direction of the turn. Only three participants were classified as frontal pointing 2 users and, because no explanation could be given to this answering pattern, those answering patterns were considered to be due to inattentiveness. We excluded participants classified as frontal pointers 2 from further analysis due to sparseness of data ($n = 3$ participants excluded). Statistical analysis was performed with the remaining $n = 498$ participants.

2.5 DATA ANALYSIS

R 2.15.2 was used for data analysis. A multinomial regression model was used for statistical analysis and a likelihood ratio test of the parameters was done using an ANOVA.

3 RESULTS & DISCUSSION

3.1 GENERAL RESPONSE BEHAVIOUR

Total counts of responses over the trials (see Fig 3) shows relatively stable strategies, the two most prominent being non-turner answers (48.35%) and turner answers (32.93%). A smaller amount of participants gave frontal pointing responses, mainly frontal pointing 1, in the direction of the turn (15.57%). Very few frontal pointing 2, in the opposing direction of the turn, were given (3.14%). While non-turner and turner answers were correct and expected, both types of frontal pointings were thought to be distractors. That is, they were not correct in either reference frame. However, a frontal pointing in the direction of the turn (frontal pointing 1) could be explained in two possible ways. First, by a turner who overestimated the turn (i.e., over $135°$). In this case, the starting point is in the frontal hemisphere. Second, participants misunderstood the task and pointed from the starting to the end point; this was reported by a few participants after the experiment. For a frontal pointing in the opposite direction of the turn (frontal pointing 2) no possible explanation could be found. We, therefore, assume them to be a wrong answer due to inattentiveness or distraction, sinse frontal pointing 2 does not seem to be a very stable strategy: 36 participants (7.19%) gave a frontal pointing 2 answer once, 8 participants (1.6%) gave it more than once, and only 3 participants more than twice (0.6%).

The overall counts of classification according to the 75% criterion (participants that used the same strategy in 75% of the trials) can be seen in Fig. 4. As expected, the two most prominent classifications were non-turner (44.78%) and turner (25.3%). 11.04% were classified as frontal pointing 1 users and only 0.6% had frontal pointing 2 as their preferred strategy. 18.88% of the participants did not show a clear preferred strategy and were classified with no preference. Evident in this overview is the high amount of non-turners in the pictorial condition compared to the text condition, and the high amount of male Caucasian turners, especially in the pictorial condition.

3.2 MULTINOMIAL REGRESSION MODEL

For statistical analysis a multinomial regression model was fitted. We included the factors condition, ethnicity, gender, and all interaction terms to model the preferred strategy. Accuracy of the model on the training data was 49.0% compared to 25% chance level. The precise parameter values can be found in Table 2.

Table 2. Parameter values and standard errors of all parameters of and each respective outcome compared to the strategy baseline no preference

	non-turner		turner		frontal pointing 1	
Parameter	Estimate	SE	Estimate	SE	Estimate	SE
(Intercept)	1.15	0.434	0.251	0.504	-0.847	0.69
EthnicityChinese	-0.0136	0.566	-0.944	0.744	0.847	0.822
EthnicityOther	-0.0469	0.58	-1.06	0.784	0.847	0.836
ConditionText	-0.452	0.699	0.704	0.729	-0.763	1.29
GenderMale	-0.766	0.564	0.516	0.605	-1.02	1.03
EthnicityChinese:ConditionText	-0.998	0.915	0.156	0.999	-0.249	1.49
EthnicityOther:ConditionText	0.453	1.04	0.396	1.21	-12	0.66
EthnicityChinese:GenderMale	1.35	0.787	0.0226	0.988	0.87	1.25
EthnicityOther:GenderMale	1.05	0.821	0.701	1	1.31	1.25
ConditionText:GenderMale	0.508	0.876	-0.824	0.884	1.85	1.6
EthnicityChinese:ConditionText:GenderMale	-0.775	1.24	0.119	1.35	-1.37	1.94
EthnicityOther:ConditionText:GenderMale	-1.08	1.39	-0.276	1.56	10.4	0.66

Likelihood ratio tests on the regression parameters revealed that the parameters ethnicity ($p_{chi^2} < 0.001$) and condition ($p_{chi^2} < 0.001$) were highly significant. Further, the interaction terms ethnicity & condition and condition & gender were found to be mildly significant ($p_{chi2} < 0.05$). In contrast to earlier studies [**Goeke et al.**, 2013], gender was not found to be significant at all. For an overview see Table 3.

