Investigating cultural diversity for extrafoveal information use in visual scenes

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Culture shapes how people gather information from the visual world. We recently showed that Western observers focus on the eyes region during face recognition, whereas Eastern observers fixate predominantly the center of faces, suggesting a more effective use of extrafoveal information for Easterners compared to Westerners. However, the cultural variation in eye movements during scene perception is a highly debated topic. Additionally, the extent to which those perceptual differences across observers from different cultures rely on modulations of extrafoveal information use remains to be clarified. We used a gaze-contingent technique designed to dynamically mask central vision, the *Blindspot*, during a visual search task of animals in natural scenes. We parametrically controlled the *Blindspots* and target animal sizes (0°, 2°, 5°, or 8°). We processed eye-tracking data using an unbiased data-driven approach based on fixation maps and we introduced novel spatiotemporal analyses in order to finely characterize the dynamics of scene exploration. Both groups of observers, Eastern and Western, showed comparable animal identification performance, which decreased as a function of the *Blindspot* sizes. Importantly, dynamic analysis of the exploration pathways revealed identical oculomotor strategies for both groups of observers during animal search in scenes. Culture does not impact extrafoveal information use during the ecologically valid visual search of animals in natural scenes.

Introduction

Culture shapes how we look at faces. Blais, Jack, Scheepers, Fiset, and Caldara (2008) have recently shown that Western Caucasians (WCs) predominantly fixate the eye region during face recognition whereas East Asians (EAs) focus more on the nose region, yet reach comparable behavioral performance in face recognition (i.e., accuracy and response time) and categorization by race. This finding is important as it shows that the biologically relevant face processing task can be achieved with diverse fundamental scan paths. However, the fixation strategy used by East Asian observers remains surprising because the abundant face literature on (Western) normal observers and brain damaged patients has robustly shown that the critical information for face recognition is located in

the eyes and not the nose (e.g., Caldara et al., 2005; Gosselin & Schyns, 2001). Since the coupling between fixated and processed information is not perfect (concepts of overt vs. covert attention, Posner, 1980), the question of whether information extracted from the eye region is universally used to perform face recognition remained to be clarified. In addition, it is worth noting that the strategy of fixating the center of the face for EA observers is not due to social interaction norms involving gaze avoidance for this group of observers but relies instead on a genuine perceptual bias during visual object identification. In line with these findings, Kelly, Miellet, and Caldara (2010) have found that the cultural diversity of eye movement strategies for faces extends to the identification of various biological (sheep) and non-biological (greebles) categories of visually homogeneous stimuli. Crucially, however, Jack, Blais, Scheepers, Schyns, and Caldara (2009)

recently showed that Eastern observers fixate the eye region when they have to decode facial expressions, more than Westerners. Indeed, facial expression decoding requires fine-grained information use, relying mostly on the foveated region, to efficiently discriminate across the transmitted expression signals (i.e., discrimination between fear and surprise from the eye region).

Therefore, one of the most plausible explanations accounting for EA fixation strategies in object identification would consist of a better use of extrafoveal information in this culture. EA adults fixate the nose region when viewing faces but actually might exploit the eye region extrafoveally to recognize faces. Caldara, Zhou, and Miellet (2010) recently investigated this issue by restricting the visual information available to observers with Gaussian apertures, sized 2°, 5°, or 8°, dynamically centered on WCs' and EAs' fixations. Crucially, in the 2° and 5° conditions, the Spotlight apertures covered an entire eye, but the eyes and the mouth were not visible when fixating the nose. By contrast, when observers fixated the nose in the 8° condition, the mouth and eyes could be simultaneously viewed. Analysis of fixation strategies showed that the differences reported by Blais et al. (2008) were abolished in the restrictive 2° and 5° conditions with both populations of observers predominantly directing their fixations to the eye region. However, in the 8° condition when the eyes were visible while fixating the center of the face, the EA participants reverted to their preferred central landing position. These data suggest that the facial information required to accurately individuate conspecifics is invariant across human beings, but the strategies used to extract this information are likely to be modulated by culture. Importantly, for the purpose of the present study, the fixations directed toward the center of gravity of faces by EA observers would suggest a more effective use of extrafoveal information for Easterners compared to Westerners. In line with this explanation, Nisbett and Miyamoto (2005) suggested that a crucial question for future investigations is whether "the actual field of vision is wider for those from interdependent cultures than for those from independent cultures?" Indeed, one of the most influential, despite arguable, view in the cultural field assumes that the organization of the social systems, in which people develop and live, leads to the diversity in cultural perceptual strategies (for a review, see Nisbett & Masuda, 2003; Nisbett & Miyamoto, 2005). In this framework, Western societies are seen as individualistic, which would favor the perception of focal objects in a context (Triandis, 1995). By contrast, Eastern societies are seen as collectivistic favoring perception biases toward the relationship between objects (but see Davidoff, Fonteneau, & Fagot, 2008).

This view relies on the assumption that culture shapes perception in a variety of perceptual tasks and paradigms including: scene perception (e.g., Miyamoto, Nisbett, & Masuda, 2006) and description (e.g., Masuda & Nisbett, 2001), perceptual categorization (Norenzayan, Smith,

Kim, & Nisbett, 2002), and eye movements during visual scene processing (Chua, Boland, & Nisbett, 2005). However, the cultural variation in eye movements during scene perception is controversial. Chua et al. (2005) recorded eye movements in an old–new task in which the scene background was manipulated to either remain identical to the encoding phase or to change in the recognition phase. The learning phase was implicit as the participants were asked to report the degree to which they liked the picture. Chua et al. observed some effects of culture on recognition performance as well as on eye-fixation patterns. American observers looked at the focal object sooner and longer than the Chinese, whereas the Chinese looked more at the background than did the Americans. East Asians were also less likely to correctly recognize old focal objects when presented in new backgrounds containing unfamiliar contextual information. These findings were interpreted as being consistent with a relative greater holistic perception of EA compared to WC observers. The core idea of the holistic-analytic theory of culture is that people in East Asian cultures focus more holistically on relationships and similarities among objects when organizing the environment (Nisbett & Miyamoto, 2005).

A series of experiments have recently challenged the existence of cultural differences during scene perception. Rayner, Li, Williams, Cave, and Well (2007) recorded participants' eye movements during 6 different tasks including scene perception. They did not observe any evidence that Chinese observers spent more time looking at the background information (and, conversely less time looking at the foreground information) than American observers. However, Rayner et al. (2007) tested native Chinese speakers, students at the University of Massachusetts at Amherst, who came to the US after their college education. Therefore, these participants may have been familiar with the American culture and social norms. Moreover, the stimuli were photographs selected to have multiple points of interest, including people, and backgrounds in which large areas of the scene contain no objects of interest at all; while Chua et al. used scenes in which observers could clearly identify a single focal object. Boland, Chua, and Nisbett (2008) noted that Rayner et al.'s (2007) study was not a direct replication of Chua et al. (2005).

More recently, Evans, Rotello, Li, and Rayner (2009) used the original scenes used by Chua et al. (as well as additional scenes for increasing the statistical power) and the same task. They did not find any difference between the two cultural groups (both with the entire set of stimuli and with the subset that had been previously used by Chua et al.). In another study, Rayner, Castelhano, and Yang (2009) examined whether there are cultural differences in how quickly eye movements are drawn to highly unusual aspects of a scene. American and Chinese viewers examined photographic scenes while performing a preference rating task. For each visual scene, participants were

presented with either a plausible or a highly unusual version (e.g., a character with three legs, or dogs playing go). Even though there were differences between the scan path used to explore normal and unusual versions of the scenes, there were no cultural differences in the eye movements deployed while viewing either scene type. The question of whether culture impacts visual information extraction for visual scenes therefore remains to be clarified, as methodological differences across studies could account for the contrasting findings.

Notably, only coarse measures of eye movements were used in the previous studies: mean fixation duration, mean saccade length, number of fixations, and time spent in a region of interest (ROI) or before looking directly at the search target. Moreover, an approach in terms of ROIs implies a dichotomic view of the eye movement sequence: the fixations are either in the ROI or not. For instance, during a fixation situated just a pixel from the border of the ROI, the analysis will determine that the participant does not process the target, despite the fact that information processed during a fixation is larger than 1 pixel. This approach can lead to analysis differences that could explain the inconsistency of eye movement patterns across studies. As quoted by Boland et al. (2008): "… we believe that differences in our findings are due to differences in the visual stimuli and in how the spatial regions of interest were defined." For example in Chua et al. (2005) and Evans et al. (2009) the ROIs followed the contours of the object itself, while in Rayner et al. (2007) the ROIs were always rectangular. We aimed to overcome these possible limitations by (1) using an unbiased data-driven approach based on fixation maps (Blais et al., 2008); (2) introducing novel spatiotemporal analyses in order to finely characterize the dynamics of scene exploration in both groups of observers.

Beside this methodological question, in order to understand the influence of culture on visual scene perception we aimed to address two crucial questions: Do EA observers use extrafoveal information more effectively than WC observers? Does culture generally modulate eye movement strategies in ecologically valid search tasks with visual scenes? To directly address these questions, we used a gaze-contingent technique designed to dynamically obscure central vision with parametric *Blindspots*, permitting only extrafoveal information use. We also used a task requiring the detection and subsequent identification of animals in natural visual scenes. In order to finely assess the central versus extrafoveal influence of visual information, we parametrically manipulated both the *Blindspot* size (natural vision, 2°, 5°, or 8°) and the size of the targets (absent, 2°, 5°, or 8°). The *Blindspot* is based on a gaze-contingent technique introduced by Rayner and Bertera (1979) and originally called *moving mask*. This technique has also been referred as *artificial scotoma*, *simulated scotoma*, or *foveal mask*, and has been used in a variety of paradigms: reading (Fine & Rubin, 1999; Rayner & Bertera, 1979, Rayner, Inhoff, Morrison,

Slowiaczek, & Bertera, 1981), search (Bertera, 1988; Bertera & Rayner, 2000; Cornelissen, Bruin, & Kooijman, 2005; Murphy & Foley-Fisher, 1989; van Diepen & d'Ydewalle, 2003; van Diepen, Ruelens, & d'Ydewalle, 1999), visual learning (Castelhano & Henderson, 2008), and object identification (Henderson, McClure, Pierce, & Schrock, 1997). This gaze-contingent technique has proven very beneficial to investigate the visual processing of peripheral versus central retinal inputs.

