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Versions

Learning to See by Learning to Draw: A Longitudinal Analysis of the Relationship Between Representational Drawing Training and Visuospatial Skill

Abstract

A growing body of correlational research has revealed systematic relationships between various aspects of visuospatial processing and representational drawing ability. However, very few studies have sought to examine the longitudinal development of the relation between drawing and visuospatial ability. The current investigation explored change in drawing and visuospatial skill in art students taking a foundational drawing course (n = 42) in a longitudinal design. Measures of representational drawing skill, dispositional traits, and visuospatial skill were taken at three time points over the course of five months. The findings reveal improvements in representational drawing, mental rotation, disembedding figures, and attentional switching. However, individual differences in change over time on one task did not predict change in another, revealing implications for domain-specific and domain-general aspects of art and design expertise.

Keywords: artists, drawing, spatial skills, visual perception, expertise

Learning to See by Learning to Draw: A Longitudinal Analysis of the Relationship Between Representational Drawing Training and Visuospatial Skill

The basis of expert performance, and the extent to which its acquisition can be attributed to innate versus experiential factors, is a venerable, multi-faceted, and still-contested issue within psychology (see, e.g., Ericsson, Hoffman, Kozbelt, & Williams, 2018; Hambrick, Campitelli, & Macnamara, 2017). Among the many domains of expertise that have been studied, that of representational drawing is one of the most intriguing (Kozbelt & Ostrofsky, 2018), given that drawing is a near-ubiquitous activity in childhood, yet few individuals master the ability to create sophisticated, accurate representations in adulthood. Yet, there is also evidence of children showing adult-like depictive skills prior to any formal training, suggesting drawing may have an innate component (Drake & Winner, 2012). Moreover, unlike many prototypical domains of expertise (like chess), which rely on a thoroughly artificial knowledge base, many scholars have argued that drawing skill builds on, or is at least associated with, basic and universal aspects of visuospatial processing (see Kozbelt & Seeley, 2007).

Artists' Visuospatial Advantages

A growing body of evidence suggests that artists see the world differently from non-artists, as drawing expertise is associated with the enhanced ability to attend to, manipulate, or more effectively process certain (but not all) aspects of visual information. Several specific perceptual or attentional advantages have been proposed as correlates of superior drawing skill. These include: the ability to overcome shape constancy (Cohen & Jones, 2008) and size constancy (Ostrofsky, Kozbelt, & Seidel, 2012), enhanced local processing of visual details (Chamberlain, McManus, Riley, Rankin, & Brunswick, 2013; Chamberlain & Wagemans, 2015; Drake & Winner, 2011) and reduction in holistic processing (Zhou, Cheng, Zhang, & Wong, 2012), greater field independence (Gaines, 1975), better visual memory (McManus et al., 2010; Winner, Casey, Dasilva, & Hayes, 1991; Winner & Casey, 1992), reduced attentional cost in switching between global and local aspects of visual displays (Chamberlain & Wagemans, 2015), an enhanced ability to recognize degraded images or to pick out embedded visual patterns (Chamberlain et al., 2013; Kozbelt, 2001), lower susceptibility to visual illusions (Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Ostrofsky, Kozbelt, & Cohen, 2015), and access to and greater understanding of robust representations of object structure in memory, which permit efficient encoding and depiction of the most important aspects of objects (Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010; Kozbelt, 2001; Ostrofsky et al., 2012; Perdreau & Cavanagh, 2011, 2013, 2014).

Not all of these claims about artists' superior perceptual processing have gone unchallenged or yielded completely consistent patterns of results. For instance, several studies (McManus, Loo, Chamberlain, Riley, & Brunswick, 2011; Ostrofsky et al., 2012) have failed to replicate earlier findings that artists outperform non-artists on shape constancy tasks. Chamberlain and Wagemans (2015) found no difference in artists' and non-artists' experience on a variety of visual illusions. Perdreau and Cavanagh (2011) similarly failed to find evidence for artists' advantages on tests of size constancy, lightness constancy, and amodal completion. Ostrofsky, Kozbelt, and Kurylo (2013) found no differences between artists and non-artists in the ability to perceptually group different sets of elements in a noisy visual display. These findings may in part reflect the methodological challenges facing researchers in this area of inquiry, such as maintaining homogeneity of participant samples in terms of levels of drawing expertise and producing reliable and robust paradigms to measure visuospatial performance. Methodological challenges notwithstanding, such findings strongly suggest that artists' perceptual advantages over non-artists are not monolithic.

The Acquisition of Drawing Expertise and Its Visuospatial Correlates

The process by which artists acquire their drawing and perceptual expertise also remains mysterious, since the nature of this development, as well as which aspects of perception might be implicated as the strongest correlates of improving drawing ability, has as yet gone largely unstudied. The extant literature largely reports correlations between visuospatial advantages on the one hand and drawing or artistic skill on the other. From correlational research alone it is not possible to determine whether individuals with latent visuospatial skills are more likely to become skilled at drawing, or whether training in art and design confers visuospatial benefits on students.

An exception to this pattern of correlational research is a recent study by Tree and colleagues (2017), in which a group of art students (*n* = 64) completed a year-long foundational art and design course with substantial training in portraiture, and completed tests of face recognition at the beginning and end of the course. There was no significant improvement in face recognition by the art students relative to a group of controls. An additional behavioural and neuroimaging study assessed changes in brain structure and function in relation to an 11-week program of training in art and design (involving a 4-hour per week training session), alongside three measures of artistic and perceptual ability (Schlegel et al., 2015). Relative to a control group, the authors reported that the art students became more creative and improved in their ability to produce gesture drawings after art and design training but did not demonstrate any changes in perceptual ability (assessed through the strength of visual illusions) over time. Further, the authors found no correlation in changes in creative ability and changes in gesture drawing ability, suggesting that these two skills develop independently. In addition, art students showed changes in neuronal activity in the cerebellum and cerebral cortex relative to controls, but no structural changes. Notably, structural differences have been previously documented in a correlational study comparing a group of art-students and non-art students with substantial amounts of art and design training

(Chamberlain et al., 2014), suggesting that functional changes may give rise to structural differences over the long-term – that is, in the course of years of artistic training. However, as Schlegel et al. (2015) did not report baseline structural differences in art students and non-art students, it is not possible to confirm if structural differences were already present in the two samples.

Whilst research by Schlegel et al. (2015) and Tree et al. (2017) provide an intriguing glimpse into the potential of art and design training to confer advantages in creative output, visual memory and perception, both studies were limited in the range of behavioural tasks utilised and the training regime employed. For instance, previous research has failed to find a reliable association between the strength of visual illusions and artistic expertise (Chamberlain & Wagemans, 2015), and the relationship between face processing and portraiture skill is still a subject of debate (Devue & Barsics, 2016; Tree et al., 2017). Therefore, it is not altogether surprising that the 11-week art and design training course did not give rise to differences in illusory strength. However, this null finding does not entail that art and design training never confers any benefits on perceptual processing – especially given the number of studies in the literature that have reported at least some artist advantages on perceptual measures, as described above. Therefore, in the current study, we aimed to evaluate the effect of a more rigorous and longer-term training regime (8-hours per week training plus substantial homework assignments for five months) encompassing a wider range of visuospatial skills that have previously been shown to reliably distinguish artists from non-artists.

