

Drawing experts have better visual memory while drawing

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Drawing involves frequent shifts of gaze between the original and the drawing and visual memory helps compare the original object and the drawing across these gaze shifts while creating and correcting the drawing. It remains unclear whether this memory encodes all of the object or only the features around the current drawing position and whether both the original and the copy are equally well represented. To address these questions, we designed a “drawing” experiment coupled with a change detection task. A polygon was displayed on one screen and participants had to copy it on another, with the original and the drawing presented in alternation. At unpredictable moments during the copying process, modifications were made on the drawing and the original figure (while they were not in view). Participants had to correct their drawing every time they perceived a change so that their drawing always matched the current original figure. Our results show a better memory representation of the original figure than of the drawing, with locations relevant to the current production most accurately represented. Critically, experts showed better memory for both the original and the drawing than did novices, suggesting that experts have specialized advantages for encoding visual shapes.

Introduction

Observational drawing is a visuomotor task in which visual information (an object, a photograph, or a figure) has to be translated into marks on the paper so that the copy ideally matches the original. As such, it is a good example of interaction between vision and action. In most daily situations, these two systems cooperate quite well, allowing us to act on or avoid objects in our environment. However, when it comes

to copying those same objects, it turns out to be a very challenging task for all but a few of us. At a first glance, this should be surprising as observational drawing only requires us to depict the contents of our own visual perception. The difficulty that most of us experience indicates that observational drawing does not emerge early in development, such as walking, but instead requires extensive practice into adulthood. Drawing experts, such as professional artists and draftspersons, are able to produce very convincing depictions of these same objects. Acquisition of skill is known to be related to the adaptation of existent mechanisms to the task constraints, and investigating expert performance may reveal processes that are unnoticed in novices (Ericsson & Lehmann, 1996). For instance, expertise in action video games or chess has been related to long-lasting improvements of sensory processes (Li, Polat, Makous, & Bavelier, 2009), visual attention (Green & Bavelier, 2003, 2007), visual working memory (Chase & Simon, 1973; Gobet & Simon, 1996) as well as changes in brain structures (Draganski & May, 2008). In the present study, we will show that a better visual memory is an important contributor to drawing skill.

An accurate drawing must respect the relative spatial positions of the object’s features. However, the encoding of the features’ spatial positions may be impaired by the many eye and hand movements made throughout the drawing process (Coen-Cagli et al., 2009; Crawford, Medendorp, & Marotta, 2004; Glazek, 2012; Land, 2006; Ogawa, Nagai, & Inui, 2010; Tchalenko, 2007, 2009; Tchalenko & Miall, 2009). One possibility is that all the features and their spatial relationships are stored in visual working memory. However, this would likely overload visual working memory (e.g., Alvarez & Cavanagh, 2004; Wheeler & Treisman, 2002). In two previous studies we hypothesized that the features themselves would

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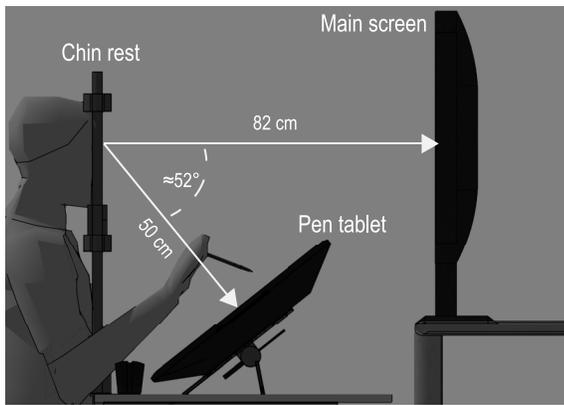


Figure 1. Experimental setup. The original figure was displayed on the main screen (Apple Cinema HD Display). Each participant copied the original figure on an interactive pen tablet. The gaze direction was approximately orthogonal to the surfaces of both displays.

not be encoded in visual working memory but only their spatial organization—the object’s structure. Similar memory mechanisms have been observed in experts in chess who encode local spatial structures of chess pieces (perceptual chunks) that are integrated into more complex chunks (memory chunks or templates) stored in long-term memory (Gobet & Simon, 1996).