The *Blindspot* (gaze-contingent moving mask) technique allows us to infer how effectively extrafoveal information is used by observers. However, the technique shares a comparable disadvantage with response classification techniques (e.g., Gosselin & Schyns, 2001), which relies in altering the information available compared to natural vision. Nonetheless, it is worth noting that our study includes a natural vision condition, providing a baseline for information intake when both central and extrafoveal information are available.

Methods

Participants

Fifteen Western Caucasian participants from the University of Glasgow, UK (6 males) and fifteen East Asian participants from the Sun Yat-Sen University, Guangzhou, China (8 males, young adults; mean age 26.1 years and 24.7 years, respectively) participated in this study. All participants had normal or corrected vision and were paid £6 or equivalent per hour for their participation. All participants gave written informed consent and the protocol was approved by the local ethical committees.

Stimuli

Stimuli were photographs taken by the first author, with the same camera and settings, in Naples (Florida, US), Lille (France), and Edinburgh (UK) zoos. These stimuli consisted of 240 pictures of zoo enclosures, 120 containing an animal. The animal size could be either 2° (40 items), 5° (40 items), or 8° (40 items) of visual angle. Figure 1 presents examples of the stimuli. The position of the animals was randomly distributed in the picture. The categories of animal were various, but all highly familiar (e.g., lion, monkey, elephant, etc.). In a pre-test, 10 East Asian and 10 West Caucasian participants, who did not participate to the experiment, were able to identify the animal without any difficulty (97% correct answers). The full-screen, 32,768 color images were 800 × 600 pixels subtending 29.25° of visual angle vertically and 39° of visual angle horizontally at a distance of 70 cm. Images
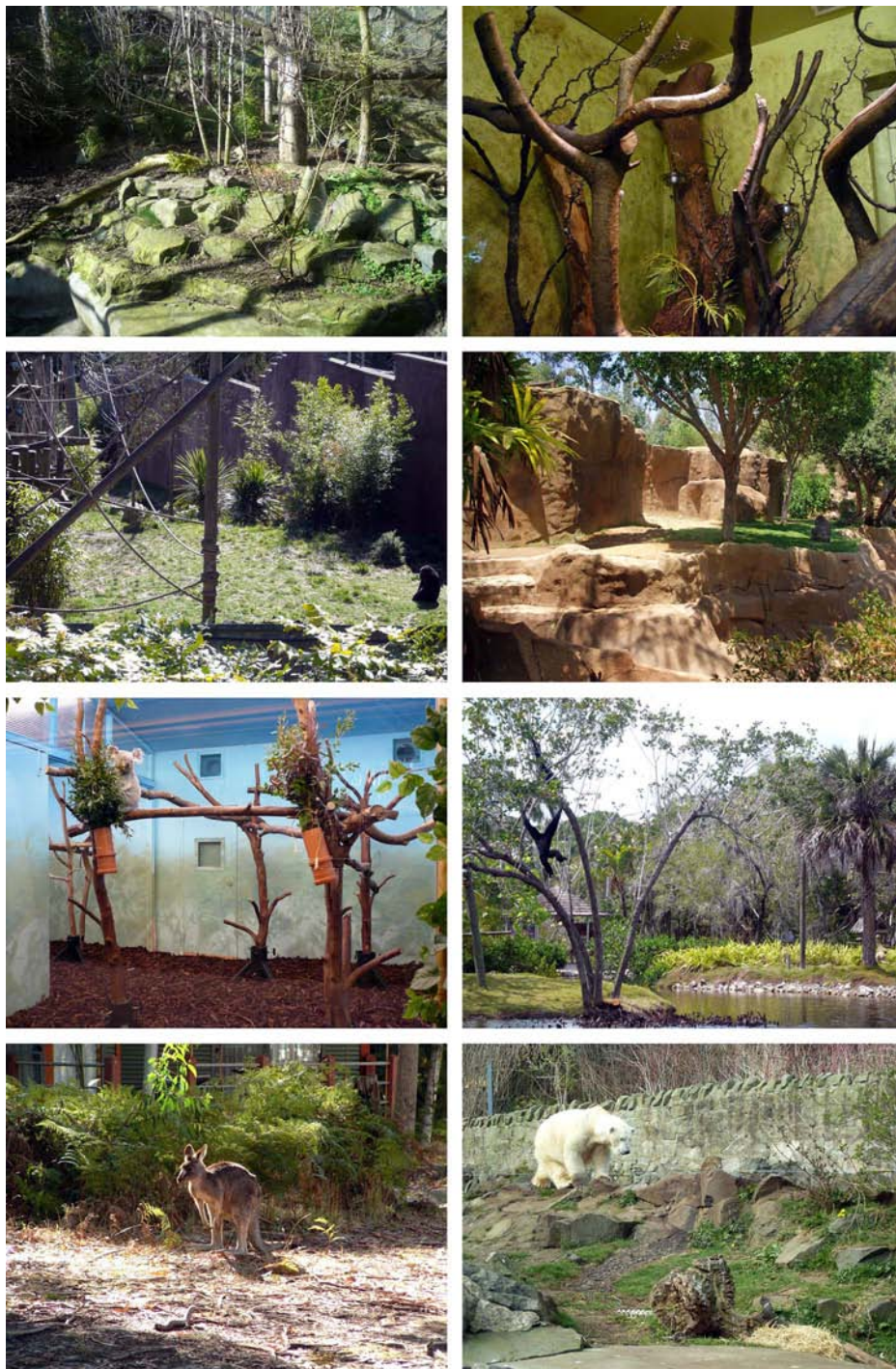
Figure 1. Examples of the stimuli. The first line shows 2 stimuli without any target. The second line shows the stimuli with a 2° target; the third line, stimuli with a 5° target; and the fourth line, stimuli with an 8° target.

were presented on a Dell P1130 19″ CRT monitor with a refresh rate of 170 Hz.

Apparatus

Eye movements were recorded at a sampling rate of 1000 Hz with the SR Research Desktop-Mount EyeLink 2K eye tracker (with a chin/forehead rest), which has an average gaze position error of about 0.25°, a spatial resolution of 0.01°, and a linear output over the range of the monitor used. Only the dominant eye of each participant was tracked although viewing was binocular. The experiment was implemented in Matlab (R2007a), using the Psychophysics (PTB-3) and EyeLink Toolbox extensions (Brainard, 1997; Cornelissen, Peters, & Palmer,

2002). Calibrations of eye fixations were conducted at the beginning of the experiment using a nine-point fixation procedure as implemented in the EyeLink API (see EyeLink Manual) and using Matlab software. Calibrations were then validated with the EyeLink software and repeated when necessary until the optimal calibration criterion was reached. At the beginning of each trial, participants were instructed to fixate a dot at the center of the screen to perform a drift correction. If the drift correction was more than 1°, a new calibration was launched to insure an optimal recording quality. The eye tracker, software, and setting used in Glasgow and Sun Yat-Sen Universities were identical.

The *Blindspot* was either absent (0°, No Blindspot), 2°, 5°, or 8° of visual angle and moved contingent to the participant gaze position. The display contingent to gaze position updating required 1 ms to receive a sample from the eye tracker, less than 7 ms to calculate the new image, and between 0 and 6 ms to refresh the screen. Therefore, the display was updated depending on observers' looking position every 11 ms on average (between 8 and 14 ms), eliminating any impression of flickering for the observers.

Procedure

The observers of each culture participated in each *Blindspot* condition in a random order. Participants started with a training session including all the *Blindspot* sizes in order to familiarize them with the gaze contingent display. Then they were informed that they would be presented with a series of pictures and that they would have to indicate, by button press, as quickly and as accurately as possible, if there was an animal in the picture or not. They were also informed that if they made a positive response, they had to identify the animal seen in the picture by verbal report. In each of the 4 *Blindspot* blocks, observers were presented with 30 images without an animal (0°), 10 with a 2°, 10 with 5°, and 10 with 8° animals. The images in each *Blindspot* block were randomly drawn from each pool of target size.

Each trial started with the presentation of a central fixation cross. Then four crosses were presented, one in the middle of each of the four quadrants of the computer screen. These crosses allowed the experimenter to check that the calibration was still accurate. In this way, we validated the calibration between each trial. A final central fixation cross served as a drift correction, followed by a scene presentation. Pictures were presented until the observer responded. Each trial was subsequently followed by the 6 fixation crosses, which preceded the next scene stimulus.

Data analyses

The behavioral performance was measured by the percentages of correct detection and correct identification, and the reaction time. Only correct trials were analyzed. We also computed the common eye-tracking measures generally used in scene exploration or search studies: number of fixations, path length, average saccade length, average fixation duration, last fixation duration, average distance between the fixation and the target, and percentage of fixations on the target. Additionally, we examined the length of the saccade preceding the first fixation on the target. Longer saccades might indicate that more extrafoveal information has been processed in order to select this target area for fixation.

To compute the fixation maps, we normalized the target coordinated so each of them was brought into the center of the new screen space. Fixation distribution maps were extracted individually for Western Caucasian and East Asian observers and each Blindspot and target size. The fixation maps were computed according to Blais et al. (2008). To establish significance, we used a robust statistical approach correcting for multiple comparisons in the fixation map space, by applying a one-tailed *Pixel test* (Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005; $Z_{crit} > 4.86$; $p < 0.05$) for the group fixation maps and a two-tailed *Pixel test* (Z_{crit} |5.01|; $p < 0.05$) on the differential fixation maps (see Figure 4). We used this method to determine whether one cultural group fixated outside the target area for a greater duration to process information extrafoveally.

To investigate the dynamics of scene exploration, we examined at each single trial gaze trajectory across time. Figure 2 shows some examples of these trajectories. First, when there is no target (EA participants, no target, no blindspot), the behavior is highly variable depending on the individual's own strategy and low-level stimuli characteristics. The second panel represents the trials with a target and no blindspot (EA participants, 2° target, and no blindspot) and shows that the scan paths quickly converge to the target. This pattern is also visible in the third panel but becomes much noisier when the blindspot is present (EA participants, 2° target, and 8° blindspot).