Table 3. Model parameters of the multinomial regression models

Parameter	LR chi^2	df	p_{chi^2}	
Ethnicity	26.8880	6	0.0001520	***
Condition	17.9785	3	0.0004444	***
Gender	2.1589	3	0.5400950	
Ethnicity:Condition	14.3335	6	0.0261252	*
Ethnicity:Gender	5.9970	6	0.4235304	
Condition:Gender	7.9853	3	0.0463172	*
Ethnicity:Condition:Gender	2.8220	6	0.8308366	

3.3 BOOTSTRAP CONFIDENCE INTERVALS FOR MODEL PERFORMANCE

To further judge the accuracy, a bootstrap analysis was conducted. For a review on bootstrap methods see [**Efron and Tibshirani**, 1986]. Two kinds of bootstrap models were created: a naive one creating random classifications for every participant with uniform probability and one where the probability of the classifications were weighted based on the observed strategy counts. 10000 random classifications were created for each model and the confidence intervals calculated. The accuracy of our model lay outside of both bootstrap confidence intervals (naive: 23.5% - 28.7%, weighted: 29.7% - 35%) indicating a decent fit. A further observation is that the model only made two classifications, non-turner or turner, but never frontal pointing 1 or no preference. This inability of the model to discriminate between all four strategies and the emergence of turner and non-turner as main strategies indicates some correlation between some of the strategies. No preference and frontal pointing 1 both seem to be correlated to one of the main strategies instead of being independent strategies. However, the fact that there is more training data for the turner and non-turner classifications could possibly account for some of the bias of the model.

3.4 ODD RATIOS

From the regression parameters of the multinomial regression model, we directly calculated the odd ratios (ORs) for more detailed interpretation of the results. Odd ratios quantify the correlation of two variables appearing together and they are calculated by dividing the number of occurrences that a participant has a given b (the odds of a given b) divided by the number of occurrences of a given not b. An OR greater 1 shows a positive correlation of a with b while an OR smaller one indicates a negative correlation. ORs equal 1 mean no correlation.

In multinomial regression models, parameters with more than two factors are dummy coded as dichotomous variables and comparisons are always performed by using one of two possible values for a factor as baseline and comparing it against the other value. To capture all effects, a model was created for every possible combination of base cases and all significant odd ratios were extracted (Wald confidence intervals that did not contain 1). Note that changing the baseline values does not change the overall performance of the model, rather, it "phrases the result in a different way". Due to the dichotomous dummy coding there is also a mirror symmetry among the reported effects (e.g., OR text makes turner instead of non-turner more likely and OR pictorial makes non-turner instead of turner more likely). This symmetry is also nicely visible in the plots. We reported both ways to avoid introducing a bias by leaving too much implicit. In the next step, all odd ratios with values under 0.001 and over 100 were excluded. Those ORs were highly likely to be artefacts of sparse data, having huge confidence intervals, indicating their unreliability. Following, only ORs greater than one will be shown. Due to the dichotomous dummy coding of parameters, every effect indicating x to be less likely for a certain parameter having value b also means x is more likely if that parameter has its other possible value a. To avoid redundancy, we will only present ORs greater than one. ORs are plotted in Fig. 5.