When drawing, a chunking mechanism for visual structure would help construct a robust internal representation of the to-be-drawn object. In support of this idea, Tchalenko and Miall (Tchalenko, 2009) found that drawing experts segment the original object into sets of related lines (segment) that can be drawn in a single movement (De Winter & Wagemans, 2004; Van Sommers, 1984). In addition, drawing experts produce more strokes from fewer, briefer fixations (Glazek, 2012) indicating a more efficient encoding of visual information. In line with this earlier work, we have found that drawing accuracy was related to the ability to better integrate object structural information across eye-movements (Perdreau & Cavanagh, 2013) as well as to a more efficient, faster encoding of object structure during a single fixation (Perdreau & Cavanagh, 2014). Despite this clear advantage in processing structural information, it has not been investigated yet whether artists have any additional advantage in visual memory during an actual drawing task.

The role of visual working memory in drawing has been discussed in several studies (Cohen, 2005; Glazek, 2012; McManus et al., 2010; Tchalenko & Miall, 2009; Tchalenko, 2009). Visual memory may have two different roles during a drawing task: guiding the production while the original is out of sight and visually comparing the original to the copy in order to detect mismatches. Regarding the former

aspect, visuomotor tasks involving high memory load are known to be associated with eye-movements strategies that reduce the amount of information to be stored: Observers more frequently update visual information by making regular eye-movements toward the source of information rather than relying on a memory representation in order to guide the ongoing action (Ballard, Hayhoe, & Pelz, 1995). A similar argument has been made for drawing where experts are found to make more frequent gaze shifts between the original and the drawing than novices (Cohen, 2005). Specifically, visual working memory would not be critical because the perceptual information would be directly mapped to the drawing production instead of being stored in visual working memory (Tchalenko & Miall, 2009; Tchalenko, Nam, Ladanga, & Miall, 2014).

Nevertheless, expertise in drawing undoubtedly depends to some extent on visual working memory. In particular, drawing experts outperform novices in visual memory tasks using complex figures and spatial organization of features (Cohen & Jones, 2008; McManus et al., 2010; Rosenblatt & Winner, 1988). However, these studies did not address how visual memory is involved in drawing itself, as the experiments did not include any actual drawing. Here, we address two questions about the nature of visual memory during drawing. First we examined whether the representation stored in memory includes the whole object structure or only the features currently being drawn. Second, drawing involves visual memory of both the original and the drawing that is being produced and we examined whether there was any difference in the accuracy of the two representations.

To examine these issues, we designed a “Pen tablet” experiment where we coupled a “drawing” task with a change detection task. Participants copied a simple shape (“original”) on an interactive pen tablet (“drawing”) in a point-by-point process that joined the previous point to the newly positioned point. They could only see one image at a time, alternating between the original and the drawing (see Figure 1). Although this point-by-point copying process is far simpler than the continuous control of a pen or pencil in a standard drawing task, it does have the element of active production of an image that is our main interest. To test the memory resources involved in this active production, changes were made to either the “drawing” or the original figure at various times throughout the “drawing” process. These changes were only made to either figure while it was not displayed, and at different possible locations more or less distant from the last drawn point. In addition to continuing the “drawing,” participants had to correct any deviations they noticed. All of these were analyzed as a function of the participant’s drawing skill, measured separately.

General method

Participants

Twenty-one adults participated in our experiment (average age: 27.7 ± 1 , 13 females). Though the present study did not aim at investigating artistic abilities (aestheticism or creativity), we did recruit professional artists ($n = 3$) in order to increase the range of drawing skills within our participant sample. All subjects were paid 20 euros for participating and were naïve about our hypotheses and about the purpose of the study. They all had normal or corrected-to-normal vision. Finally, informed consent was obtained in writing prior to participation and the protocols for the study were approved by the Université Paris Descartes Review Board, CERES, in accordance with French regulations and the Declaration of Helsinki.