This analysis effectively affords a sense of the participants' exploration strategy, and how many "local attractors" can be considered given the task and the stimuli. However, it does not allow a direct comparison of the oculomotor behavior in different conditions or for different groups. Thus, we then normalized the duration of each trial in order to compute, at each time step, the center of gravity of the cloud of fixations (*k*-means with one cluster because there is one target per picture) and the dispersion around the centroid (median of the distances between the fixation locations and the centroid, see Figure 3). In this way, we summarized the data with two parameters for each time step and each group of observers: the distance between the centroid and the center of the target (distance "a" in Figure 3), and the dispersion around the centroid (distance "b" in Figure 3). For each of the target and *Blindspot* size conditions, we computed, based on a bootstrapping procedure (5000 samples with replacement),
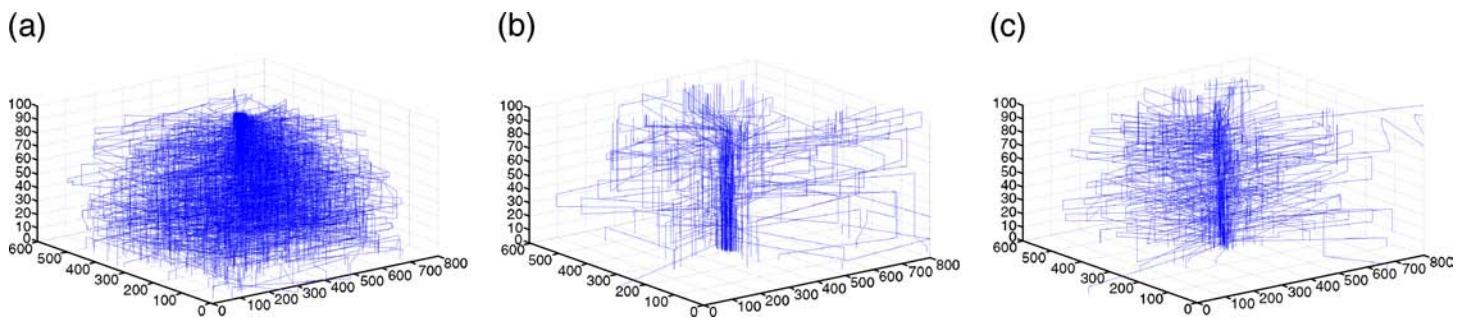
Figure 2. Gaze trajectories for the single trials. The top of the z-axis (100) represents the beginning of the trial, the bottom (0) is when the participant presses the response key. The three examples are for EA participants, (a) no target and no *Blindspot*, (b) 2° target and no *Blindspot*, (c) 2° target and 8° *Blindspot*.

the 95% confidence interval (CI) of the two parameters for EA and WC observers at each time step (see Figures 5–8). The benefit of this method compared to a "region of interest" type of approach is that we have a sensitive, continuous measure of the distance between the eye and the target; and not just a dichotomic measure of fixations in an area of interest, leading to proportion of fixations on the target. Here, we wanted to establish if the distance between the fixations and the target is larger for one cultural group than for the other at specific processing stages.

Finally, we used the ScanMatch Matlab toolbox (Cristino, Mathôt, Theeuwes & Gilchrist, in press) to compare the saccadic eye movement sequences (scan paths). This method is based on the Needleman–Wunsch algorithm, which is commonly used in bioinformatics to align protein or nucleotide sequences. This technique returns a unique matching score between the two input

sequences. Here, we computed the mean matching scores within each cultural group and across groups. The intra-group matching scores were calculated by matching the scan paths of each participant with all the other participants of the same group. Only the scan paths for identical stimuli were compared. The inter-group matching scores were obtained by matching the scan paths of each participant of one group with all the participants of the other group. We did not use any temporal binning and the ScanMatch threshold was set to 3.5 (see the ScanMatch Toolbox web site for details about the options and specifications). The substitution matrix was based on the Euclidian distance and the spatial binning included 16 * 12 bins, so each spatial bin was 2° high and wide. These analyses allowed us to directly compare the exploration strategies for both cultural groups. If the exploration pathways are different between cultural groups of observers, then the inter-group matching scores should be
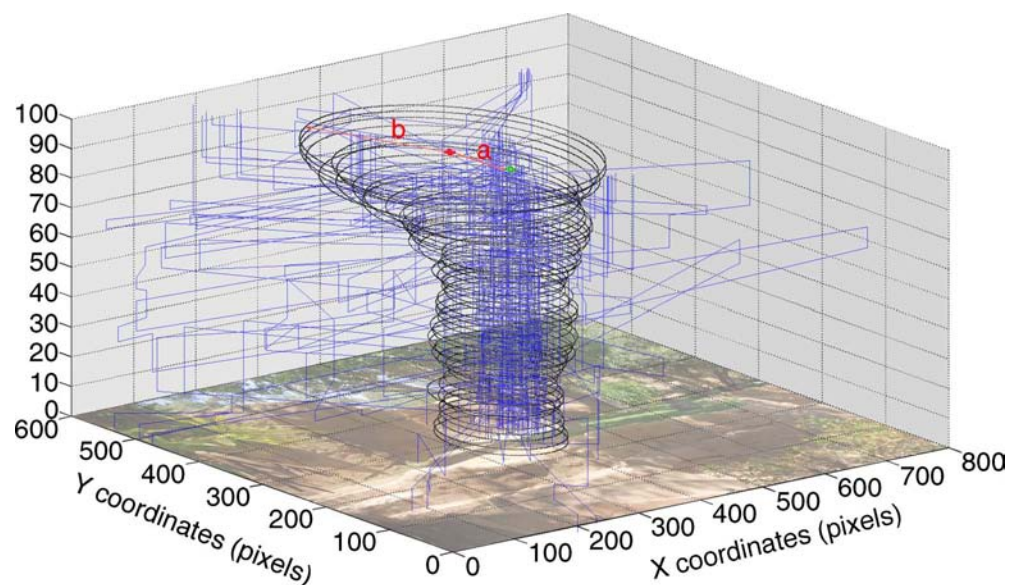

Figure 3. Graphical depiction of the spatiotemporal analysis based on the distance between the fixation centroid at each time step and the center of the target. The red and green crosses represent the centroid of the fixation cloud and center of the target, respectively. The blue lines represent the eye trajectories during each single trial. The black circles represent the dispersion around the centroid at each time step.

smaller than the intra-group matching scores. We compared the inter- versus intra-group matching scores separately for each of the 16 experimental conditions, using a *t*-test and Bonferroni correction for multiple comparisons.

Results

Behavioral performance

Percentage of correct detection, percentage of correct identification, and average reaction time are presented in Table 1; 2 (Culture of Observer: British or Chinese) × 4 (*Blindspot* size: No Blindspot, 2°, 5°, 8°) × 3 (target size: 2°, 5°, 8°) ANOVAs were conducted on participant's behavioral performance indexes. For the percentages of correct detection and correct identification, and the reaction time, the ANOVAs yielded main effects of *Blindspot* size ($F_{(3, 84)} = 15.80$, $p < 0.001$; $F_{(3, 84)} = 99.06$, $p < 0.001$; $F_{(3, 84)} = 32.20$, $p < 0.001$, respectively) and target size ($F_{(2, 56)} = 59.55$, $p < 0.001$; $F_{(2, 56)} = 124.34$, $p < 0.001$; $F_{(2, 56)} = 53.20$, $p < 0.001$, respectively). Detection and identification were more accurate and faster for small *Blindspots* (Correct detection: 96%, 93%, 88%, and 89% for no *Blindspot* to 8° *Blindspot*, respectively; Correct identification: 92%, 86%, 76%, 67%, respectively; Reaction time: 1.50, 1.71, 2.36, 2.68 s) and large targets (Correct detection: 84%, 93%, and 98% for 2° to 8° targets, respectively; Correct identification: 67%, 81%, and 92%; Reaction time: 2.59, 2.01, 1.59 s). In addition, the interaction between *Blindspot* and target sizes was also significant ($F_{(6, 168)} = 10.26$, $p < 0.001$; $F_{(6, 168)} = 21.38$, $p < 0.001$; $F_{(6, 168)} = 13.52$, $p < 0.001$, respectively). The effect of target size on correct detection, correct identification, and reaction time was globally larger for wider *Blindspots* (Correct detection: $F_{(2,56)} = 8.72$, $p < 0.001$, partial eta-squared (pη^2) = 0.28; $F_{(2,56)} = 13.13$, $p <$

0.001, pη^2 = 0.37; $F_{(2,56)} = 45.47$, $p < 0.001$, pη^2 = 0.67; $F_{(2,56)} = 25.97$, $p < 0.001$, pη^2 = 0.54 for the 4 *Blindspot* conditions, respectively; Correct identification: $F_{(2,56)} = 9.99$, $p < 0.05$, pη^2 = 0.15; $F_{(2,56)} = 22.60$, $p < 0.001$, pη^2 = 0.51; $F_{(2,56)} = 73.71$, $p < 0.001$, pη^2 = 0.77; $F_{(2,56)} = 95.21$, $p < 0.001$, pη^2 = 0.81, respectively; Reaction time: $F_{(2,56)} = 2.75$, $p = 0.07$, pη^2 = 0.11; $F_{(2,56)} = 25.60$, $p < 0.001$, pη^2 = 0.54; $F_{(2,56)} = 49.20$, $p < 0.001$, pη^2 = 0.69; $F_{(2,56)} = 15.23$, $p < 0.001$, pη^2 = 0.41). For all the target sizes (2°, 5°, and 8°), the correct detection was above 90% with no *Blindspot* and with a 2° *Blindspot,* but it was between 75% and 80% in the 5° and 8° *Blindspot* conditions when the target was 2° large and reached 90% only when the target was 5° or larger. The correct identification and reaction time indexes showed a similar but somehow more sensitive pattern; the slope of the target size effect (less correct identifications and longer reaction times for smaller targets) progressively increased as the *Blindspot* became bigger. In the no *Blindspot* condition, the reaction time had a floor value around 1.5 s for any target size. In the 2° *Blindspot* condition, this value was reached when the target was at least 5° large; then 8° in the 5° *Blindspot* condition; finally, the floor reaction time was not reached, for any target size, in the 8° *Blindspot* condition. No other effect was significant including the three-way interaction and the main effect of culture.