Ethnicity: (see Fig. 5 A) All Ethnicity effects were found with the pictorial condition as baseline. Chinese and Other Ethnicities were more likely to be frontal pointers 1 instead of turners, compared to male Caucasians (Chin. OR: 14, Other E. OR: 12.45) and female Caucasians (Chin. OR: 6, Other Ethnicity OR: 6.75). Further, compared to male Caucasians, Other Ethnicities were more likely to be non-turners instead of turners (OR:3.93). Chinese males were non-turners instead of no preference (OR: 3.81) or turners (OR: 9.58). Vice versa, Caucasians were more likely to be turners instead of front pointers 1, compared to Chinese (male OR: 13.99, female: 6) or Other Ethnicities (male OR: 12.45, female OR: 6.75). Male Caucasians were also more likely to have no preference (OR: 3.81) or to be turners (OR: 9.58) instead of non-turners, compared to Chinese. Lastly, male Caucasians were more likely to be turners instead of non-turners (OR: 3.93) or have no preference instead of being frontal pointers 1 (OR: 8.67), compared to males of Other Ethnicities. The effects of ethnicity again seem to be more pronounced when a male baseline is used, possibly explained by the extreme amount of male Caucasian turners. Another noteworthy observation is no significant difference between Chinese and Other Ethnicities, and their comparisons against Caucasians are quite similar. This can be interpreted in two ways: either a high similarity between the Chinese and Other Ethnicities or Caucasians are quite unusual in their navigation behaviour compared to other ethnicities. It seems unlikely that the differences might be mediated by a difference in video gaming or navigation skills, since both were not significantly different in both groups, as revealed by a Kruskal Wallis Test (self rated navigation skills $H = 0.17, df = 1, p = 0.68$ and gaming $H = 0.82, df = 1, p = 0.37$).

Condition: (see Fig. 5 B) A significant effect of the condition for Caucasians can only be observed among females (OR: 3.18), and a significant effect is present for both sexes among Chinese participants (male: 6.5, female: 10.07). In both cases, the pictorial condition makes a non-turner strategy more likely compared to a turner strategy. For Chinese participants, a non-turner strategy is also more likely compared to a no preference strategy (male OR: 5.57, female OR: 4.26). Among female Chinese, a frontal pointing 1 strategy also becomes more likely (OR: 6.5). On the other hand, the text condition has the opposite effect, rendering a turner strategy more likely in the same groups: Chinese males and females are now turners instead of non-turners (male OR: 6.5, female OR: 10.8) and have no preference instead of non-turner (male OR: 5.57, female OR: 4.26). Chinese females were also more likely to be turners instead of frontal pointers 1 (OR: 6.5). Among Other Ethnicities, no significant effects for condition emerged. Effects are stronger compared to a non-turner strategy as baseline.
We replicated the results of Avraamides and colleagues [**Avraamides et al.**, 2004], showing that the use of spatial language indeed makes turner responses more likely. Moreover, we extended the findings, showing the effect also remains present for simple multiple choice response sheets using more abstract pictograms and written spatial language for indicating the direction of origin. Interestingly, this effect is not significant in male Caucasians, which could be due to an already quite high amount of turners in this group in the pictorial condition. There was no effect within Other Ethnicities, which may be due to the heterogeneous composition of different ethnicities within this group averaging out any effects.

Gender: (see Fig. 5 C) Gender effects only emerged among the Caucasians with the pictorial condition as baseline. Here, males were more likely to use a turner strategy (OR: 3.6) and females tended more towards a non-turner strategy (OR: 3.6). In addition, a few implicit gender effects emerged, such as the stronger difference between male Caucasians and male Chinese participants compared to their female counterparts.
Against our expectations, females were not, in general, more likely to be non-turners than males, contradicting the results of [**Goeke et al.**, 2013]. Gender was not found to be a significant model parameter, and it only turned out to be significant within the interaction term of the model. Examining further, we found that the only significant OR for gender was found in comparison to the Caucasian and Pictorial baseline. All in all, our results suggest that the gender effect found in **Goeke et al.** [2013], where most participants were from Germany and Spain, could be an artefact of a very specific task and sample instead of a general bias in reference frame use.

Interactions: (see Fig. 5 D) Only the interaction between Ethnicity and Condition yielded some significant ORs. The interaction again emphasized effects already seen before: in the pictorial condition Caucasians are more likely to be turners (OR: 7.75) or have no preference (OR: 5.89), both compared to being a non-turner. The same holds for Chinese in the text condition where they are also more likely to be turners (OR: 7.75) or have no preference (OR: 5.89). Consequently, male Caucasians are more likely to be non-turners in the text condition (OR against no pref.: 5.89, OR against turner: 7.75) while the higher likelihood of a non-turner classification for Chinese males was found for the pictorial condition (same ORs). The interaction effects show common directions instead of influences of single parameters for given baselines. Chinese & text push in the same direction as Caucasian & Pictorial, towards a turner or no preference strategy, while Chinese & Pictorial and Caucasian & Text push in the other direction towards a non-turner strategy.