Some additional hints about the longitudinal relation between perceptual and drawing skill and perceptual performance may be obtained from a few studies that have examined their general relations. For instance, Kozbelt (2001) found that artists outperformed non-artists on both drawing and perceptual tasks, supporting the idea that artists perceive the world differently than non-artists; moreover, performance on the two sets of tasks was positively correlated. Statistically controlling for one or the other kind of task revealed that artists' perceptual advantages appear to be developed in the service of their drawing skills. Thus, artists' perceptual advantages are best viewed as a subset of their drawing advantages. A recent extension of this work is a more comprehensive study by Chamberlain et a. (2019), examining artists' and non-artists' performance on a wide range of perception and drawing tasks, and largely replicating this basic finding (see also Kozbelt & Seeley, 2007).

The upshot of these two studies (Chamberlain et al., 2019; Kozbelt, 2001) is that artists' perceptual advantages appear to be developed largely to the extent that they are useful in drawing. This suggests that the acquisition of drawing skill drives changes in perception, but it does not rule out the possibility that artist may have some initial perceptual advantages as well. Along these lines, Chamberlain et al. (2019) found that art students, even at the very beginning of their college-level art and design education, outperformed college-level non-artists on several standard visuospatial tasks, including mental rotation, embedded figures, and bistable figure perception. In other low-level visual tasks, such as visual illusions and identifying degraded pictures, art students performed similarly to non-art students. The overall findings indicated that tasks that emphasize top-down (i.e., knowledge-, expectation-, or endogenous attention-driven) influences on visual attention appear to be already facilitated among art students before they embark on their undergraduate studies, either as a result of latent ability or prior training. These findings (alongside the aforementioned correlational research; e.g. Chamberlain et al., 2013; Chamberlain & Wagemans, 2015; Kozbelt, 2001; McManus et al., 2010; Ostrofsky et al., 2015, 2012; Zhou et al., 2012) suggest artists' perceptual advantages are best viewed as a subset of their drawing advantages.

The Current Study

While the preceding studies have begun to constrain the nature of the relation between perception and drawing, the longitudinal relation between the two – a potentially rich source of evidence – has received little attention. It is thus the main motivation for the current study. Specifically, we examined a sample of college-level art students as they progressed through an intensive first-year drawing curriculum at Pratt Institute for Art and Design, New York. We compared their performance on a wide range of drawing and visuospatial tasks at three points, spanning five months. The group of visuospatial tasks measured: mental rotation, local and global visual processing (embedded figures, out-of-focus picture test, visual illusions, Navon hierarchical shape task) and attentional flexibility (bistable perception). These tasks were selected to represent a range of levels of visual processing (top-down and bottom-up) and have been validated and investigated in relation to artistic skill in previous research (Chamberlain, Heeren, Swinnen, & Wagemans, 2018; Chamberlain et al., 2013; Chamberlain & Wagemans, 2015; Kozbelt, 2001). As mentioned previously, those tasks which emphasize top-down effects on visual perception, are most reliably found to be correlated with drawing skill, while tasks representing bottom-up mechanisms usually produce null effects. It was valuable to include tasks of the latter variety (e.g. visual illusions) as a form of control measure, such that it was not anticipated that participants would improve on these measures. Since artists' perceptual advantages still represent a nascent area of inquiry, it is important to attempt to replicate even previous null findings.

The data from the first testing session are the same as the art student data reported by Chamberlain et al. (2019); the longitudinal aspect of the data, from the remaining two testing sessions, is new and speaks directly to the question of how drawing skill emerges, and what its perceptual correlates are.

We expect drawing performance to improve over the three sessions, since after all this is what the art students are being trained in. More open is the question of what will happen to performance in the various visuospatial tasks over time, and how those tasks are themselves inter-related. Given the relatively low correlations among visuospatial tasks previously reported (Chamberlain et al. 2019), we expect that many of our visuospatial tasks will be largely independent. Even if this is the case, we expect that at least a subset of the visuospatial tasks will show improvement over time. Which ones? On the one hand, tasks on which art students already show early advantages (as found by Chamberlain et al. 2019) might already be approaching a ceiling effect, even if there is some slight room for continued improvement; in this view, other visuospatial tasks relevant to drawing might have greater scope for improvement, simply because of their initial lower performance level. On the other hand, tasks that already show an art student advantage might inherently be more important for drawing (at least the kind of drawing emphasized in the training regimen we are studying) and more amenable to ongoing improvement; thus, artists may continue to make marginal gains in performance on such tasks, beyond their initial advantages. This is an empirical question, one at the heart of the present study.

Besides possible longitudinal changes in drawing and perceptual abilities taken one task at a time, we are also interested in exploring the extent to which different tasks show similar trajectories. That is, are individual differences in longitudinal improvement on one kind of visuospatial task related to individual differences in longitudinal improvement in drawing? This is a more exploratory question, but one which the acquired data will allow us to answer. In a similar vein, we will compare observed longitudinal changes in drawing and perception with certain demographic factors such as personality, approaches to learning, and non-verbal IQ. These background variables have previously been shown to be correlated with representational drawing ability in a large sample of art students, and as such may shape aspects of drawing skill as it develops (Chamberlain, McManus, Brunswick, Rankin, & Riley, 2015).

Method

Participants

The sample consisted of 42 first-year art students enrolled at Pratt Institute, who were taking an intensive foundation drawing course (37 females; M_{age} = 18.6; *SD* = 1.0).

The foundation year drawing course at Pratt Institute includes courses in Drawing, Light, Color and Design, Material and Three-dimensional Form, Stills to Motion, and Shaping Time. The drawing training component of the course constitutes eight hours of instruction per week, with additional homework assignments. This is aimed at developing skills in understanding and analysing space and 3D structure, and synthesising and inventing new forms. Art students were registered for a wide range of artistic majors: animation (*n* = 8), graphic design (*n* = 7), fine arts (*n* = 6), illustration (*n* = 5), industrial design (*n* = 4), advertising (*n* = 4), interior and fashion design (*n* = 3), photography and film (*n* = 3), and art therapy (*n* = 1). Most art students (*n* = 35) reported practicing drawing every day or a few times a week for the past two years, both inside and outside of class (for full practice data see Table 1 in Chamberlain et al., 2019).

Materials and Procedure

All participants were tested in three 1.5-hour sessions spanning a five-month period. Testing sessions took place in a quiet room on the Pratt Institute campus. The first testing session (T1) took place within the first two weeks of the fall semester, as students were starting their studies. The second testing session (T2) took place approximately two months after the first, when the students were halfway through the intensive drawing training component of the course. Between T1 and T2 students had learnt two-point perspective and how to construct paraline drawings, and they had begun to draw invented forms in perspective. The final testing session (T3) took place approximately three months later (i.e., five months after the initial session), at the end of the drawing training component of the foundation course, before the students began work on their final semester projects. Between T2 and T3 students had learnt how to convey tonal contrast in their drawings, how to integrate tonal contrast with structural drawing elements (e.g. contour lines) and how to convey movement in drawing. For practical reasons, tasks were administered in a standardized order, the same order in which they are described below, with participants completing visuospatial tasks on the computer first, followed by pencil and paper drawing tasks. In the first session, participants also completed questionnaires prior to the series of computer-based visuospatial tasks and non-computer-based drawing tasks. In subsequent sessions, participants completed only the computer-based visuospatial tasks and non-computer-based drawing tasks. All computer tasks were performed on a 13-in. liquid crystal computer screen with a 60 Hz refresh rate. Stimulus presentation was presented using the Psychopy package (Peirce, 2007). Each participant received $100 for participating in all three testing sessions.