Eye-tracking measures

Table 2 presents the number of fixations, path length, average saccade length, average fixation duration, and last fixation duration; 2 (Culture of Observer: British or Chinese) × 4 (*Blindspot* size: No Blindspot, 2°, 5°, 8°) × 4 (target size: No Target, 2°, 5°, 8°) ANOVAs were conducted on these measures. Table 3 presents the average distance between the fixation and the target, the percentage of fixations on the target, and the saccade length before target fixation; 2 (Culture of Observer:

		No Blindspot			Blindspot 2°			Blindspot 5°			Blindspot 8°		
		Target size (degrees)											
		2	5	8	2	5	8	2	5	8	2	5	8
Percentage of correct detection	EA	91	95	99	91	88	98	74	92	96	77	92	95
	WC	95	99	100	92	92	100	76	91	100	81	97	99
Percentage of correct identification	EA	87	89	94	78	83	94	51	82	91	45	67	81
	WC	93	96	97	78	85	96	57	78	96	53	71	88
Reaction time for correct detection	EA	1.66	1.49	1.45	2.29	1.69	1.40	3.42	2.07	1.49	3.00	2.75	1.90
	WC	1.51	1.43	1.45	1.97	1.49	1.34	3.39	2.33	1.47	3.43	2.82	2.27

Table 1. Average percentage of correct detection and identification, and reaction time (in seconds) for each culture of the observer, *Blindspot* size, and target size.

		No Blindspot				Blindspot 2°				Blindspot 5°				Blindspot 8°			
		No target	2	5	8	No target	2	5	8	No target	2	5	8	No target	2	5	8
Nb fixations	EA	6.17	4.46	4.56	4.74	7.54	5.25	4.70	3.75	6.45	6.37	5.64	4.49	8.66	7.68	6.59	6.23
	WC	9.50	4.45	4.73	4.59	9.17	5.05	4.38	3.61	9.22	7.14	5.84	4.38	10.74	7.31	5.72	5.13
Path length (degrees)	EA	42.20	18.10	15.56	14.54	53.06	22.70	18.11	10.15	46.83	31.62	23.12	15.97	73.90	56.15	35.53	29.02
	WC	69.36	17.96	18.91	12.60	62.67	22.71	15.92	9.58	72.39	37.36	25.67	14.87	92.45	55.68	31.21	21.70
Saccade length (degrees)	EA	6.18	3.77	3.24	2.89	6.28	4.07	3.46	2.39	6.32	4.57	3.66	3.14	7.53	6.17	4.98	4.38
	WC	7.10	3.68	3.67	2.76	6.25	4.13	3.46	2.45	7.06	4.74	3.67	2.99	7.81	6.79	4.61	3.83
Fixation duration (ms)	EA	228	257	252	260	249	293	269	303	248	296	280	265	225	261	287	254
	WC	219	274	252	242	244	273	290	274	241	302	278	264	235	277	306	265
Last fixation duration (ms)	EA	227	309	312	297	243	349	311	374	255	357	348	303	230	296	335	258
	WC	213	326	336	304	239	327	367	288	238	348	334	307	257	352	381	294

Target size (degrees)

Table 2. Average number of fixations, path length (in degrees), saccade length (in degrees), fixation duration (in milliseconds), and last fixation duration (in milliseconds) for each culture of the observers for Blindspot size and target size including the trials without target.

British or Chinese) × 4 (*Blindspot* size: No Blindspot, 2°, 5°, 8°) × 3 (target size: 2°, 5°, 8°) ANOVAs were conducted on these measures.

The number of fixations revealed main effects of Blindspot and target sizes ($F(3, 84) = 19.83$, $p < 0.0001$; $F(3, 84) = 23.53$, $p < 0.0001$, respectively), as well as an interaction between Blindspot and target sizes ($F(9, 252) = 6.32$, $p < 0.0001$). The observers made more fixations with larger *Blindspots* (5.34, 5.41, 6.13, and 7.26 for no *Blindspot* to 8° *Blindspot,* respectively) and smaller targets (8.27, 5.96, 5.28, and 4.64 for no target to 8° target, respectively). The effect of *Blindspot* size on the number of fixations was smaller in the no target condition than in the other 3 target size conditions ($F(3,84) = 7.82$, $p < 0.001$, $p\eta^2 = 0.26$; $F(3,84) = 18.73$, $p < 0.001$, $p\eta^2 = 0.46$; $F(3,84) = 11.27$, $p < 0.001$, $p\eta^2 = 0.34$; $F(3,84) = 17.67$, $p < 0.001$, $p\eta^2 = 0.45$ for No Blindspot to 8° *Blindspot,* respectively). In the no *Blindspot* condition, the number of fixations attained a floor value of 4 to 5 fixations as soon as the target was 2° large. In the 2° *Blindspot* condition, this was reached when the target was at least 5° large; then when the target was 8° in the 5° *Blindspot* condition; and not reached in the 8° *Blindspot* condition. The triple interaction *Blindspot* × target size × observers' culture was not significant ($F < 1$). The interaction between target size and culture reached significance ($F(3, 84) = 3.73$, $p < 0.05$), mainly because of higher number of fixations for WC observers in the no target condition (no target: WC = 9.66, EA = 7.2; 2° target: WC = 5.99, EA = 5.94; 5° target: WC = 5.16, EA = 5.37; 8° target: WC = 4.43, EA = 4.80). However, in the four target size conditions, none of the post-hoc two-tailed *t*-tests between EA and WC observers reached significance ($ts(28) < 1$). No other effect was significant.

A similar pattern of main effects and interaction between *Blindspot* and target sizes was observed for the following variables: Path length ($F(3, 84) = 35.43$, $p < 0.0001$; $F(3, 84) = 37.15$, $p < 0.0001$, $F(9, 252) = 7.67$, $p < 0.0001$); Average distance between the fixation and the target ($F(3, 84) = 35.89$, $p < 0.0001$; $F(2, 56) = 100.68$, $p < 0.0001$, $F(6, 168) = 8.68$, $p < 0.0001$); Percentage of fixation on the target ($F(3, 84) = 29.50$, $p < 0.0001$; $F(2, 56) = 674.33$, $p < 0.0001$, $F(6, 168) = 6.83$, $p < 0.0001$). The path length and average distance to the target were longer and the percentage of fixation in the target area was lower with larger *Blindspots* (Path length: 25.69°, 26.75°, 32.94°, and 49.35° for no *Blindspot* to 8° *Blindspot,* respectively; Average distance: 2.24°, 2.32°, 2.66°, and 3.30°; Fixation on the target: 52.78%, 50.63%, 48.87%, and 43.18%) and smaller targets (Path length: 62.79, 32.70, 23.02, and 16.23 for no target to 8° target, respectively; Average distance: 3.40, 2.48, and 2.00 for 2° to 8° targets, respectively; Fixation on the target: 27.77%, 53.27%, and 65.57%). Like for the number of fixations, in the no *Blindspot* condition, the path length showed a floor value between 10° and 20° as soon as the target was 2° large. In the 2° *Blindspot* condition, this was reached

		No Blindspot			Blindspot 2°			Blindspot 5°			Blindspot 8°		
		Target size (degrees)											
		2	5	8	2	5	8	2	5	8	2	5	8
Distance fixation–target (degrees)	EA	2.54	2.29	2.04	3.18	2.24	1.75	4.03	2.25	1.95	4.17	3.50	2.86
	WC	2.15	2.55	1.79	3.39	1.66	1.63	3.64	2.41	1.61	4.02	2.86	2.23
Percentage of fixations on target	EA	34	54	69	34	55	64	26	56	65	19	44	64
	WC	32	56	71	31	57	62	24	56	66	21	49	63
Saccade length before target fixation (degrees)	EA	4.65	7.48	7.59	5.51	7.12	7.27	4.84	6.46	7.27	5.37	7.30	7.06
	WC	5.38	8.72	7.77	4.02	7.07	8.22	4.87	7.13	7.09	6.60	7.64	7.51

Table 3. Average distance between the fixation and the target (in degrees) and percentage of fixations on the target for each culture of observer, *Blindspot* size, and target size including the trials without target.

when the target was at least 5° large; then when the target was 8° for the 5° *Blindspot*; and not reached for the 8° *Blindspot* (effect of target size on path length: $F(3,84) = 29.86$, $p < 0.001$, $p\eta^2 = 0.58$; $F(3,84) = 30.54$, $p < 0.001$, $p\eta^2 = 0.58$; $F(3,84) = 22.06$, $p < 0.001$, $p\eta^2 = 0.50$; $F(3,84) = 32.46$, $p < 0.001$, $p\eta^2 = 0.60$ for the 4 *Blindspot* conditions, respectively). In a similar way, in the no *Blindspot* condition, the average distance to the center of the target was in the range of 2° to 2.5° for all the target sizes. In the 2° and 5° *Blindspot* condition, this range was reached when the target was at least 5° large; and this range was not reached in the 8° *Blindspot* condition (effect of target size on distance to the target: $F(2,56) = 4.92$, $p < 0.05$, $p\eta^2 = 0.18$; $F(2,56) = 43.88$, $p < 0.001$, $p\eta^2 = 0.67$; $F(2,56) = 39.77$, $p < 0.001$, $p\eta^2 = 0.64$; $F(2,56) = 30.62$, $p < 0.001$, $p\eta^2 = 0.58$ for the 4 *Blindspot* conditions, respectively). The pattern of interaction was a bit less clear for the percentage of fixation inside the target area, maybe because the effect of target size was very strong in all the *Blindspot* conditions (effect of target size on percentage of fixation: $F(2,56) = 224.80$, $p < 0.001$, $p\eta^2 = 0.91$; $F(2,56) = 151.56$, $p < 0.001$, $p\eta^2 = 0.87$; $F(2,56) = 274.56$, $p < 0.001$, $p\eta^2 = 0.93$; $F(2,56) = 238.49$, $p < 0.001$, $p\eta^2 = 0.92$ for the 4 *Blindspot* conditions, respectively).