Another interesting observation is the effects grouping in a way where two strategies are likely to appear together, with turner and no preference on the one side and non-turner and frontal pointing 1 on the other. This connects to the emergence of turner and non-turner as main classifications of the model and its inability to make frontal pointing 1 or no preference classifications. Although the two correlating classifications do not always appear together, they never appear in different combinations. This fact was also reflected by the classification behaviour of the model, that classified data into turner or non-turner but never in no preference or frontal pointing 1. While 93% in the no preference group gave at least one turner answer, this was only the case for 31% in the frontal pointing 1 group. A possible explanation for the link between the turner and no preference strategies could be that no preference acts as a kind of pre-stage to a complete turner strategy. Participants with strong proclivities for the use of a non-turner strategy might start to partially apply a turner strategy for some of the trials. The data even suggest a temporal development in which turner responses become more frequent among participants in the no preference group, as can be seen in Fig. 6. The number of turner answers is the only one constantly growing and ends up being the most frequent question in the fourth trial. However, since the experiment only included four trials, conclusions about temporal development have to be taken with a grain of salt.

4 CONCLUSION

4.1 LIMITATIONS

The small number of trials, especially the finding about a trend towards a turner strategy within the group classified with no preference have to be taken with care. Because the study was conducted in classrooms, several limitations are present: a biased perception of the stimulus due to extreme viewing angle, interaction and copying between participants, and simple issues like lack of motivation or inattentiveness. Also, although the experimenter took care to explain the task thoroughly, not all participants perfectly understood the task as indicated by the frontal pointings 1. Nevertheless, we minimized those issues wherever possible and were able to overcome the remaining noise with a large sample size.

4.2 REVISITING THE HYPOTHESIS

Concerning the initial hypothesis of the study we can conclude the following:

Gender effects are quite limited. Our results contribute to the controversy around gender differences in spatial navigation. We could not replicate a general influence of gender as in [**Goeke et al.**, 2013]. A gender influence appeared only in the pictorial condition and, even more interesting, only among Caucasians. This may may be due to the extremely high amount of turners among male Caucasians. Sex difference in human spatial abilities are well established in the literature [**Linn and Petersen**, 1985; **Voyer et al.**, 1995], the most stable difference being found for mental rotation tasks. Here, women scored significantly worse compared to men, which was assumed to be correlated with the female bias towards the use of landmark based strategies compared to orientation based navigation strategies [**Moffat et al.**, 1998; **Dabbs et al.**, 1998; **Astur et al.**, 1998]. However, this view was somewhat challenged by Parsons and colleagues [**Parsons**, 2004], who found, that gender difference observed in mental rotation tasks vanished when a 3D virtual environment instead of a paper and pencil test was used for the task. They offered the possible explanation that it was the creation of a 3D representation from 2D drawings that actually caused or inflated the bias, not necessarily the task itself. If female participants in our study had higher difficulties in relating the 2D pictogram to the solution of the task, this could be an explaination for more female non-turners and for why this bias vanished in the text condition. Moreover, our findings might offer a possible answer for the high controversy of gender differences in earlier studies. Our results can be read in the way that those differences are not universally present gender differences ,but gender differences tied to cultural background, explaining why their presence or absence is highly dependant on the sample demographics.

It is important how the question is posed. We were able to replicate the findings of [**Avraamides et al.**, 2004] and extend them insofar as they also hold for a more abstract level were written spatial language and pictograms are used for answering instead of pointing and responding with spatial language. Our results add more evidence to the hypothesis that non-turner answers may be due to a conflict of mental orientation and current body orientation that is more severe when answering mode is more embodied.