Material

Original figures were presented on a 30-inch flat screen (Apple Cinema HD Display, Apple CA) with a resolution of 1920×1080 pixels ($42^\circ \times 28^\circ$) and a refresh rate of 60 Hz (main screen). “Drawings” were made on an interactive pen tablet (Wacom Cintiq 24HD, ARP Suisse SA, Rotkreuz, Switzerland) with a resolution of 1920×1080 pixels ($55^\circ \times 36^\circ$) and a refresh rate of 60 Hz. The participant’s chin was held in a chinrest so that his or her eyes were at a distance of 82 cm from the main screen’s center and 50 cm from the pen tablet’s center. The chin rest’s height was held constant (the chair’s height was adjusted for each participant), so that the viewing angle was approximately orthogonal to the surfaces of both displays (Figure 1).

Assessment of drawing skill

As we did in a previous study (Perdreau & Cavanagh, 2014), we assessed our participants’ drawing skill by asking them to perform a drawing task and then by ranking their drawings through a web-based experiment. Participants had 15 minutes to copy a gray-scale picture of an inverted house as accurately as possible. Because of the many details in the picture and the limited time, we instructed our participants to start by copying the house’s structure, then its details, and if they had enough time, to copy the house’s environment. This process made sure that all participants had at least drawn the house’s structure, which was used in our subsequent analysis.

Next, drawings were compared through an online experiment. Randomly selected pairs of drawings as well as the original picture were presented to independent observers ($n = 171$, average age: 30.4 ± 0.9 , 128 females) who had to choose which of the two drawings more precisely matched the original house. Each drawing pair has been compared a minimum 60 times by independent observers. Then, drawings were ranked using an ELO ranking system (Elo, 1978; Perdreau & Cavanagh, 2014). The web-application can be found on the website of one of the authors: www.florianperdreau.fr). Higher ELO scores mean better drawing accuracy. These scores were used to characterize our participants’ drawing skill and were correlated to the participants’ performances in the subsequent experiment. However, in order to make the interpretation of the data easier, we also split our participants into two groups according to the median ELO score: Participants were considered as “skilled” if they scored above the median (median = 1557.6), and “novices” if they scored below.

Experiment

Stimuli

Target figures that our participants had to copy were randomly-generated polygons with 10 points each (Figure 2). Each figure was initially designed to fall within a circle of 600 pixels of diameter (approximately 13.90° of visual angle on the main screen) and was generated by randomly selecting points with a distance from the circle’s center greater than half of the radius and distant from the other points by at least 60 pixels (1.4°). Moreover, every figure was designed to have a total area equal to 80% of that of the circle. A total of 72 figures were generated and used in this experiment.

Procedure

All participants started the experiment with a “practice drawing block” of 12 drawing trials in order to make them more familiar with the pen tablet. The task was to copy on the pen tablet the original figure displayed on the main screen as accurately as possible (i.e., respecting the shape, size and position). A “drawing trial” consisted in the full completion of a single “drawing” (see Movie 1). The drawing process was characterized by two alternating phases: an encoding and a drawing phase (Figure 3A). During the encoding phase, the original figure was shown for 1 s, while the drawing was blanked out on the pen tablet. In contrast, the original figure was not visible during the drawing phase and the drawing was