The average saccade length showed the same general pattern ($F(3, 84) = 65.81$, $p < 0.0001$; $F(3, 84) = 88.73$, $p < 0.0001$, $F(9, 252) = 7.92$, $p < 0.0001$) and a triple interaction ($F(9, 252) = 2.27$, $p < 0.05$); however, the interactions between Blindspot size and culture or between target size and culture were not significant ($Fs < 1$). The observers made shorter saccades when the *Blindspot* was smaller (4.14°, 4.06°, 4.51°, and 5.77° for no *Blindspot* to 8° *Blindspot,* respectively) or the target larger (6.78, 4.73, 3.84 and 3.12 for no target to 8° target, respectively). As for other measures, the average saccade length showed a plateau in the no *Blindspot* condition, here between 3° and 4° for targets of 2° or larger. This range was attained for 5° targets or larger in the 2° and 5° *Blindspot* conditions; and the average saccade length was never below 4° in the 8° *Blindspot* condition (effect of

target size on average saccade length: $F(3,84) = 101.04$, $p < 0.001$, $p\eta^2 = 0.82$; $F(3,84) = 87.60$, $p < 0.001$, $p\eta^2 = 0.80$; $F(3,84) = 45.83$, $p < 0.001$, $p\eta^2 = 0.68$; $F(3,84) = 55.99$, $p < 0.001$, $p\eta^2 = 0.72$ for the 4 *Blindspot* conditions, respectively).

The average fixation duration also showed the general pattern ($F(3, 84) = 14.79$, $p < 0.0001$; $F(3, 84) = 63.67$, $p < 0.0001$, $F(9, 252) = 8.36$, $p < 0.0001$) and a three-way interaction ($F(9, 252) = 2.47$, $p < 0.05$) with trends of interaction between *Blindspot* size and culture ($F(3, 84) = 2.42$, $p = 0.074$) and between target size and culture $F(3, 84) = 2.75$, $p = 0.05$). The fixation durations were the shortest in the no *Blindspot* and no target conditions; when a *Blindspot* or a target was present, the fixations durations decreased as the size of the *Blindspot* or the target increased (248, 275, 272, and 263 ms for No Blindspot to 8° *Blindspot,* respectively; 236, 279, 276, and 266 ms for no target to 8° target, respectively). For this variable, the pattern of interaction between *Blindspot* and target sizes showed a global increase of the target size effect for larger *Blindspots* (effect of target size on average fixation duration: $F(3,84) = 19.03$, $p < 0.001$, $p\eta^2 = 0.46$; $F(3,84) = 15.94$, $p < 0.001$, $p\eta^2 = 0.42$; $F(3,84) = 29.03$, $p < 0.001$, $p\eta^2 = 0.57$; $F(3,84) = 40.12$, $p < 0.001$, $p\eta^2 = 0.65$ for the 4 *Blindspot* conditions, respectively). The pattern of interaction was nonetheless relatively more complex than for other variables, probably due to the fact that fixation durations are also impacted by more complex online visual and cognitive processing. From the three-way interaction, we examined separately the results for EA and WC participants. EA and WC observers showed main effects of *Blindspot* and target sizes (EA observers: $F(3,42) = 12.16$, $p < 0.001$, $p\eta^2 = 0.50$; $F(3,42) = 35.87$, $p < 0.001$, $p\eta^2 = 0.75$, respectively; WC observers: $F(3,42) = 5.97$, $p < 0.01$, $p\eta^2 = 0.40$; $F(3,42) = 29.34$, $p < 0.001$, $p\eta^2 = 0.77$) as well as the *Blindspot* × target interaction (EA observers: $F(9,126) = 7.39$, $p < 0.001$, $p\eta^2 = 0.38$; WC observers: $F(9,126) = 3.92$, $p < 0.001$, $p\eta^2 = 0.30$, respectively). We also examined more specifically the *Blindspot* size by culture, and the target size by culture interactions. In none of the 4 *Blindspot*

conditions the effect of culture was significant ($ts(28) < 1$). The interaction between culture and *Blindspot* size on fixation duration seemed to be due to the slightly different effect of *Blindspot* size for EA and WC observers only in the *Blindspot* conditions (excluding the no *Blindspot* condition, EA = 249 ms, WC = 247 ms). For EA observers, the fixation durations decreased when the *Blindspot* size increased (278, 272, and 257 ms for 2°, 5°, and 8° *Blindspot,* respectively). In contrast, for WC observers, the fixation durations remained constant across *Blindspot* conditions (270, 271, and 271 ms). However, as showed earlier, there was no significant effect of culture in any of the *Blindspot* conditions (with a 0.05 threshold and the results would be even further from significance with applying a multiple comparisons correction). For the target size by culture interaction, none of post-hoc two-tailed *t*-tests between EA and WC observers were significant in the 4 target size conditions ($ts(28) < 1$) and the pattern of results did not show any specific trend (EA observers: 238, 277, 272, and 270 ms for the 4 target size conditions, respectively; WC observers: 235, 282, 281, and 261 ms).

The last fixation duration revealed a main effect of target size ($F(3, 84) = 61.10$, $p < 0.0001$), an interaction between *Blindspot* and target sizes ($F(9, 252) = 2.19$, $p < 0.05$), an interaction between culture and *Blindspot* size

($F(3, 84) = 3.35$, $p < 0.05$), and a triple interaction ($F(9, 252) = 2.29$, $p < 0.05$). The last fixation duration was the shortest in the no target condition and shorter in the 8° target condition than in the 2° and 5° target conditions (237.92, 332.46, 338.57, and 303.74 ms for the 4 target size conditions, respectively). The interaction between Blindspot and target sizes was due to a *Blindspot* effect significant only in the no target and 8° target conditions, explaining why the main effect of *Blindspot* size is not significant for this variable (effect of *Blindspot* size on last fixation duration: $F(3,84) = 4.26$, $p < 0.01$, $p\eta^2 = 0.52$; $F(3,84) = 2.15$, $p > 0.1$, $p\eta^2 = 0.09$; $F(3,84) = 1.06$, $p > 0.3$, $p\eta^2 = 0.05$; $F(3,84) = 3.75$, $p < 0.05$, $p\eta^2 = 0.15$ for the 4 target conditions, respectively). Like for the average fixation duration, the interaction between culture and *Blindspot* size seemed to be due to the slightly different effect of *Blindspot* size for EA and WC observers only for the *Blindspot* conditions (excluding the no *Blindspot* condition, EA = 286 ms, WC = 295 ms). For EA observers, the last fixation durations decreased when the *Blindspot* size increased (319, 316, and 280 ms for 2°, 5°, and 8° *Blindspot,* respectively). In contrast, for WC observers, the last fixation durations slightly increased for larger *Blindspots* (305, 307, and 321 ms). However, there was no significant effect of culture in any of the 4 *Blindspot* conditions ($ts(28) < 1$). From the three-way
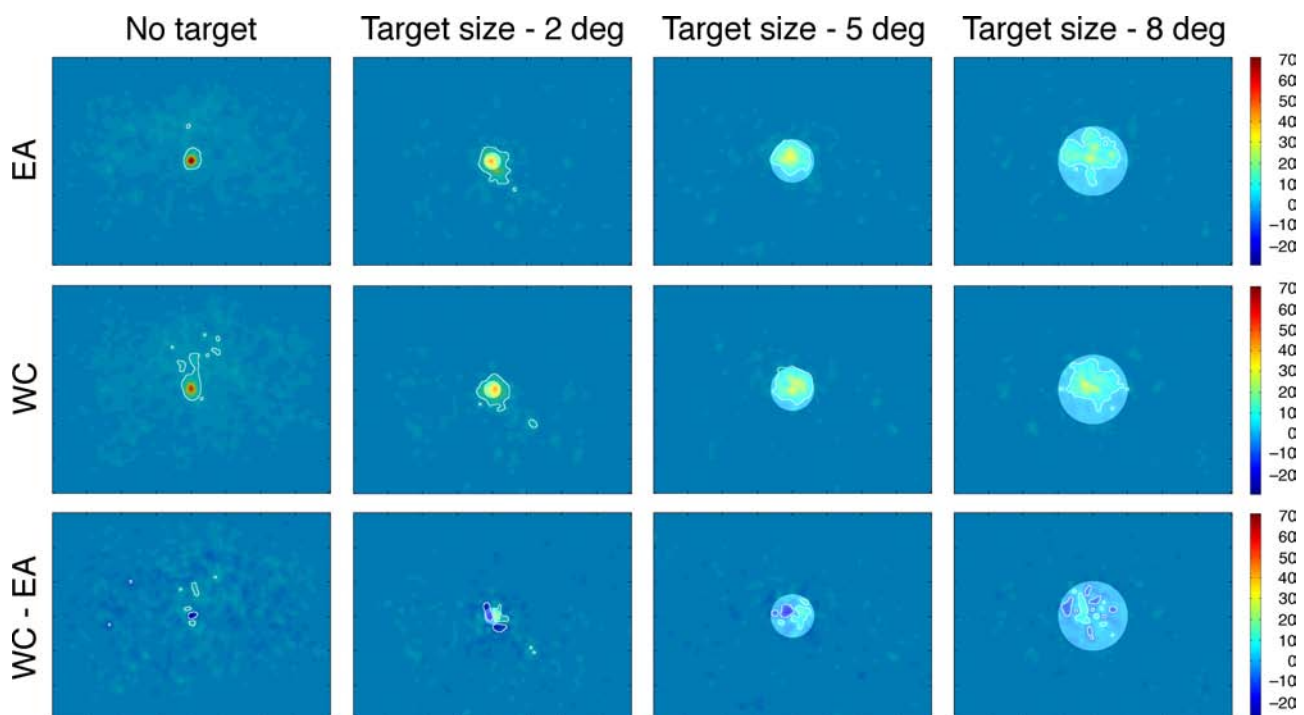

Figure 4. Group and differential fixation maps for the 8° *Blindspot* condition. Note that the position of the targets has been centered to normalize the location in order to compute the fixation maps across targets. *First and second line*: Fixation maps of East Asian (EA) and Western Caucasian (WC) observers for each target size condition. *Third line*: Fixation biases for Western Caucasian (WC—red) and East Asian (EA—blue) observers are highlighted by subtracting WC and the EA *Z*-scored group fixation maps. The target areas are represented by the brighter circle in the middle of the screen. Areas fixated above chance are delimited by white borders. Similar fixation maps were obtained for the other *Blindspot* conditions.

interaction, we examined separately the results for EA and WC participants. For EA and WC observers, the last fixation duration showed a main effect of target size (EA observers: $F(3,42) = 28.86$, $p < 0.001$, $p\eta^2 = 0.71$; WC observers: $F(3,42) = 33.08$, $p < 0.001$, $p\eta^2 = 0.79$). The main effect of *Blindspot* size and the *Blindspot* × target interaction were only significant for EA observers (EA observers: $F(3,42) = 5.80$, $p < 0.01$, $p\eta^2 = 0.33$; $F(9,126) = 3.96$, $p < 0.001$, $p\eta^2 = 0.25$, respectively; WC observers: $F(3,42) = 0.94$, $p > 0.4$, $p\eta^2 = 0.09$; $F(9,126) = 0.94$, $p > 0.4$, $p\eta^2 = 0.09$, respectively). However, only 1 of the 16 post-hoc two-tailed *t*-tests (4 *Blindspot* sizes × 4 target sizes) between EA and WC observers lead to a *p*-value smaller than 0.05 (2° *Blindspot* and 8° target: $t(28) = 0.99$, $p = 0.0081$) and this comparison did not reach significance when using the Bonferroni multiple comparisons correction (corrected $\alpha = 0.0031$).