Questionnaire measures. In the first testing session only, participants completed a demographic questionnaire on their date of birth, gender, ethnicity, handedness, academic major, and the amount of time they spent drawing in the two years prior to the study. In addition, participants completed a series of validated questionnaires:

Study habits/approaches to learning. The Study Process Questionnaire (SPQ) assessed the self-rated study habits and approaches to learning on three separate scales (Surface Learning, Deep Learning and Achieving [Strategic] Learning). A shortened version of the questionnaire was presented (Fox, McManus, & Winder, 2001), which had 18 items that were each rated on a 4-point scale (1 = Strongly disagree; 4 = Strongly agree). Surface approaches learning are motivated by a fear of failure, a deep approach learning is motivated by interest in the subject matter itself, and an achieving learning style is motivated by a desire for success. This questionnaire was previously used in a study relating drawing skills to personality factors in a sample of art students (Chamberlain et al., 2015), but the content refers to learning in a general sense rather than being tailored to learning in an art and design context.

Big Five personality measures. Participants were provided with the 15-item list of questions from the Household Panel Survey based on the Big Five Inventory (John, Naumann, & Soto, 2008). Items were each rated on a 5-point scale (1 = Strongly disagree; 5 = Strongly agree). Scores were calculated for the standard Big Five dimensions of Neuroticism, Extraversion, Openness to Experience, Agreeableness and Conscientiousness.

Visuospatial tasks.

Raven's Advanced Progressive Matrices. (RAPM: Arthur, Tubre, Paul, & Sanchez-ku, 1999). Participants completed a shortened version of the RAPM, which represents a valid and normalized predictor of non-verbal IQ. Participants were given one practice item from Set I of the RAPM. They were then given 12 items from Set II of the longer 36-item RAPM to complete in 15 min.

Mental Rotation Task (MRT). Individual differences in the manipulation of visuospatial information were tested using a Mental Rotation Task (Hunt, Davidson, & Lansman, 1981; Shepard & Metzler, 1971). Pairs of 2D drawings rendering 3D block constructions were presented to participants. The stimuli were presented as black drawings on a white background. There were 10 practice trials followed by 16 experimental trials, presented in a randomized order. In each trial, participants had to indicate via key press whether the drawings presented depicted the same object from two different angles (key = S) or two different objects (key = D). There was no per trial time limit, but participants had a time limit of 3 min to complete as many of the 16 trials as they could. Accuracy and reaction times were recorded.

Out-of-Focus Pictures Task. Individual differences in the processing and recognition of degraded images were tested using an Out-of-Focus Pictures Task similar to that used by Kozbelt (2001). We selected 125 photographs from the International Affective Picture System (IAPS: Lang, Bradley, & Cuthbert, 1999) because of their easily recognizable subject matter. In Photoshop, each image was resized to 4 inches in height at 100 pixels per inch and converted to grayscale. We then modified each image into four progressively blurrier versions based on a Gaussian blur of 100 pixels at 2-, 4-, 6-, and 8-pixel radii. Thus, each image had five versions (the original and the four levels of blurriness). A pilot test on the images was conducted with 100 participants using Amazon's Mechanical Turk. We created five sets of images with no image duplicated within the set and randomly assigned participants to view one of the sets. For each image, participants were asked to indicate the scene or object depicted. Based on the pilot data, 45 of the 125 images were selected for inclusion in the main study; these elicited good variation in performance, without floor or ceiling effects. These were then separated into three groups of 15 stimuli for use in the three testing sessions. Each group of 15 had an even distribution of easy and difficult images.

In the main task, participants were instructed that they would be shown a series of 15 blurred pictures for up to 15s each and that they should try to identify what was in each picture by typing a free response after the image was shown. Participants were given unlimited time to type their response before proceeding to the next trial. Participants first completed two practice trials (with feedback) and then completed 15 test trials. Free-responses were coded for accuracy by two independent raters (inter-rater reliability $r = .96$). Responses that named an exemplar or the class of the object (e.g., tulip or flower) were counted as correct. Summed accuracy scores were calculated for each participant.

Embedded Figures Task (EFT). Individual differences in disembedding performance were examined using a modified version of the Embedded Figures Test (Witkin, 1950), which has been validated and used in previous research (Chamberlain, Van der Hallen, Huygelier, Van de Cruys, & Wagemans, 2017; Chamberlain & Wagemans, 2015; de-Wit, Huygelier, Van der Hallen, Chamberlain, & Wagemans, 2017; Huygelier, Van der Hallen, Wagemans, de-Wit, & Chamberlain, 2018). Stimuli were presented as black patterns on a white background. Participants were presented with complex 2D or 3D patterns presented below a 2D target shape. Participants were asked to search for the upper target shape in the lower complex pattern and report whether the target was present (key = J) or absent (key = F) within 12s. Participants were given six practice trials with feedback before completing the experimental trials. There were 40 experimental trials containing an equal number of target present and absent trials. The order of trials was randomized for each participant. Accuracy and reaction times were recorded.

Navon Hierarchical Shape Task. Individual differences in local and global visual processing were assessed in a selective attention Navon shape task, similar to that used in Caparos, Linnell, Bremner, de Fockert, and Davidoff (2013). On each trial, a large shape made up of smaller white shapes on a black background was presented. On some trials, many small shapes comprised the larger shape; on other trials, the shapes that made up the larger shape were fewer and larger (Figure 1). This created trials in which the local level (small shapes) was more salient and trials in which the global level (large shape) was more salient.

Participants were instructed to focus on either the large shape or the small shapes in blocks of 16 trials. There were 32 practice trials (two blocks) followed by 128 experimental trials (eight blocks). In each trial participants were instructed to respond to the identity of the shape (square = F key, triangle = J key) at the allocated level of attention (local/global). The stimulus shape was presented onscreen for 300ms and participants were given up to 2s to respond. The inter-trial interval was 1s. Participants were given positive or negative feedback with a colored fixation cross after each trial in both the practice and experimental blocks. Accuracy and reaction times were recorded.

Visual illusions task. Individual differences in the strength of visual illusions were investigated via three illusions: the Ebbinghaus, Muller-Lyer, and Rod-Frame. The method of continuous adjustment was used to measure participants' responses. Illusions were presented as black shapes on a white background. For each trial, an illusory stimulus was presented on one half of the screen while a test shape was presented on the other half (the locations of the illusory stimulus and the match stimulus were randomized). Participants were required to match the test shape (a line or a circle) to the illusory stimulus on the screen, adjusting the relevant parameters (line angle or length/circle radius) using the up and down arrow keys. When participants were satisfied with their match, they could continue to the next trial. There was no time limit. Participants matched stimuli in two illusion trials and two control trials per illusion. Control trials consisted of matching the size of two circles without surrounding circular inducers (Ebbinghaus), matching the length of two lines without surrounding arrow inducers (Muller-Lyer), and matching the angle of two lines without a surrounding frame inducer (Rod-Frame).