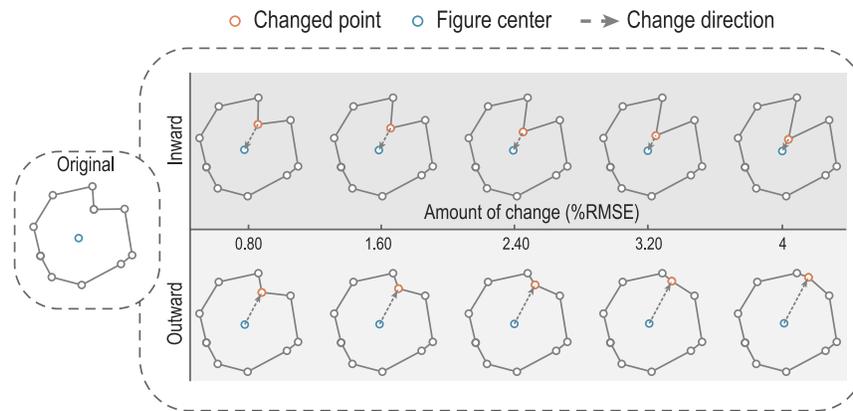


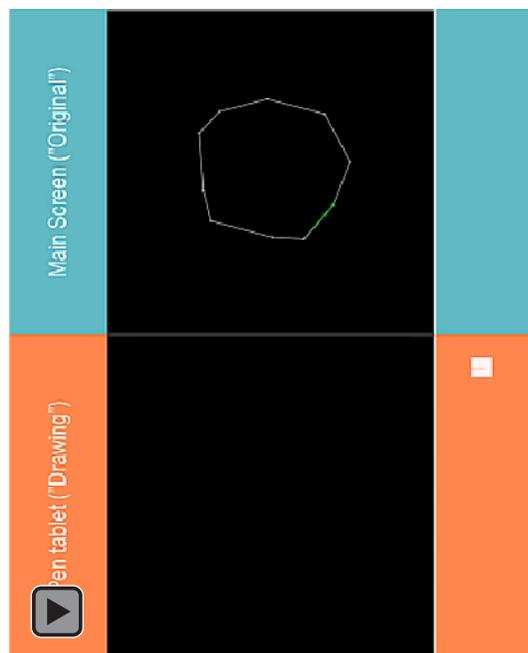
Figure 2. Example of change in a polygonal figure. A change was defined as a displacement of a single figure's point. This displacement could be either inward or outward relative to the Figure's center. Even though each change was local, we represented the size of the change as a percentage of change in the global structure (percentage root mean square error, %RMSE, between all initial locations and the new locations, with only one different). We measured our participants' sensitivity to change as a function of this dependent variable.

displayed on the pen tablet until the participant drew one point (average drawing duration for each point: 1514 ms [SE: 69]). These phases were repeated until the “drawing” was completed. Specifically, participants did not have to trace the line segments of the figure but only to mark the ending point, and they were only allowed to trace a single point during each drawing phase. However, each line segment was automatically traced on the pen tablet as the participant's hand was moving over the pen tablet's surface, which allowed participants to use visual feedback as in natural drawing conditions.

Each “drawing trial” started with the display of the target figure on the main screen with a randomly chosen point colored in red indicating the first point to be drawn, and an adjacent point colored in green indicating the next point to be drawn. On the next presentations of the original figure, the to-be-drawn segment and its corresponding ending point were colored in green. We measured the accuracy of the participant's “drawings” across the 12 trials of this practice block by computing the difference (%RMSE) between the locations of the final 10 points on the “drawing” and those on the original figure: the smaller this difference, the more accurate the “drawing” (see Perdreau & Cavanagh, 2014).

Next, each participant performed seven test blocks (12 “drawing trials” in each block), which used the same procedure. Although the task was identical to that of the “practice drawing block,” participants were instructed that several changes (“change detection events”) could be made at unpredictable moments throughout the copying process, either on the invisible original figure during the drawing phase or on the invisible “drawing” during the encoding phase. Participants had to correct their “drawing” every time they noticed a change in either the drawing or the original, so that their “drawing” always matched the currently displayed original shape. Particularly, they were allowed to only correct one point at a time by clicking on its position with the pencil's eraser to remove it and then by drawing it again at the desired location. The first of these seven blocks was considered practice for the change detection and correction procedure and the data from this first block were not included in the analyses.

“Change detection events” consisted in the displacement of a figure's point relative to the figure's



Movie 1. Experiment demonstration.