The length of the saccade preceding the first fixation on the target revealed again main effects of *Blindspot* and target sizes ($F(3,84) = 3.17$, $p < 0.05$; $F(2,56) = 111.3$, $p < 0.001$) as well as an interaction between these two factors ($F(6,168) = 2.72$, $p < 0.05$). The saccade before the first fixation on the target was the longest in the no *Blindspot* and 8° *Blindspot* conditions (6.88°, 6.55°, 6.26°, and 6.87° for the 4 *Blindspot* conditions). It was shorter for the 2° target conditions relatively to the 5° and 8° target conditions (5.14, 7.33, and 7.45 for the 2° to 8° targets). The effect of the target size on the saccade length before fixating the target was smaller for larger *Blindspots* (effect of target size on saccade length before target: $F(2,56) = 59.93$, $p < 0.001$, $p\eta^2 = 0.73$; $F(2,56) = 30.23$, $p < 0.001$, $p\eta^2 = 0.58$; $F(2,56) = 14.43$, $p < 0.001$, $p\eta^2 = 0.40$; $F(2,56) = 10.59$, $p < 0.001$, $p\eta^2 = 0.32$ for the 4 *Blindspot* conditions, respectively). The three-way interaction
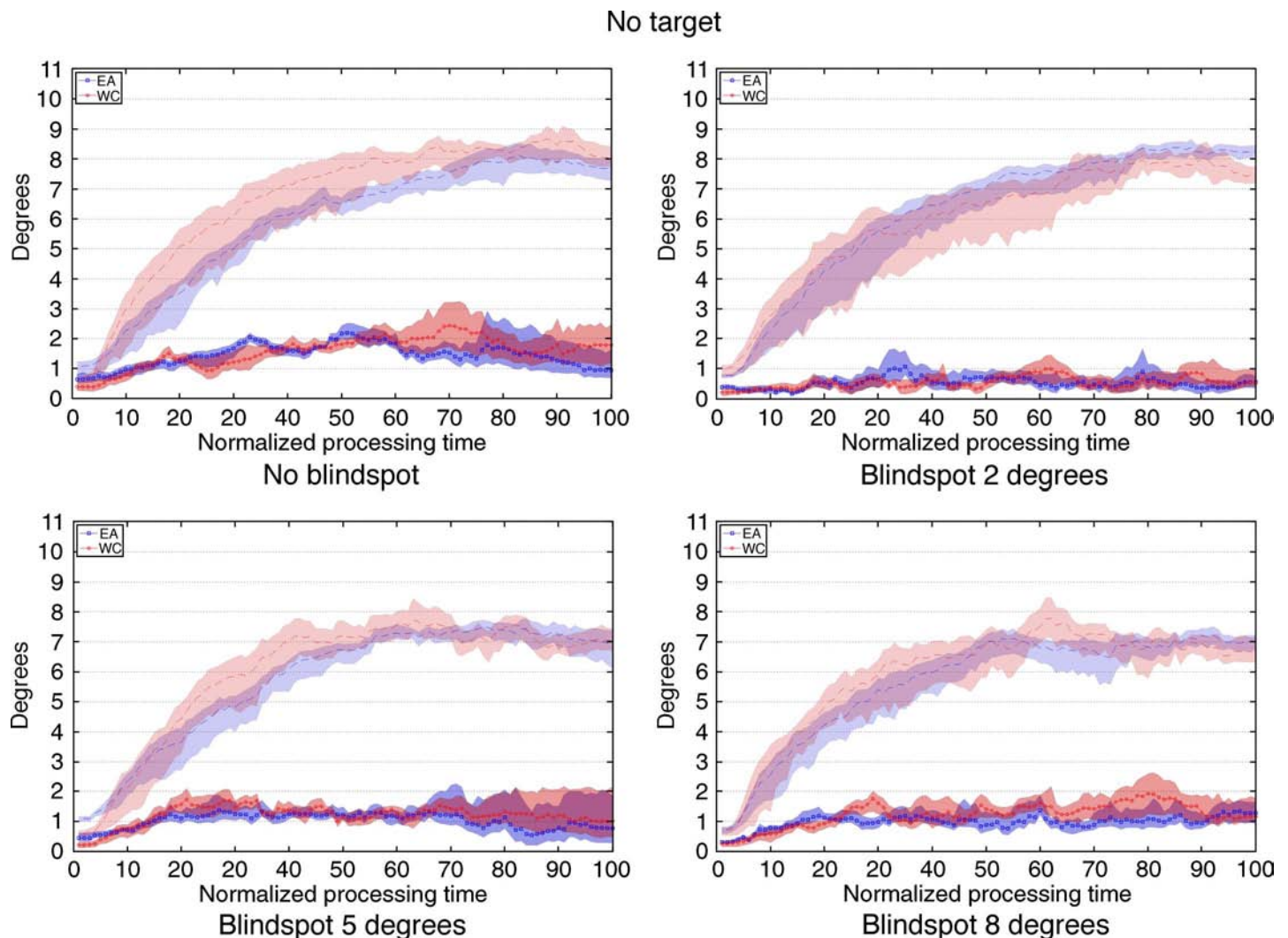

Figure 5. Average distance between the centroid and the target (solid lines with markers) and dispersion around the centroid (dashed lines, no marker) in degrees over time. The 4 graphs represent the 2 parameters in the no target condition and for the 4 *Blindspot* conditions, for East Asian (EA—blue) and Western Caucasian (WC—red) observers. The shade area around each curve represents the 95% CI.

between *Blindspot* size, target size, and culture was significant ($F_{(6,168)} = 2.26$, $p < 0.05$). EA observers showed only a significant main effect of target size ($F_{(3,42)} = 0.54$, $p = 0.057$; $F_{(2,28)} = 47.70$, $p < 0.001$; $F_{(6,84)} = 1.10$, $p > 0.37$) while WC observers showed main effects of *Blindspot* and target size, as well as the interaction between these 2 factors ($F_{(3,42)} = 3.81$, $p < 0.05$; $F_{(2,28)} = 72.00$, $p < 0.001$; $F_{(6,84)} = 3.66$, $p < 0.005$). However, only 1 of the 12 post-hoc two-tailed *t*-tests (4 *Blindspot* sizes × 4 target sizes) between EA and WC observers lead to a *p*-value smaller than 0.05 (2° *Blindspot* and 2° target: $t(28) = 0.99$, $p = 0.0172$) and this comparison did not reach significance when using the Bonferroni correction for multiple comparisons (corrected $\alpha = 0.0042$).

Crucially, we did not observe any main effect of culture on any of these measures (all *F*s < 1 except for the average distance between fixation and target, $F_{(1, 28)} = 2.86$, $p = 0.11$ and saccade length before target fixation, $F_{(1,28)} = 2.1$, $p = 0.16$).