Bistable Figure Task. Individual differences in the ability to manipulate internal perceptual representations were tested using the Bistable Figure Task. Specifically, participants viewed a structure-from-motion (SFM) rotating cylinder consisting of two transparent planes of random white dots (6 pixels in diameter) moving in opposite directions on a black background, along a vertical axis (Chamberlain et al., 2018). There were 400 dots on screen at any time moving at a speed of 0.20 full cycles per second. The global percept of motion of the stimulus can be perceived as going from left to right or from right to left (that is, as counter-clockwise or clockwise rotation, if one imagines viewing the cylinder from the top). Participants were shown a practice stimulus and instructed how to access each percept.

Only when participants had reported that they could experience each percept were they allowed to proceed to the experimental trials.

Three trials were presented to each participant, each lasting 120s. In each trial participants were asked to gently fixate on a red point in the centre of the visual stimulus. As they viewed the stimulus they were asked to indicate which of two competing percepts they were currently experiencing. They did this by holding down one of two keys (F = clockwise, J = counter-clockwise) on the keyboard for as long as they experienced that direction. If they saw a mixture of the two percepts or no one percept dominated they were asked to refrain from pressing either of the response keys. Participants completed three trials one of each of the following conditions, presented in a fixed order:

1. Passive fixation: Participants were instructed to focus on the stimulus but not to try to control which percept they saw at any given time.
2. Hold fixation: Participants were asked to hold one percept in mind for as long as possible.
3. Switch fixation: Participants were asked to switch between percepts as quickly as possible.

Participants were encouraged to take breaks between trials to avoid fatigue. Rates of reversal and percept duration were measured by recording the length of time the key corresponding to each percept was pressed as well as the number of times the participant changed keys during each trial. For efficiency of data analysis, only the Switch trials of the Bistable Figure Task were analysed, as these have been shown in a previous study to relate to artistic expertise (Chamberlain et al., 2018).

Drawing tasks.

Observational Drawing Task. To assess freehand drawing skill, participants were given a still-life set-up consisting of common objects including a cup, bowl, fork, bottle, and paper bag. Participants were asked to draw the arrangement as accurately and completely as possible in 10 min; if they had time, they were permitted to add shading and detail. Participants were instructed not to move the objects while drawing.

Limited-Line Tracing Task. Individual differences in the ability to select the most important information to include in a depiction were tested using a Limited-Line Tracing Task, developed by Kozbelt et al. (2010). Here the stimulus was a grayscale photograph of an elephant on a white piece of 8.5×11-in letter paper (as in Ostrofsky et al., 2012). For the tracing task, the photo was placed inside a clear plastic folder. Participants were instructed to create depictions of the elephant by tracing over the photo directly onto the folder using 40 2cm × 2mm pieces of dark brown duct tape. A white piece of paper was available for sliding between the tracing and the photograph, so participants could see their tracing without interference from the photo underneath. Participants were instructed to use all the available line segments to create a tracing that was as accurate as possible, given the constraints of the medium. Participants could bend segments but could not tear them into smaller pieces; they could also move a piece of tape after having used it in the tracing if they decided it would go better somewhere else. Participants had 10 min to complete the task.

Drawing ratings. Participants' drawings for the Observational Drawing Task were rated by a sample of 10 non-expert student judges from Brooklyn College and six expert judges who were art and design tutors teaching the foundational drawing course at the Pratt Institute, who were blind to the identity of the creator of each drawing. Each judge was asked to rate the quality of each drawing by sorting them into seven categories. Judges were asked to rate the overall quality of the drawings based on the following rubric:

1. Does the drawing follow a consistent viewpoint?
2. Is the 3D rendering of oval shapes correct (cup, bowl, bottle)?
3. Are the relationships between the objects rendered appropriately?

4. Does the drawing hold together?
5. Is the drawing sitting on a ground plane?
6. Do the details in the picture follow the form of the objects?
7. Does the drawing sit well on the page?
8. Is the line-quality effective in depicting depth?

The same judges rated the Limited Line Tracing Task in terms of overall accuracy relative to the original photograph.

The judges were not restricted in terms of how many drawings they could put into any one category from 1 being the worst to 7 being the best. When the judges were satisfied with their distribution of drawings, each drawing was assigned the number of the category in which it was placed in (1 = worst, 7 = best). Inter-judge reliability indices (equivalent to Cronbach's alpha) were very high for both judge groups (artist judges = 0.95 for the Limited-Line Tracing Task and 0.98 for the Observational Drawing Task, non-artist judges = 0.97 for the Limited-Line Tracing Task and 0.95 for the Observational Drawing Task). The ratings of non-expert and expert raters correlated strongly for both the Observational Drawing Task (r [155] = 0.81, $p < .001$) and the Limited Line Tracing Task (r [153] = 0.58, $p < .001$). Therefore, a composite rating score for each participant was calculated by averaging the ratings of all 16 raters for each task.

Abbreviated Torrance Test of Creative Thinking. As a proxy measure of creativity focusing on divergent thinking, we used one form (A: figural) of the Abbreviated Torrance Test of Creative Thinking (ATTA; Goff, 2002). The task consisted of two subtests, both timed at 3 min. The first required participants to create a drawing from their imagination based on a simple shape provided on a sheet of paper. In the second, participants were required to make a series of drawings based on a simple repeated shape of triangles. After completing each subtest, participants were asked to provide titles for their drawings.

Participants were encouraged to create drawings that were as novel and as interesting as possible. Responses to the ATTA were scored by two independent judges (post-graduate psychology students at Brooklyn College, City University New York) according to criteria specified in the ATTA handbook (Goff, 2002). Four key creative facets were derived from the two subtests of the ATTA:

1. Fluency: the ability to produce a number of task-relevant ideas.
2. Originality: the ability to produce uncommon or unique ideas.
3. Elaboration: the ability to embellish ideas with details.
4. Flexibility: the ability to produce a variety of different ideas

Inter-rater reliability was 0.72 for Test 1 and 0.80 for Test 2. For each drawing, a score was calculated for each of the four creative facets based on the average of the two raters. These four facets were then averaged to give total scores for Test 1 and Test 2. Scores for the two tests were then averaged to give a total creativity score for each participant.

Ethics

The study was approved by the Institutional Review Board at Brooklyn College, City University New York.

Results

The results are organized into two sections. First, we analyze change in performance on each dependent measure (drawing and visuospatial tasks) over the three sessions, using linear mixed effects analyses. Second, we assess the roles of various dispositional characteristics and visuospatial skill in understanding individual differences in the rate of change in representational drawing performance over time. Descriptive statistics (Table A1) and correlations between variables at each time point (Table A2) are included in the Appendix.

The variables selected for the linear mixed effects analysis were the same ones analyzed previously in a between-groups design comparing art students and non-art students (Chamberlain et al. 2019; the art student data in that study were identical to the session 1 data analyzed here; the current study adds the longitudinal element of data from the second and third sessions). These variables were:

1. Visuospatial tasks: accuracy and RT in the Navon hierarchical shape task, Bistable figure reversals, error in visual illusions (Muller-Lyer; Rod-Frame and Ebinghaus), accuracy in the out-of-focus pictures task, accuracy and RT in the EFT, and accuracy and RT in the mental rotation task.
2. Drawing tasks: rated performance on the ATTA, Limited-Line Tracing Task, and Observational Drawing Task

Correlation matrices (Table A2) at each time point showed few inter-task dependencies, justifying analysis of each visuospatial task independently, rather than as amalgamated variables.