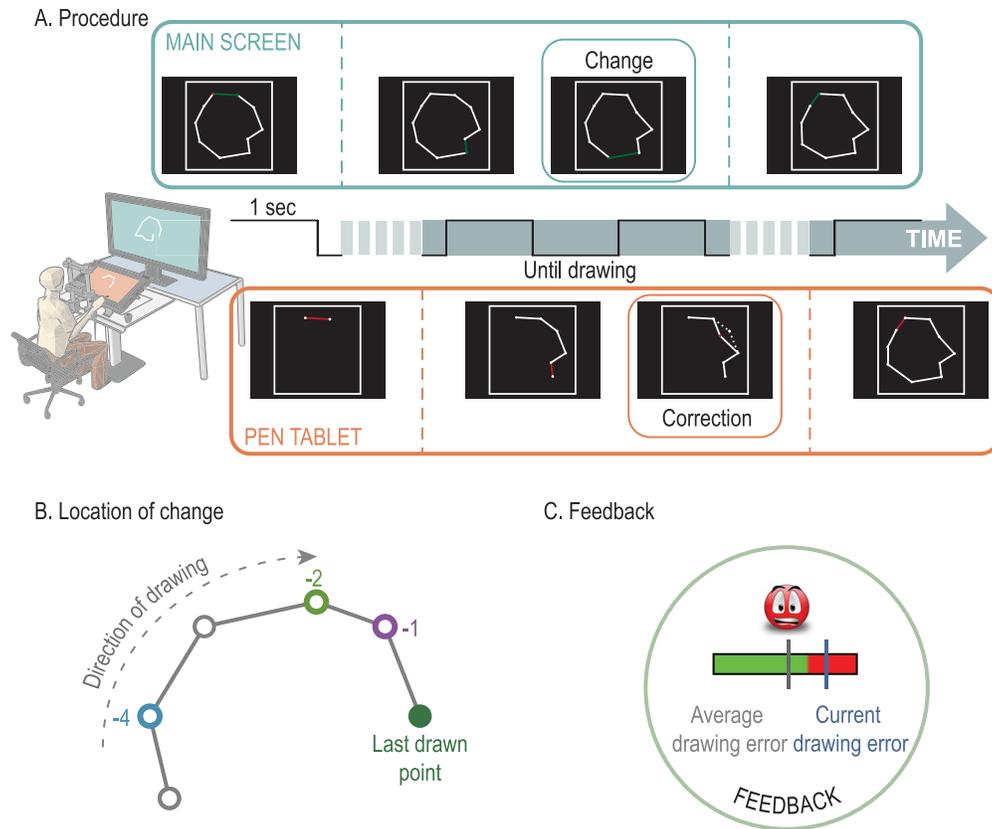


Figure 3. (A) Experimental procedure. Throughout the drawing process, the original and the “drawing” were displayed in alternation. While the original was displayed on the main screen (duration 1 second), the participant’s “drawing” was blanked out, and conversely. The participant was only allowed to draw a single point when the original was not presented. Once the participant had drawn a point, the “drawing” was removed from the pen tablet, and the original was then presented on the main screen. Each trial started with the display of the original on the main screen. A red point on the original figure indicated the first point to draw, and a green point indicated the next to-be-drawn point. (B) Location of change. In addition to varying the amount of change (size of displacement relative to the overall figure’s size), we manipulated the location of change relative to the last drawn point in both the original and the “drawing.” (C) Feedback. Feedback was given to participants at the end of each “drawing” that indicating their drawing’s accuracy (defined as the %RMSE) relative to their average accuracy during the practice trials. Participants were encouraged to keep their current performance within the green area (i.e., not exceeding their average drawing error in the practice drawing block by more than 2 SD).

center, which could be either inward or outward (Figure 2). Although the change was only local, it affected the whole figure’s shape so that we computed a global percentage of change resulting from this local modification across all 10 points (%RMSE):

$$\%RMSE = \sqrt{\frac{\sum (c_d - c_o)^2}{n} \times \frac{100n}{\sum c_o}} \quad (1)$$

where C_d are the coordinates of the points in the modified figure, C_o the coordinates of the points in the original figure, and n the number of points ($n = 10$). We varied this percentage of change from 0% (no actual change) to 4%. Finally, “change detection events” could occur at different locations relative to the last drawn point (Figure 3B): either on the previously

drawn point (–1), on second previously drawn point (–2) or on the fourth previously drawn point (–4).

Finally, to encourage participants to focus on their drawing accuracy, a feedback “meter” was presented at the end of each “drawing trial” (see Figure 3C). Feedback consisted in a horizontal bar with a gray line centered on it that indicated the participant’s average drawing error (i.e., difference between the “original” and the “drawing” expressed as %RMSE) from the “practice drawing block” and a blue line that indicated the current drawing’s accuracy. Participants were encouraged to keep their accuracy at a level similar or better than they had in their initial block (in the green region) by monitoring their current performance on this feedback meter. The green region (OK performance) extended to the right of the vertical line to allow some margin of error (actually set to two standard