Male Caucasians are a very specific subpopulation. Caucasians, especially males, seem to be a very specific subpopulation when it comes to virtual point-to-origin tasks. The number of male Caucasians using a turner strategy in the pictorial condition was extremely high while in all other groups the trend was exactly the other way around, strongly in favour for a non-turner strategy. This effect might have carried over to several other effects: gender effect was only observed among Caucasians, condition effect was not present for male Caucasians, and interaction effects were only present against a male baseline and in comparing Chinese and Caucasians. We currently have no conclusive possible explanation for this effect and further research is needed on this topic.

4.3 FURTHER EFFECTS

An effect not hypothesised beforehand is the co-occurrence of front pointing with non-turner strategy, and turner with no preference strategy. We concluded that the border between the main strategies non-turner and turner might be harder to draw than previously assumed, especially during the first trials of a point-to-origin task. Interestingly the trend in the no preference group went clearly towards a turner strategy. Along the lines of Avraamides hypothesis this could mean that some participants, after an initial confusion due to the conflict of actual and virtual body orientation, get to a point were they resolve the conflict and adapt the virtual orientation as the one relevant for solving the task. The fact that we observed a trend in this direction, and not towards a stable non-turner strategy, might be due to our more abstract answering modes of which none involved physical pointing, the most embodied form of answering. We considered our answering modes more in between the continuum spanned by physical pointing and verbal description with spatial language.

4.4 OUTLOOK

The search for gender differences may be a complicated quest since our results suggest an interaction with task and possibly ethnicity. Instead of directly searching for gender differences, future studies should focus on investigating these interactions and aim for demographically more diverse samples. Our work gives more evidence to the embodied reference frame conflict hypothesis of **Avraamides et al.** [2004], however further investigations are needed to determine if non-turner answers are reflecting the use of an allocentric reference frame or the use of an egocentric reference frame that is still aligned with the physical body orientation. A focused investigation of the turner and non-turner behaviour over more trials without feedback, looking for a resolution of a the hypothetical reference frame conflict might be fruitful. The newly found influence of ethnicity on the strategy selection for triangle completion tasks adds a new facet to the influence of individual proclivities, motivating more studies with demographically diverse samples to get a more complete picture.

DISCLOSURE/CONFLICT-OF-INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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FIGURES

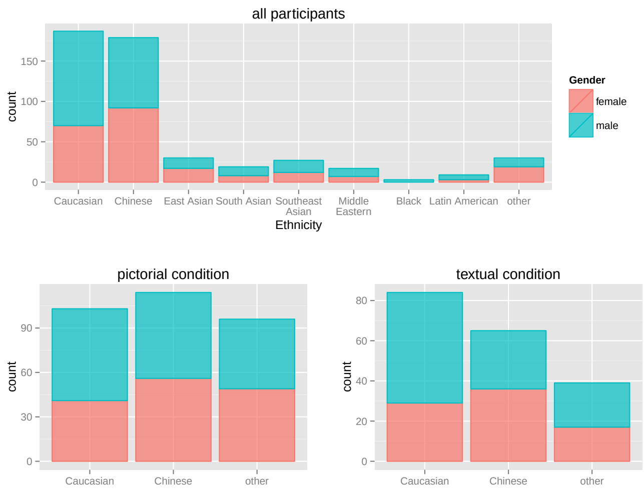

Figure 1. Demographics of the participants. The two main groups are Caucasian and Chinese, all other Ethnicities were pooled into a third group. Two thirds of the Caucasian participants were male, and for all other groups the male female ratio was one to one. This distribution is also reflected in the allocation to the two conditions (lower two plots)