We used the program *R* (R Core Team, 2013) and package *nlme* (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2018) to perform a linear mixed effects analysis of the relationship between the independent variable of time (that is, session number) and performance on each experimental task. Linear mixed effects analyses model hierarchical or nested data, which are common in longitudinal datasets: here, time points (T1/T2/T3) in a longitudinal dataset are nested within each participant. Linear mixed effects analysis was used to characterise overall patterns in the data (i.e., mean trajectories of time-related change) and, within these overall patterns, to assess individual variation in intercepts (i.e., baseline performance) and slopes (i.e., patterns of change over time). This approach enabled us to include fixed effects that account for a mean trajectory, characterising the mean skill development of the whole sample, whilst simultaneously including random effects that identify individual-level variation among the intercepts and slopes.

Change in Drawing and Visuospatial Performance Over Time

To test for the effect of time on performance for each of the drawing and visuospatial tasks, we followed a formal model-fitting procedure.

1. We started with a null (unconditional) model with a fixed intercept only (variable ~ 1).
2. We then created a model with random intercepts, to allow for individual differences in starting points (variable ~ 1|subject).
3. We then added a fixed effect for time (T1/T2/T3) to the model (variable ~ time|subject).
4. Finally, we added random slopes for the effect of time (full model; variable ~ time + (1 + time|subject).

Where inspection of residual plots indicated a deviation from homoscedasticity and normality we performed appropriate transformation of the raw data.[1] Statistical *p* values were obtained by likelihood ratio tests for each model against the previous model.

Table 1 shows the longitudinal results for the linear mixed effects analysis for each task. First, we report the fixed effect of change in performance over time. Most importantly, art student performance changed reliably over time on several tasks, evident in the column showing estimates for fixed effect of Time. Specifically, among the drawing tasks, participants showed reliable improvements on the Observational Drawing Task over time (Figure 1) – a sensible result consistent with participants' intensive training in drawing – but no improvement on the Limited-Line Tracing Task or the ATTA. In terms of visuospatial

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[1] A logarithmic transformation was applied to the reaction time data of the Mental Rotation Task as it was positively skewed.

task performance, participants showed a reliable decrease in reaction time on both the Mental Rotation Task and the Embedded Figures Task, implying greater efficiency in performing these tasks as their training progressed, with the caveat that we cannot rule out the influence of practice effects (see Discussion). In addition, participants showed a decrease in accuracy on the Mental Rotation Task, indicating a speed-accuracy trade-off, however with a much greater decrease in reaction time than in accuracy (Table 1). In addition, there was a reliable increase in the number of voluntary reversals participants could make on the Bistable Figure Task. There were no reliable changes in performance on the Out-of-Focus Pictures Task, the Visual Illusions Tasks, or the Navon Task.

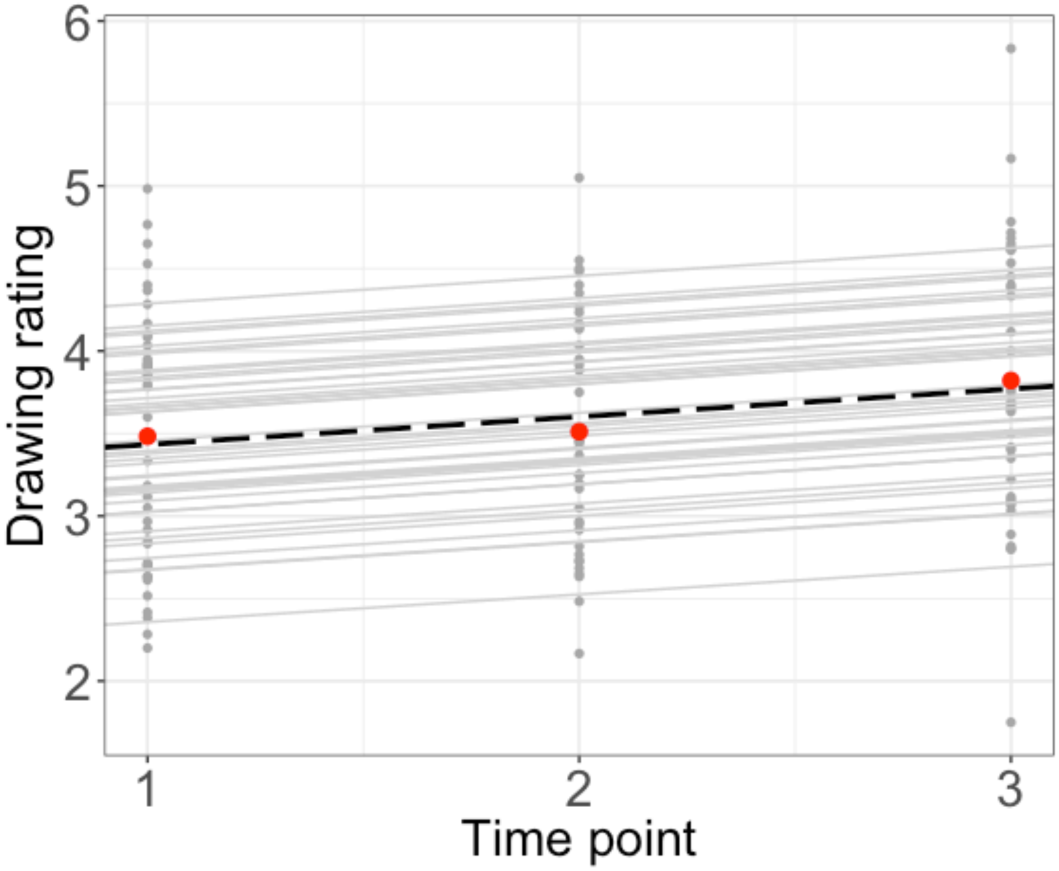

Figure 1. Score change over time in the Observational Drawing Task. The black dotted line indicates fixed effect of time in linear mixed effects analysis and the red dots represent mean scores at each time point. Grey lines represent participants' random slopes between time points.

Table 1

Linear mixed effects models with time as fixed effect and intercepts and slopes as random effects.

Variable	Fixed Effect (time)			Random Effects (Intercept and Slope)			
				Intercept		*Time*	
Drawing Tasks	Coefficient	SE	*t* test	SD	Chi-squared test	SD	Chi-squared test
Observational Drawing	0.17	0.06	2.82**	0.54	24.27***	0.009	< .01
Limited-Line Tracing	0.07	0.09	0.80	0.84	2.14	0.43	10.05**
ATTA	-0.03	0.54	0.06	5.48	7.77**	1.82	1.93
Visuospatial Tasks							
MRT RT	-0.26	0.03	8.42***	0.50	20.22***	0.10	5.63
MRT Accuracy	-0.04	0.01	3.04**	0.11	10.27**	0.02	0.75
EFT RT	-0.55	0.07	7.65***	0.52	1.92	0.25	2.81
EFT Accuracy	-0.02	0.01	1.44	0.11	<0.001	0.05	1.61
Out-of-Focus	0.31	0.19	1.62	2.13	9.84**	0.56	3.33
Muller-Lyer	-0.43	1.82	0.24	16.73	13.12***	6.58	1.69
Rod-Frame	-0.14	0.15	0.93	0.80	< .001	0.32	0.25

Ebbinghaus	-0.35	0.78	0.45	10.85	10.42**	3.85	13.16**
Bistable switch reversals	2.67	0.84	3.18**	7.14	26.70***	0.85	0.49
Navon Local Inter RT	-0.01	0.008	1.17	0.06	<.001	0.02	1.20
Navon Global Inter RT	0.001	0.006	0.17	0.006	0.02	<0.001	0.001

Notes: *$p < .05$, **$p<.01$, ***$p < .001$; ATTA = Abbreviated Torrance Test for Adults; MRT = Mental Rotation Task; EFT = Embedded Figures Task; RT = Reaction Time; Inter = Interference. *n* = 42

Time-point specific changes. We explored the extent to which significant fixed effects revealed in the linear mixed effects analysis, were indicative of improvements in task performance between specific time-points (T1/T2/T3). Table 2 shows a series of within-subjects *t* tests for changes in the dependent variable between each time-point. With Bonferroni correction ($p < .004$) comparisons between all time-points are significant for the MRT and EFT RT. However, only T1-T3 comparisons remain significant for accuracy on the observational drawing task and the number of voluntary switches made in the bistable perception task.