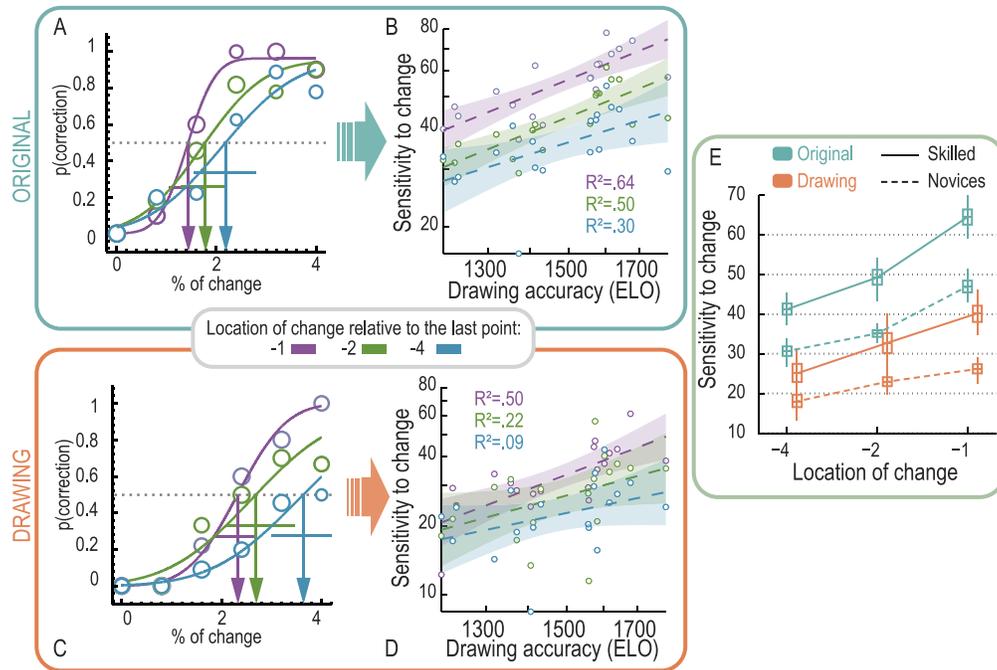


Figure 4. Skilled participants detect more changes in the “drawing” task. (A) and (C) For each participant, we measured the threshold percentage of change leading to 50% of correct responses, for both place of change (Drawing and Original) and for every location of change relative to the current drawing location. Next we computed the inverse of the threshold as sensitivity to change. (B) and (D) We computed a linear mixed-effects model with participants’ drawing skill and the location and place of change as fixed factors. Sensitivity was higher for changes occurring in the original figure than in the “drawing,” and more skilled participants were overall more sensitive to changes regardless of these conditions. (E) Summary graph were participants have been divided in two levels of drawing skill relatively to the median value (ELO score) measured during the traditional drawing task (Skilled: $n = 10$; Novices: $n = 11$). Error bars represent the 95% confidence interval of the means.

deviations of the error scores of the practice drawing block). Participants were instructed to keep the blue line (current performance) out of the red zone. To reinforce this feedback, a smiley face was displayed above the horizontal bar, and its emotion corresponded to the result (“happy” if the blue line was within the green area, “disgruntled” if it was within the red area).

Our experimental design included three within-subject factors: the place of change (original, drawing), the location of change relative to the last drawn point (-1 , -2 , -4) and the percentage of change (six intensities from 0% to 4% of global change); and participants’ drawing accuracy as between-subject factors. We collected a total of 360 change detection events for each participant (10 events per condition), where 83.3% of them were actual changes (global change greater than 0%).