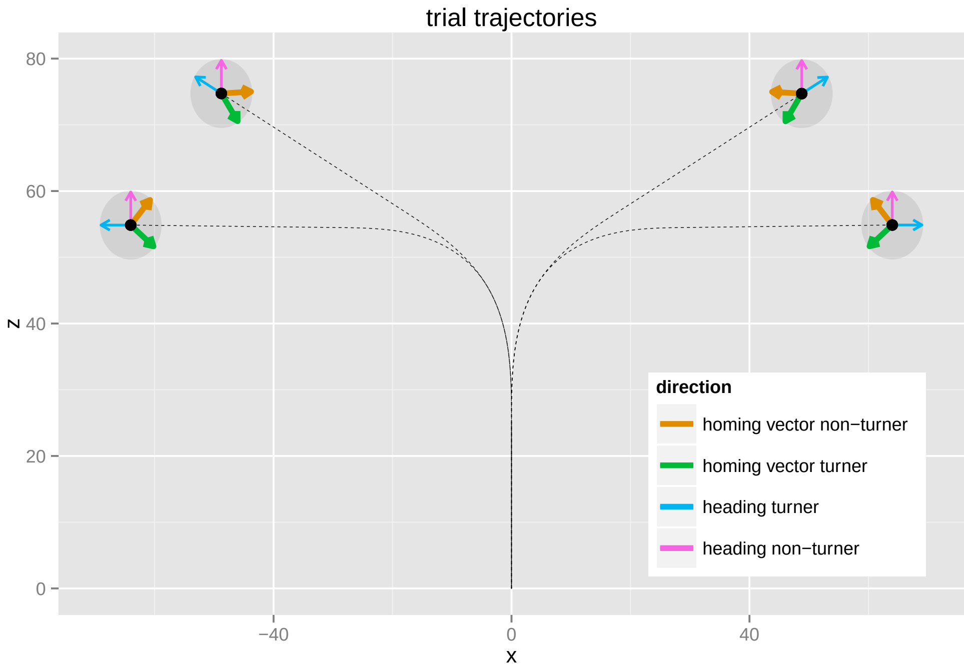

Figure 2. The trajectories of the four trials from a birds-eye-view perspective. Thin arrows are the heading at the end of the trajectory, and the thick arrows are the egocentric and allocentric homing vectors. X and Z axes are the displacement in the plane in meters.

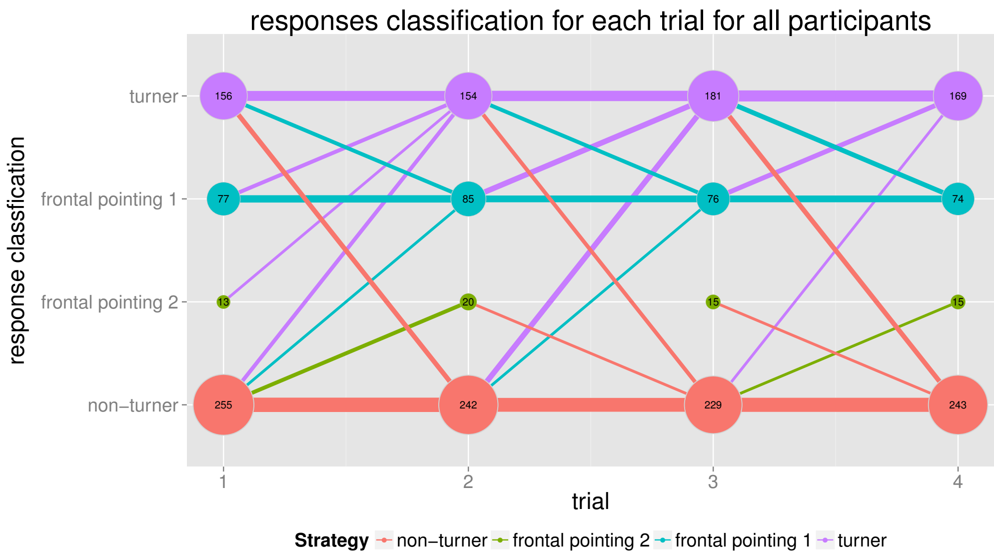

Figure 3. Total counts of answering types per trial. Y position and colour of the dots indicate the type of the answer, x position the trial and area of the dot corresponds to the count, also given by the number within the dot. The bars indicate how many changed from giving one answer type in a previous trial to which answer type in the next trial, e.g. a bar from frontal pointing 1 in trial 1 to turner indicates the amount of participants that changed from giving a frontal pointing 1 response in the first trial to a turner answer in trial 2. Thickness again stands for amount of people changing in this way. A cutoff of $n > 5$ for the bars was chosen to only show stable trends. Strategies are relatively stable. The turner strategy draws the most participants over time from all other strategies and is the only strategy that is growing overall while frontal pointing 2 is the most isolated. The interaction between frontal pointing 1 is highest with the turner answers, giving more evidence that frontal pointing one might be turners overestimating the turn. Non-turner interacts moderatly, mainly with the turner answers and the frontal pointing 2 answers