Table 2

Between time-point comparisons for tasks showing a significant fixed effect of time in the linear mixed effects analysis.

	T1 – T2	T2 – T3	T1 – T3
Observational drawing	$t(38) = 0.08$, $p = .94$	$t(38) = 2.59, p = .01$	$t(38) = 3.03, p = .004$*
MRT RT	$t(37) = 4.51, p < .001$*	$t(37) = 4.49, p < .001$*	$t(37) = 8.19, p < .001$*
EFT RT	$t(37) = 4.65, p < .001$*	$t(37) = 3.82, p < .001$*	$t(37) = 7.19, p < .001$*
Bistable switch reversals	$t(35) = 1.91, p = .06$	$t(35) = 1.35, p = .19$	$t(35) = 3.44, p = .002$*

Notes: *significant after Bonferroni correction for multiple comparisons ($p <. 004$); MRT = Mental Rotation Task; EFT = Embedded Figures Task

In sum, artist participants showed longitudinal gains in some (but not all) aspects of drawing performance and visuospatial processing. In addition, many tasks also showed substantial remaining unexplained variability in intercepts or slope, as given by the significant chi-squared statistics in Table 1. This mixed pattern of longitudinal change (together with the low correlations among tasks within each session, reported in Appendix Table A2) suggests that the perceptual and performative basis of skilled drawing is not monolithic, but rather is nuanced and highly multi-faceted.

While such probing for longitudinal changes on each task is useful for establishing which measures might be amenable to improvement through training, this approach does not inform the longitudinal relations among the variables. That is, how might different measures change in tandem as training progresses? Of greatest interest, which measures co-vary with the observed improvement in drawing skill? The second part of the Results section takes up this question.

Predictors of Change in Representational Drawing Ability Over Time

The sum of random conditional models and the fixed effect coefficients per participant were derived from the previous linear mixed effects models with time as a fixed effect and performance on each drawing or visuospatial task as the dependent variable. The slopes of the drawing tasks were then correlated with the slopes of each visuospatial task, alongside the personality measures (Big Five, Study Process Questionnaire) and the measure of baseline drawing ability – that is, performance on the Observational Drawing Task at T1 (Table 3). The change in drawing performance as a function of time predicted change in the Limited-Line Tracing Task performance (despite the non-significant overall effect for the Limited-Line Tracing task reported above) after Bonferroni correction, but it did not reliably predict change in performance on those tasks that also showed improvement over time: Embedded Figures, Mental Rotation or Bistable Figures tasks (Table 3). Drawing change over time was mildly negatively predicted by drawing score at T1, deep and achieving approaches to learning, and conscientiousness, and positively by neuroticism. Change in the Limited-Line tracing task was significantly correlated with drawing change and a reduction in interference by local elements in the Navon figure task, while changes in performance on the ATTA were only mildly negatively correlated with deep approaches to learning and errors on the Ebbinghaus illusion, and did not survive statistical correction (Table 2). A full correlation matrix of all the visuospatial task random slopes and background variables can be found in the Appendix (Table A3).

Table 3

Pearson correlations between individual participant slopes representing score change on the Observational Drawing Task, Limited-Line Tracing Task, and ATTA, compared to individual participant dispositional variables and visuospatial task slopes (*n* range = 39-42).

	Observational Drawing	Limited-Line Tracing	ATTA
Dispositional Variable			
Visual IQ	-0.09	0.14	-0.20
T1 observational drawing	-0.26	-0.20	-0.28
Deep approach	-0.25	-0.21	-0.37*
Achieving approach	-0.25	-0.15	0.09
Surface approach	0.08	0.25	0.20
Neuroticism	0.32*	0.14	-0.22
Extraversion	0.01	-0.01	0.03
Agreeableness	-0.01	0.11	0.04
Openness	-0.09	-0.14	-0.16
Conscientiousness	-0.33*	-0.31	-0.01
Drawing Task Slope			
Observational drawing	1.00	0.50***	-0.11
Limited-Line Tracing	0.50***	1.00	0.05
ATTA	-0.11	0.05	1.00
Visuospatial Task Slope			
MRT RT	0.19	0.20	-0.27

MRT Accuracy	0.03	-0.03	-0.14
EFT RT	-0.05	0.002	0.02
EFT Accuracy	0.05	0.16	0.15
Out of focus	-0.05	0.06	0.23
Muller-Lyer	-0.19	-0.22	0.07
Rod-frame	0.04	-0.04	0.006
Ebbinghaus	0.06	-0.03	-0.35*
Bistable reversals	-0.11	0.02	-0.11
Navon Global Inter RT	0.06	-0.12	0.04
Navon Local Inter RT	-0.36*	-0.43**	-0.15

Note. *$p < .05$, **$p < .01$, ***$p < .0007$ (Bonferroni corrected p-value = 0.05/72 = 0.0007). The slopes for each drawing and visuospatial task are computed as the sum of random conditional modes and the fixed effect coefficients per participant for that task.

Discussion

The current study tracked the development of drawing and visuospatial skills in foundation level college art students taking a five-month intensive drawing training course. The study of the acquisition of drawing skill – and its perceptual correlates – speaks to active psychological debates surrounding the nature of expertise (Ericsson, Hoffman, Kozbelt & Williams, 2018), and it provides new evidence on the role of practice and talent in the visual arts (Kozbelt & Ostrofsky, 2018).

Our present findings indicate that art students improved in several aspects of visuospatial and artistic skill over the observed five-month period. Specifically, their performance on observational drawing, mental rotation, disembedding figures, and attention switching tasks increased over the course of the study. However, other aspects of perceptual processing did not change: susceptibility to visual illusions, local and global attentional processing, identification of degraded images, as well as performance on the limited-line tracing and creativity tasks. In terms of correlations among patterns of change across tasks, the results were somewhat haphazard, with a few learning approaches and personality measures, as well as some perceptual measures, being associated with changes in performance on the three drawing measures here and there. No clear, consistent overall pattern emerged that would be suggestive of a core set of associated skills that develop as an ensemble over the course of drawing training.