Results

First, to be considered valid, a correction had to be made on a point where a change detection event had occurred. Corrections made on points where change detection events did not occur were excluded from the

subsequent analyses. Next, we computed the proportion of valid corrections as the ratio between the number of valid corrections over the total number of change detection events for each degree of change (six intensities ranging from 0% to 4% of global change). Then we fitted cumulative Gaussian function to the participant’s proportion of correct responses as a function of the percentage of change (Figure 4A and 4C) for each location of change relative to the last drawn point and for each screen of change (Drawing vs. Original). Next, we measured the threshold percentage of change needed so that the participant reported a change in 50% of the cases. Finally, we computed our participants’ sensitivity to change by taking the inverse of these thresholds:

$$\text{Sensitivity} = \frac{1}{\text{threshold}} \quad (2)$$

Next, we evaluated whether participants’ sensitivity was affected by the context, “Drawing” versus the “Original,” by its location relative to the last drawn point (-1 , -2 , -4) or by participants’ drawing skill. To do so we fitted a linear mixed-effects model to participants’ sensitivity with all of these fixed factors, and with subjects as a random factor to account for our

repeated measures design (Figure 4B and 4D). We found that overall, our participants' sensitivity was higher for changes occurring in the original figure than in their own "drawing," $\chi^2(1) = 275.4$, $p < 0.0001$, and higher for changes occurring on locations closer to the last drawn point, $\chi^2(2) = 155.1$, $p < 0.0001$, for the linear regression of sensitivity over the -1 , -2 , and -4 locations. As expected by our hypothesis, skilled participants were overall much better at detecting changes, and this was true regardless of the location of the change (in the drawing or in the original) or of its location relative to the last drawn point, $\chi^2(1) = 22.8$, $p < 0.0001$. We found a significant interaction between the place of the change and its location, $\chi^2(2) = 14.2$, $p < 0.0008$, and also between participants' drawing skill and the location of change, $\chi^2(2) = 12.3$, $p < 0.002$. There was a marginally significant interaction between participants' skill and the place of change, $\chi^2(1) = 2.94$, $p = 0.086$. However, these interactions should be considered as artifacts of the nonlinearity of the decay of sensitivity as a function of the location of the changed point relative to the last drawn points (see Figure 4E). These interactions were no longer significant when participants' sensitivity was log-scaled, $0.23 < P < 0.86$, whereas the main effects previously described remained highly significant ($p < 0.0001$).

The decrease of sensitivity with distance from the last drawn point held for each participant individually and suggests a recency effect in the memory for locations rather than a complete representation of the object structure. It should be noted that all the figure's points were always simultaneously presented, so that this result may indicate an effect of the time since attention was last directed to the point. There may only be a memory representation of recently attended points, a claim that also underlies the blindness to changes of unattended locations in other studies (Rensink, O'Regan, & Clark, 1997; Simons & Rensink, 2005).

Interestingly, more skilled participants did show the advantage for more recent locations, although they were more sensitive than novices to changes occurring at these locations by about 48% (SE: 10) in the "original" condition and by about 54% (SE: 24) in the "drawing" condition. It should be noted, however, that the duration of the drawing phase (when only the "drawing" is visible) varied across participants, since it lasted until a segment was drawn. Therefore, the time interval between two successive presentations of the original figure may vary between participants and therefore could have contributed to the better performances observed in our skilled participants. However, this was not the case. More skilled participants took more time on average to complete the drawing phase (skilled: 1760 ms [SE: 74], novices: 1353 ms [SE: 70]), which should make the recall of the original figure even more challenging.

It is possible that skilled participants were not holding more positions in memory but rather holding the same number as novices but with better resolution (Zhang & Luck, 2008). To test this, we measured the residual errors in the corrections made by our participants (the remaining deviation after correction) and compared that to their accuracy in the original drawing evaluation when copying the house. The correlation between log-transformed residual spatial errors and the initial drawing accuracy (ELO score) was significant and negative, $r(19) = -0.52$, $p < 0.02$, $R^2 = 0.27$, suggesting that more skilled participants made more accurate corrections. This result suggests that skilled participants do have better resolution in visual memory. More skilled participants were not only overall better at identifying which point had changed, but they were also more accurate at remembering its previous position.