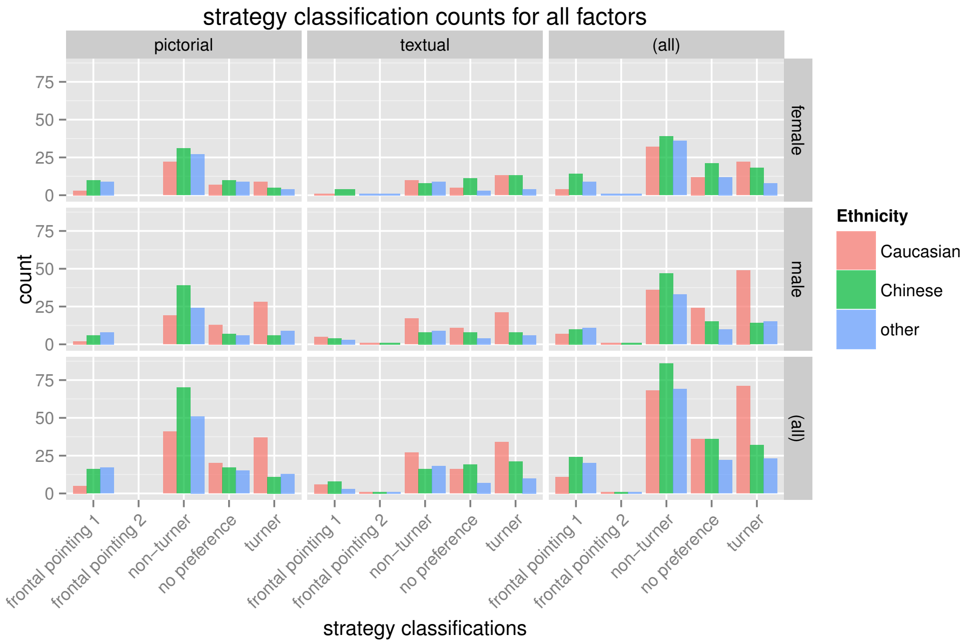

Figure 4. Total counts of preferred strategy classifications factored out into each of the model factors condition, ethnicity and gender and respective marginal sums. It can be seen that the two most dominant classifications were turner and non-turner followed by no preference, while the frontal pointing classifications, especially frontal pointing 2, were quite rare.