Among these various results, one notably discrepant finding was that participants did not improve in performance on the ATTA, a result that conflicts with the findings of a previous study (Schlegel et al., 2015), which showed longitudinal improvements in creative performance and gestural drawing. However, there are key differences between the current study and that of Schlegel and colleagues. First, the participants in Schlegel et al.'s (2015) study were non-art students, and as such had little prior artistic training. In contrast, the art students in the current study already had amassed several years of artistic experience and had gained entry to a prestigious art and design school. As our prior study demonstrated (Chamberlain et al. 2019), these students were already outperforming non-art students prior to starting their foundation course. Therefore, it is possible that the ATTA may not have been sensitive enough to measure changes in artistic creative output over time in an expert group. Moreover, recent research has also shown complex interactions between divergent thinking tasks and self-report measures of actual artistic creative activity (Lunke & Meier, 2016), suggesting that there may not be a clear link between artistic training and performance on standard creativity or divergent thinking tasks. This highlights the importance of matching specific training regimes (i.e., the intensity and duration of the training as well as the kinds of skills it targets) to specific sets of perceptual and cognitive skills.

As noted above, it was not possible to directly link the impact of drawing training on the change in visuospatial skills, as there were almost no reliable correlations between drawing performance change and visuospatial performance change; perhaps other aspects of the course that the students were engaged in were responsible for their improvement on skills such as mental rotation (e.g., 3D design work). In the case of mental rotation, decreases in reaction time could be linked to the degree of rotation of the stimulus from the target, making more specific characterization of the gains in mental rotational abilities conferred by the development of a specific artistic skill. It was not possible to clarify this from the stimuli used in the current study, but future research may be able to tie improvements in mental rotation to underlying stimulus parameters which would better link into the type of training undertaken. This discussion further motivates the need for research in which numerous intervention groups are employed, with specific kinds of art and design skills isolated (e.g., expressive drawing versus technical drawing). Individual differences in change in drawing performance were moderately correlated with performance at baseline (those who started with lower performance improved the most) as well as with deep and achieving approaches to studying and conscientiousness and neuroticism. The most likely explanation for these latter findings is that those low in deep/achieving motivations and conscientiousness started off with poorer drawing performance, and therefore began the study with more room for improvement. This tallies with the fact that those scoring lowest in drawing at T1 showed the most improvement over the course of the study.

Also, whilst recent research has characterized the role of practice in drawing expertise (Chamberlain et al., 2015) in finding that certain kinds of practice and dispositional traits predict high-level drawing ability, little evidence has been advanced to suggest that there is a *causal* relationship between training in drawing and other skills putatively associated with artistic expertise. As such, it is not known whether individuals with certain (predominantly visuospatial) skills are more inclined to pursue further training in art and design, or whether the training and practice itself confers these benefits. This is in stark contrast to the large body of evidence from longitudinal designs suggesting that musical training exerts causal impacts on perceptual and cognitive abilities (e.g. Hallam, 2001; Moreno et al., 2011; Rodrigues, Loureiro, & Caramelli, 2013; Tierney, Krizman, & Kraus, 2015).

A more significant limitation of the current study was that there was no control group in which to measure change in visuospatial performance over time without a drawing intervention. Previous research (albeit with much larger sets of stimuli) demonstrated that reaction times decrease as a function of practice in mental rotation (Heil et al. 1998; Kail & Park, 1990) and embedded figures tasks (Ludwig & Lachnit, 2004). However, a few factors support the notion that the improvements witnessed in drawing and visuospatial skill over time are due to some aspect of the students' foundational art and design training. First, we ensured that the stimuli presented were sufficiently different in each testing session and participants were given practice sessions for each task prior to the onset of each task, such that practice effects were minimized as much as possible. Furthermore, it is pertinent to note that art students did not improve uniformly across experimental tasks, and that they significantly improved in the same tasks in which they outperformed non-art students at baseline (Chamberlain et al. 2019). Undoubtedly in future studies it would be advantageous to include a control group without a drawing training intervention, with a focus on those tasks that are likely to elicit change over time, in order to robustly demonstrate that the improvement in these tasks could not be explained by practice effects.

In conclusion, the current study is the first to our knowledge to explore the longitudinal development of drawing and visuospatial skills via intensive drawing training using a large battery of well-validated tasks. The results demonstrate the malleability of a range of visuospatial abilities, including disembedding figures and mental rotation, although it was not possible to directly link these improvements to improvements of the variable of interest: representational drawing. Notably, those particular tasks that show improvement over time – including mental rotation, disembedding figures, and attentional switching – are for the most part the same tasks that have been shown to distinguish artists from non-artists at baseline (Chamberlain et al. 2019). This suggests that this subset of visuospatial tasks may play a role in the development of artistic skill, and represents a clear focus for future attempts at replication and extension.

Identifying which perceptual processes contribute to and undergird drawing skill is important because it helps demarcate the nature of artistic expertise. This domain differs from many prototypical domains of expertise (like chess) in its flexible, non-artificial nature, in that artists must solve precisely the same kinds of problems in creating depictions that the visual system does generally (Kozbelt & Ostrofsky, 2018). This line of research also raises other issues in the study of expertise, such as the degree to which training in an expert domain transfers benefits inside (near) or outside (far) of that domain, a question under considerable debate. Recent research has produced conflicting findings with regards to the impact of musical and computer game training on attention, intelligence, working memory and processing speed, calling into question whether training in these domains truly leads to far transfer (Sala & Gobet, 2017; Sala, Tatlidil, & Gobet, 2018). As there is very little extant research in this domain, the current study focuses on aspects of near-transfer; those skills such as mental rotation and flexible visual attention that have robust links to artistic ability already, and are conceivably domain-specific (see Chamberlain, 2018 and Kozbelt & Ostrofsky, 2018, for discussions on what constitutes the domain of artistic expertise). However, if drawing training is seen to lead to tangible benefits in skills like mental rotation and attention switching, there may be downstream effects for more domain-general skills, such as analogical or mathematical reasoning (Goldsmith, Hetland, Hoyle, & Winner, 2016).

This, like many other issues raised in this project, is an empirical question and a promising avenue for future research.

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Table A1. Descriptive Statistics (*n* = 42)

		T1		T2		T3	
	Experimental Measure	Mean	SD	Mean	SD	Mean	SD
Drawing Tasks							
Observational Drawing	Rating (/7)	3.48	0.76	3.51	0.71	3.82	0.81
Limited-Line Tracing	Rating (/7)	2.71	0.67	2.70	0.65	2.85	0.79
ATTA	Total score (/19)	13.20	6.04	15.03	5.33	13.07	4.40
Visuospatial Tasks							
Visual IQ	Acc (/12)	6.95	2.51	-	-	-	-
MRT	Acc (%)	0.82	0.14	0.79	0.12	0.75	0.13
MRT	RT (s)	9.59	5.95	7.38	4.58	5.41	2.00
EFT	Acc (%)	0.78	0.14	0.84	0.08	0.73	0.11
EFT	RT (s)	6.07	0.62	5.48	0.82	4.99	0.77
Out-of-focus	Acc (/15)	5.44	2.26	6.21	1.87	6.05	1.85
Muller-Lyer	Length error (deviation from baseline in pixels)	32.82	20.49	32.12	15.80	32.58	19.54
Rod-frame	Angle error (°)	1.35	1.33	3.68	1.26	1.08	1.26
Ebbinghaus	Radius error (deviation from baseline in pixels)	-4.44	9.49	-5.18	3.80	-5.22	6.98
Bistable reversals	Switch (number per minute)	17.62	10.70	19.92	11.08	22.71	11.28
Navon	Global RT (s)	0.61	0.13	0.64	0.10	0.64	0.11
	Local RT (s)	0.65	0.15	0.70	0.11	0.68	0.12
	Global Interference RT (s)	0.03	0.06	0.02	0.05	0.03	0.06