Fixation maps

The fixation maps revealed that participants fixate significantly longer on the target area ($Z_{crit} > |4.25|$; $p < 0.05$). The differential fixation maps (WC − EA Z-scored group fixation maps) did not show any cultural bias. Neither of the observer groups looked more than the other inside or outside the target area (Z_{crit} |5.01|; $p <$
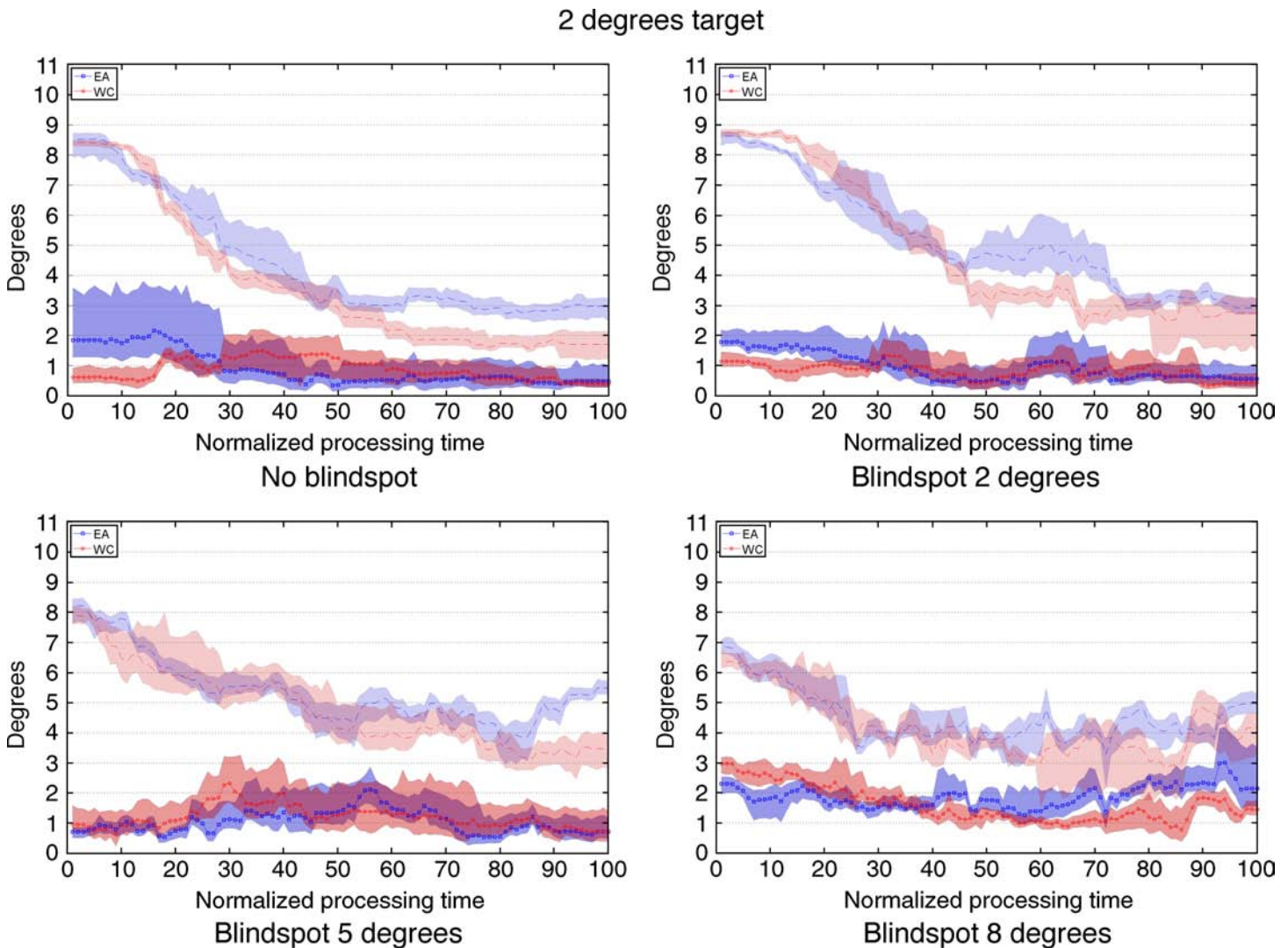

Figure 6. Average distance between the centroid and the target (solid lines with markers) and dispersion around the centroid (dashed lines, no marker) in degrees over time. The 4 graphs represent the 2 parameters in the 2° target condition and for the 4 *Blindspot* conditions, for East Asian (EA—blue) and Western Caucasian (WC—red) observers. The shaded area around each curve represents the 95% CI.

0.05). The same pattern was observed for the four *Blindspot* sizes and four target sizes. Figure 4 represents the group and differential fixation maps for the most severe degradation of central information, the 8° *Blindspot* condition. The fixation maps were similar for the other *Blindspot* conditions.

Dynamic of scene exploration

As shown in Figures 5–8, there is no indication of obvious and consistent differences between the 2 groups of observers in the dynamic of scene exploration. The no target conditions show a divergent pattern for all the *Blindspot* conditions. The conditions with targets show a convergent pattern toward the target. As we would expect,

the exploration pattern is noisier with smallest targets and largest *Blindspots*. In all of the conditions, the dynamic of scene exploration is remarkably similar for EA and WC observers. Both groups of observers converge to the target at the same time during the exploration and stay on the target until they give their answer.

ScanMatch

The matching scores for each culture and between cultures are shown in Table 4. *t*-Statistics and *p*-values for the contrasts intra-culture vs. between cultures are also presented for all experimental conditions. The Bonferroni-corrected α is 0.0031. The ScanMatch analysis revealed significantly lower matching scores between
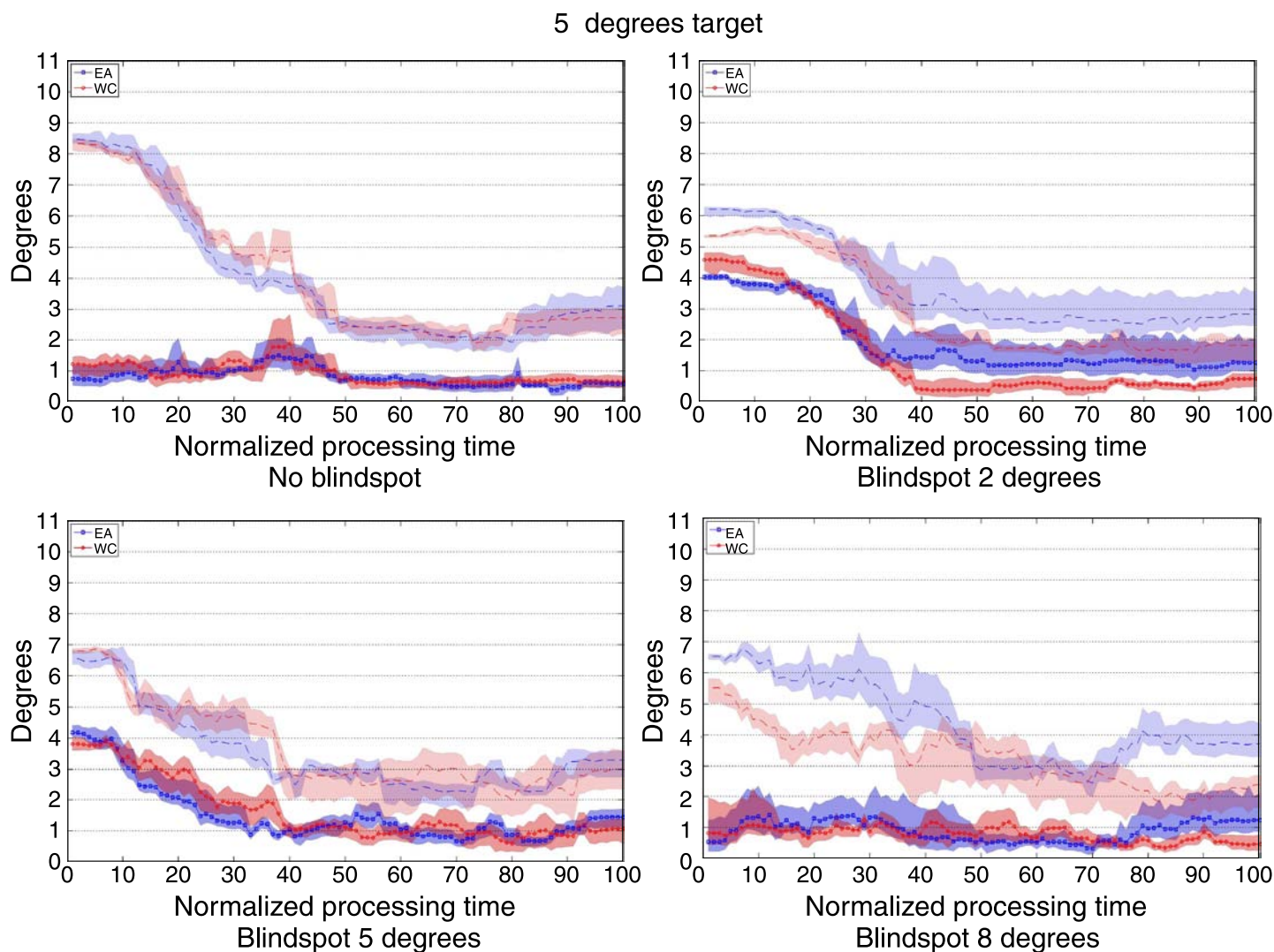

5 degrees target

Figure 7. Average distance between the centroid and the target (solid lines with markers) and dispersion around the centroid (dashed lines, no marker) in degrees over time. The 4 graphs represent the 2 parameters in the 5° target condition and for the 4 *Blindspot* conditions, for East Asian (EA—blue) and Western Caucasian (WC—red) observers. The shaded area around each curve represents the 95% CI.
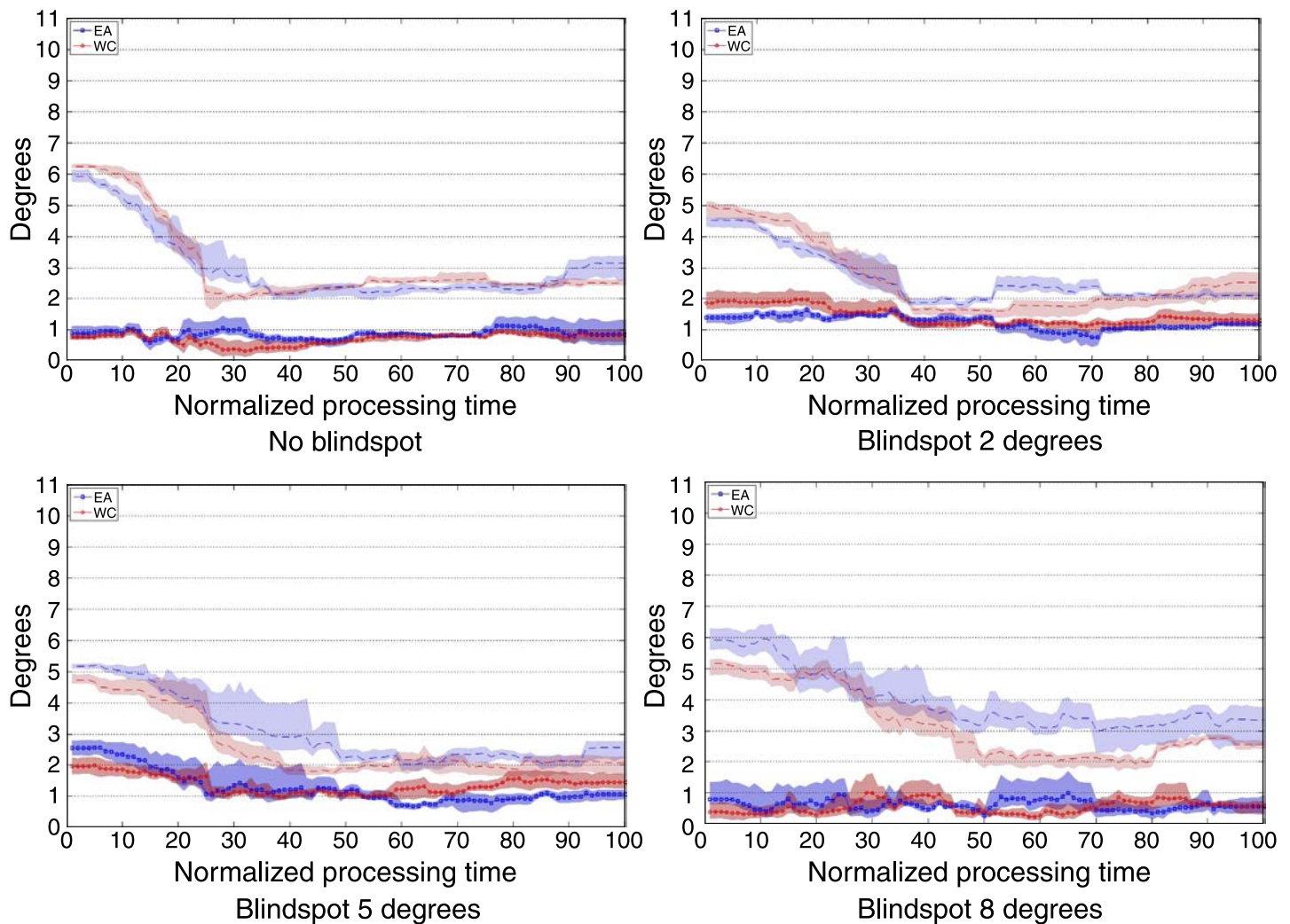
Figure 8. Average distance between the centroid and the target (solid lines with markers) and dispersion around the centroid (dashed lines, no marker) in degrees over time. The 4 graphs represent the 2 parameters in the 8° target condition and for the 4 *Blindspot* conditions, for East Asian (EA—blue) and Western Caucasian (WC—red) observers. The shaded area around each curve represents the 95% CI.