General discussion

We have addressed a number of questions concerning the nature of memory representations while drawing: Are all features' locations stored in visual memory or only those relevant to the current drawing action? Are the original figure and the drawing represented at an equal level of detail or does one prevail and guide the drawing process? Moreover, we asked in both cases whether experts in drawing had an advantage. Although the role of visual memory in drawing has been discussed in previous studies (Cohen, 2005; Glazek, 2012; McManus et al., 2010; Perdreau & Cavanagh, 2013, 2014; Tchalenko, 2009; Tchalenko & Miall, 2009), it has never been directly tested during the drawing process itself yet. Here, we designed an interactive pen tablet experiment coupled with a change detection task that allowed us to measure visual memory performances of participants while they were copying a figure. Participants of various levels of drawing skill had to copy an original figure on a pen tablet and were instructed that several modifications could be brought to both the original figure and their own production. They had to correct their "drawing" every time they noticed a change so that it always matched the current version of the original, although the original and the "drawing" were never presented at the same time. We varied the amount of overall change resulting from the displacement of a point as well as the location of the change relative to the last drawn point.

Our results showed that participants were overall better at detecting a change when it occurred in the original figure than in their own "drawing" and that their sensitivity to change decreased with increasing distance of the change from the current point being

copied. Because change detection performance indicates what has been attended (Rensink et al., 1997; Simons & Rensink, 2005), the first finding suggests that the original figure receives more attention than the drawing possibly because of the requirements of planning the upcoming pen motion to copy the locations in the original (Bock, Dose, Ott, & Eckmiller, 1990; Favilla, Gordon, Hening, & Ghez, 1990; Gordon & Ghez, 1987; Kalaska & Crammond, 1992; Tchalenko & Miall, 2009).

We found a strong relationship between participants' drawing skill and their sensitivity to change, although this relationship did not interact with the previously mentioned effects. This suggests that more skilled participants may have a more accurate representation of both the original figure and their own drawing. Although there was an advantage for more skilled participants in their sensitivity to change, there was no difference in the effect of the location (relative to the current location) for skilled versus unskilled participants. This suggested that the skilled participants were not holding more locations in memory but had a more accurate representation of the locations that were stored (Zhang & Luck, 2008). In support of this hypothesis, we found that more skilled participants made more accurate corrections when they repositioned the point where they had detected a change.

What would explain the greater accuracy of the more skilled participants? The simplest explanation is that more skilled participants might allocate their attention more efficiently to locations in the original and the drawing that are critical for the task. This more efficient focus of attention may increase the resolution of stored visual representations and decrease the amount of irrelevant information (Awh, Jonides, & Reuter-Lorenz, 1998; Zhang & Luck, 2008). An alternative hypothesis is that more skilled participants call on a specialized form of visual memory while creating the drawing (e.g., Gobet & Simon, 1998; Perdreau & Cavanagh, 2013). We cannot discriminate between these two alternatives with our data here and further research will be required to disentangle them.

Our task was a simplified version of a natural drawing task in that our participants only needed to control the end point of the segment and not the position throughout the tracing of a segment. Nevertheless, this simplified task did require participants to actively produce a figure rather than passively remember one. Moreover, a previous study failed to report a difference in accuracy in simple line copying between drawing experts and novices, suggesting that motor control of hand movements for copying isolated segments was not an important aspect of drawing experts' skill (Tchalenko, 2007; and particularly Tchalenko, 2009, p. 793). Therefore, despite the simplified nature of our task, it shared the critical aspects of active production with the traditional drawing task that allowed us to examine

whether drawing skills are related to memory advantages when actively producing an image.

Conclusions

This study investigated the role of visual memory in the drawing process and its relation to drawing skill. Although this issue has been discussed in previous studies (Cohen, 2005; Glazek, 2012; McManus et al., 2010; Rosenblatt & Winner, 1988; Tchalenko, 2009), the present study is the first to measure memory performances during “drawing.” Using an interactive pen tablet experiment coupled with a change detection task, we showed that all the feature positions are not equally represented in visual memory. First, spatial positions in the original are more accurately remembered than those of the drawing itself, suggesting that an internal representation of the original would be adequate to guide the production. Second, spatial positions related to the segment currently being reproduced are more accurately represented than those of previous segments, which is consistent with the idea that only information relevant to the current hand movement are stored and maintained in visual memory (Ballard et al., 1995; Ballard, Hayhoe, Pook, & Rao, 1997). Finally, more skilled participants in drawing had a strong overall advantage in detecting changes in both the original and the drawing. This suggests that drawing skill may be related to a better resolution of spatial positions in memory (Zhang & Luck, 2008).

Keywords: drawing accuracy, visual memory, spatial position, change detection

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