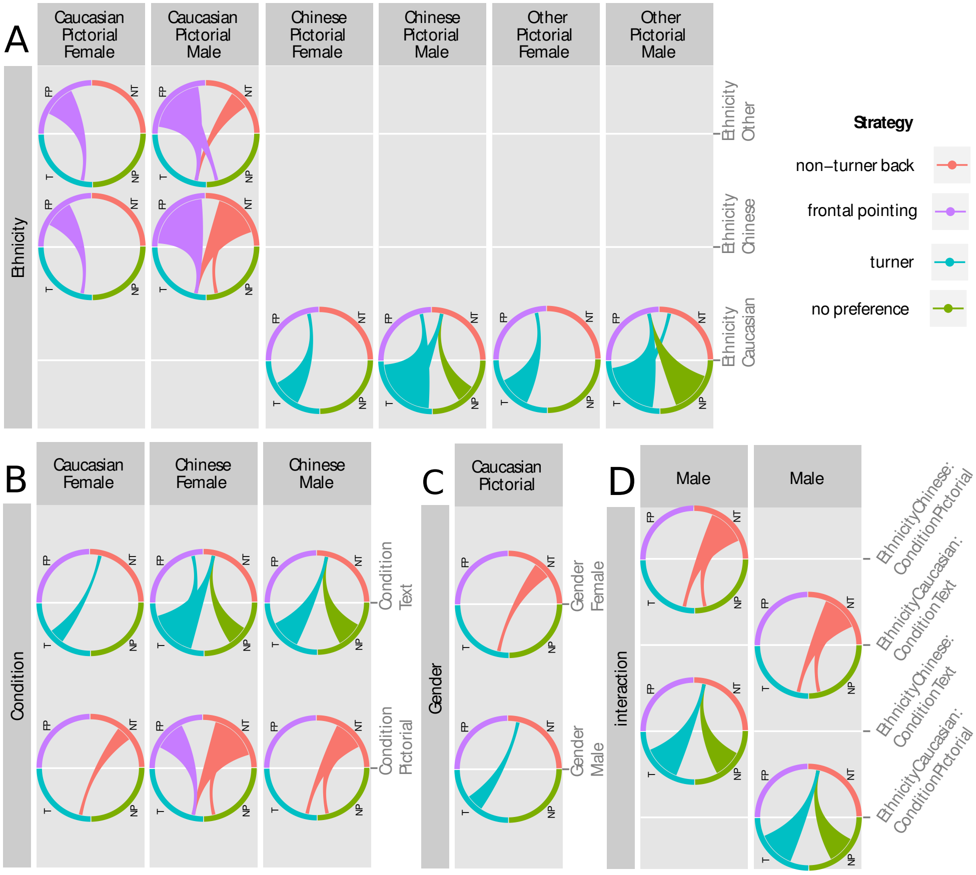

Figure 5. Significant and reasonable odd ratios. Each chord marks a significant comparison. The thin end is the baseline strategy, the thick end the strategy that is more likely instead of the baseline. Example left circle of **C**: for Caucasians in the pictorial condition being male means a classification as turner is significantly more likely than being a non-turner compared to being female (3.6 times more likely).
A: The effect of condition was significant for female Caucasians and both genders among Chinese participants. They were more likely to be non-turners or frontal pointers in the pictorial condition and turners or have no preference in the text condition.
B: Gender related ORs were only significant for Caucasians in the pictorial condition. Males were more likely to be turners while females were more likely to be non-turners.
C: All effects for Ethnicity only emerged in comparison to a pictorial baseline. Here Chinese and Other were more likely to be frontal pointers (men and women) or non-turners (only males). Vice versa, Caucasians were more likely to be turners compared to Chinese and Other, while having no preference was also more likely but only for males.
D: The interaction terms go into a similar direction than before, showing an opposing trend: while Caucasians are turners or have no preference in the pictorial condition where Chinese are more likely to be non-turners, this reverses for both ethnicities in the text condition. Here the effects only appear compared to a male baseline.

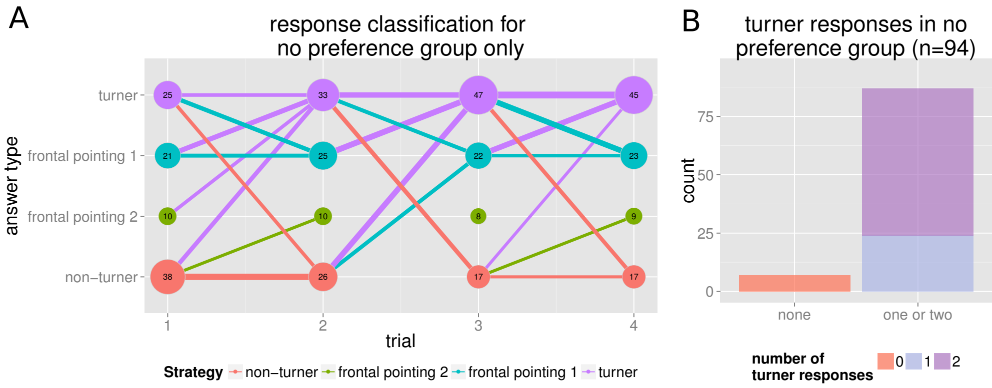

Figure 6. A: Strategy graph for the no preference group. While the number of frontal answers stay almost constant, the number of turner answers constantly grows and the number of non-turner answers shrinks. Also participants giving all sorts of answers before change to a turner answer in subsequent trials, whole exchange among other answering types is more limited.
B: 87 participants (93%) within the no preference group gave at least one turner answer.