cultures only for the 5° and 8° *Blindspot* conditions and when there was a target. None of the other conditions was significant.

Discussion

The core finding of the present study is that EA and WC observers show comparable abilities in the use of extrafoveal information during the visual search of an animal in natural scenes. The gaze-contingent *Blindspot* technique revealed similar exploration strategies in both groups of observers. Such similarity in eye movements was also paired by equal behavioral performances in both cultures.

The larger the *Blindspot* size, the smaller were the target detection and identification rates. Reaction times also directly increased as a function of the *Blindspot* aperture size. These behavioral results are consistent with previous findings showing that performance is impaired by a central scotoma (Bertera, 1988; Murphy & Foley-Fisher, 1989; Rayner & Bertera, 1979). Despite such performance impairments due to the *Blindspot,* enough information can be extracted extrafoveally during the movement of attention that accompanies saccade programming to allow a good detection and identification performance in all conditions: 77% and 81% correct detection, 45% and 53% correct identification for EA and WC observers, respectively in the most difficult situation, that is 8° *Blindspot* and 2° target.

In line with previous studies (Evans et al., 2009; Rayner et al., 2009, 2007), none of the global eye-tracking

| | No Blindspot | | | | Blindspot 2° | | | | Blindspot 5° | | | | Blindspot 8° | | | |
| | Target size (degrees) | | | | | | | | | | | | | | | |
	No target	2	5	8	No target	2	5	8	No target	2	5	8	No target	2	5	8
EA	0.42	0.54	0.53	0.53	0.44	0.54	0.56	0.57	0.41	0.48	0.46	0.50	0.42	0.48	0.46	0.49
WC	0.42	0.51	0.52	0.51	0.37	0.45	0.45	0.45	0.40	0.44	0.49	0.50	0.38	0.44	0.48	0.50
EA vs. WC	0.41	0.51	0.53	0.51	0.42	0.52	0.53	0.54	0.40	0.40	0.43	0.45	0.40	0.42	0.44	0.44
$t(43)$	0.30	3.00	0.19	2.29	0.75	1.55	1.28	1.26	0.67	8.02	5.91	7.27	0.34	5.13	5.58	8.36
p	0.768	0.005	0.847	0.027	0.457	0.129	0.209	0.215	0.508	0.000	0.000	0.000	0.738	0.000	0.000	0.000

Table 4. Average matching scores (using ScanMatch) within each culture of observer, between cultures and for each Blindspot size, and target size. t-Statistics and p-values for the contrasts intra-culture vs. between cultures are also presented for all experimental conditions (Bonferroni-corrected α = 0.0031, significant p-values are in italics).

measures was significantly different between the two groups of observers. The number of fixations, path length, average saccade length, average fixation duration, last fixation duration, average distance between the fixation and the target, percentage of fixations on the target, and the length of the saccade preceding the first fixation on the target, all showed that culture does not impact on the global oculomotor strategy during animal search in scenes. The *Blindspot* manipulation also confirmed previous observations from gaze-contingent studies masking central vision. The foveal degradation results in increased saccadic amplitudes (Cornelissen et al., 2005; van Diepen et al., 1999) and fixation durations (Cornelissen et al., 2005; van Diepen, 2001; van Diepen, De Graef, & d'Ydewalle, 1995; van Diepen & d'Ydewalle, 2003). The fixation maps revealed that, not surprisingly, the observers fixate the target most of the time during trials in natural vision (without *Blindspot*). In a less intuitive way, the fixation maps were similar regardless of the size of the *Blindspot*. The observers fixated on the target even if, in doing so, the target is no longer visible (particularly in the cases where the *Blindspot* is larger than the target). This counterproductive tendency to fixate with the scotoma area has been observed by Bertera (1988) and Henderson et al. (1997), and the capacity to overcome this compulsive fixation tendency seems to take a long time to develop (20 months or more in patients with central scotoma, Timberlake et al., 1986).

A more efficient strategy to adapt to the task at hand would have consisted of fixating beside the target to process it extrafoveally. This would be possible at least when the target and the *Blindspot* are small, as the projection of the target is close enough to the fovea. However, such an eye movement strategy was not deployed by either group of observers. If EA observers had shown better extrafoveal information use, we would have expected more fixations outside the target area for these observers than for WC observers. The differential fixation maps between the two cultures show that this is not the case, as no significant fixation differences, in terms of looking inside or outside the target area, were found between the groups of observers. One possible interpretation of the fixation map data is that EA observers, like WC observers, cannot repress saccades toward the target but their extrafoveal processing is more efficient than WC observers. However, this interpretation is inconsistent with the fact that there is no performance difference between the two groups of observers.

The analysis of the dynamics of scene exploration across time revealed a divergent behavior in the absence of target. When no target captures attention, the low-level features of the scene drive the oculomotor behavior, leading to individual strategies in information sampling. The presence of a target leads to its detection and the rapid convergence of eye movement scan paths, with observers maintaining fixations on the target until response. This is true with normal vision, but more surprisingly, this

pattern is observed even with a *Blindspot*. We would have expected that, when the foveal information is masked, the most efficient strategy would consist in making a saccade away from the target in order to process the animal extrafoveally after localization. We did not observe such a strategy. Instead, even in the most difficult condition (8° *Blindspot* and 2° target), the observers of both groups keep foveating the target until response. Previous research showed that visually guided saccadic eye movements most often closely follow shifts of attention (Hoffman & Subramaniam, 1995; Remington, 1980; Shepherd, Findlay, & Hockey, 1986). Hence, our data suggest that the strategy adopted by the participants is to use the extrafoveal information extracted during the shift of attention preceding the saccade toward the target. This may be due to a tight coupling, during scene processing, between overt and covert attention. The movement of attention to the target in order to process it extrafoveally is probably extremely difficult to perform without launching a saccade. All together, the relatively short reaction times (EA: 3 s; WC: 3.43 s in the most difficult condition, 8° *Blindspot* and 2° target conditions), low number of fixations (EA: 7.68; WC: 7.31 in the 8° *Blindspot* and 2° target conditions), and the fast convergence to the target suggest that high-level information related to the task can be extracted extrafoveally and that not only high-contrast or high-saliency features draw attention and gaze. This is consistent with the view that the human visual system makes extensive use of top-down mechanisms at an early stage of visual processing for facilitating object search in natural scenes (see for instance Torralba, Oliva, Castelhano, & Henderson, 2006).

The ScanMatch analysis revealed differences in the scan paths between EA and WC only in the most dramatic foveal degradation conditions (*Blindspot* 5° and 8°) and when there was a target in the scene. In the most natural conditions, without a *Blindspot*, we did not observe any cultural effect on exploration strategies. However, these observations show that culture impacts exploration strategies in specific visual constrained conditions, with large central scotomas. Future studies are necessary to clarify the nature of such cultural variation in information sampling.

Our results are in line with Evans et al. (2009) and Rayner et al.'s (2009, 2007) studies and do not confirm the cultural influence on oculomotor strategies observed by Chua et al. (2005). However, the task and stimulus complexity used here are different from those used in Chua et al. (2005) and Evans et al. (2009), which used aesthetic judgments and memory tasks; or Rayner et al. (2009) that used anomalous stimuli, whereas here we used an animal search task. As noted by Rayner et al. (2007), the number of objects of interest in the scene, for example, can modulate the cultural differences in scene exploration. Moreover, as argued above, analyses based on ROI could lead to differences and inconsistency across studies. Our

results invite caution to the generalization that there are cultural variations in eye movements. The cultural differences observed in specific tasks are not due to general perceptual strategies.

Crucially, nothing in our data allows us to draw the conclusion that culture impacts on extrafoveal information use during visual search in natural scenes. We did not observe any evidence of greater use of extrafoveal information in EA compared to WC observers, neither in the eye movement strategies nor in the behavioral performance. However, the results of our study do not allow us to draw firm conclusions about the precedence of holistic vs. analytical perception in Eastern vs. Western cultures, respectively. Indeed, extrafoveal information extraction during each single fixation can be similar in both cultures, but how observers integrate the information extracted during multiple fixations could differ depending on cultural factors. This study indicates that the cultural differences consistently observed in face perception are not due to general perceptual biases modulating extra-foveal information use, but instead most probably pertain to the identification of visually homogeneous object processing. In order to test the hypothesis of a better use of extrafoveal information in EA observers, it is necessary to *directly* use the *Blindspot* paradigm and analysis during face recognition.

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