Local Interference RT (s)	0.02	0.07	0.02	0.08	0.04	0.07

Table A2. Correlations between visuospatial and drawing variables at T1, T2 and T3 (*n* range = 34-42)

		Min Line	ATTA	MRT Acc	MRT RT	EFT Acc	EFT RT	Out-of-Focus	Muller-Lyer	Rod-frame	Ebbing-haus	Bistable Switch	Navon Global RT Inter.	Navon Local RT Inter.
Observational Drawing	T1	0.56	0.31	-0.04	-0.04	0.01	0.11	0.17	-0.04	0.07	0.03	-0.04	-0.01	-0.20
	T2	0.71	0.45	-0.15	-0.17	0.42	-0.06	0.10	-0.17	-0.26	0.18	0.20	-0.23	0.03
	T3	0.36	0.08	0.22	-0.04	-0.11	0.11	-0.02	-0.20	0.09	-0.17	0.006	-0.06	-0.09
Limited-Line	T1	-	0.06	-0.11	0.16	0.003	0.16	0.15	-0.18	0.06	0.10	-0.13	0.05	-0.23
	T2	-	0.29	0.13	0.05	0.10	0.22	-0.11	-0.19	-0.18	0.28	-0.003	-0.12	0.18
	T3	-	0.31	0.19	0.04	0.36	0.04	-0.07	-0.23	0.01	0.36	-0.08	-0.19	-0.06
ATTA Total	T1	-	-	0.10	-0.12	0.21	-0.09	-0.16	-0.19	-0.12	-0.14	0.06	-0.30	-0.12
	T2	-	-	-0.01	-0.38	0.23	-0.28	0.03	-0.24	-0.09	0.07	-0.15	-0.15	0.20
	T3	-	-	0.11	-0.06	0.45	-0.21	-0.08	0.03	0.01	0.12	-0.20	0.07	-0.06
MRT Accuracy	T1	-	-	-	0.09	0.41	0.11	-0.10	-0.46	-0.21	0.04	0.12	-0.11	0.08
	T2	-	-	-	0.45	0.03	0.47	-0.07	0.07	-0.02	-0.11	-0.14	-0.21	0.23
	T3	-	-	-	0.31	0.01	0.03	0.05	-0.15	0.18	-0.31	-0.18	0.31	0.12
MRT RT	T1	-	-	-	-	0.13	0.12	0.11	0.03	-0.17	0.04	-0.14	-0.05	0.12
	T2	-	-	-	-	0.003	0.59	-0.27	0.21	0.04	-0.03	0.19	0.19	-0.06

	T3	-	-	-	-	-0.02	0.37	-0.03	0.11	0.01	0.09	0.02	0.12	-0.19
EFT	T1	-	-	-	-	-	-0.10	-0.21	-0.38	0.07	-0.10	-0.05	-0.16	0.08
Accuracy	T2	-	-	-	-	-	0.15	0.14	-0.11	-0.26	0.08	0.13	-0.22	0.03
	T3	-	-	-	-	-	-0.01	0.09	-0.11	-0.14	0.43	0.25	-0.13	-0.05
EFT RT	T1	-	-	-	-	-	-	-0.25	-0.06	-0.11	0.14	-0.10	0.13	0.08
	T2	-	-	-	-	-	-	-0.13	0.07	-0.15	0.11	0.02	0.14	0.02
	T3	-	-	-	-	-	-	0.30	0.009	0.01	0.17	0.22	-0.09	-0.06
Out-of-Focus	T1	-	-	-	-	-	-	-	-0.16	-0.13	-0.30	-0.03	0.11	-0.16
	T2	-	-	-	-	-	-	-	0.09	-0.24	-0.10	-0.17	-0.24	0.11
	T3	-	-	-	-	-	-	-	0.03	0.03	0.21	0.25	-0.18	-0.02
Muller-Lyer	T1	-	-	-	-	-	-	-	-	0.18	0.25	-0.05	0.02	-0.24
Error	T2	-	-	-	-	-	-	-	-	0.09	-0.05	-0.09	0.01	0.03
	T3	-	-	-	-	-	-	-	-	0.13	-0.11	0.03	0.23	-0.26
Rod-Frame	T1	-	-	-	-	-	-	-	-	-	0.27	-0.05	0.02	-0.24
Error	T2	-	-	-	-	-	-	-	-	-	0.09	0.05	0.07	0.05
	T3	-	-	-	-	-	-	-	-	-	-0.17	-0.03	0.43	-0.07
Ebbinghaus	T1	-	-	-	-	-	-	-	-	-	-	-0.10	-0.02	0.19
Error	T2	-	-	-	-	-	-	-	-	-	-	0.20	0.14	-0.06
	T3	-	-	-	-	-	-	-	-	-	-	0.32	-0.21	-0.17
Bistable	T1	-	-	-	-	-	-	-	-	-	-	-	-0.21	-0.15
Switch	T2	-	-	-	-	-	-	-	-	-	-	-	-0.11	-0.18

	T3	-	-	-	-	-	-	-	-	-	-	-	-0.29	0.02
Navon Global	T1	-	-	-	-	-	-	-	-	-	-	-	-	0.06
RT	T2	-	-	-	-	-	-	-	-	-	-	-	-	-0.16
Interference	T3	-	-	-	-	-	-	-	-	-	-	-	-	-0.07

Table A3. Correlations between individual participant slopes (sum of random conditional modes and the fixed effect coefficients per participant) for drawing performance change and visuospatial task slopes, and dispositional variables (*n* range = 34-42).

	Obs Draw	Min Line	ATTA	MRT RT	MRT Acc	EFT RT	EFT Acc	Out-of-focus	Muller-Lyer	Rod-frame	Ebbinghaus	Bistable Switch	Navon Glob RT Inter.	Navon Loc RT Interfere
Background Variable														
Visual IQ	-0.09	0.14	-0.20	0.02	-0.50	0.06	-0.39	-0.14	0.09	0.15	0.17	0.04	-0.004	-0.15
T1 Observational drawing	-0.26	-0.20	-0.28	0.04	0.01	0.06	-0.06	-0.22	-0.11	0.04	-0.01	0.10	-0.20	0.16
Deep approach	-0.25	-0.21	-0.37	-0.26	0.08	0.28	0.13	-0.20	-0.10	0.06	-0.10	0.14	0.01	0.07
Achieving approach	-0.20	-0.15	0.09	-0.12	0.25	0.09	0.22	0.06	-0.14	-0.15	0.01	0.26	-0.19	0.18
Surface approach	0.10	0.25	0.20	-0.12	-0.01	-0.26	0.02	0.15	-0.15	-0.23	-0.13	-0.26	-0.20	-0.07
Neuroticism	0.32	0.14	-0.22	0.08	0.04	-0.17	-0.002	-0.01	-0.20	0.20	0.13	-0.15	-0.04	0.14

Extraversion	0.01	-0.01	0.03	-0.15	0.41	0.05	-0.11	0.23	-0.26	-0.22	-0.15	-0.16	-0.04	-0.13
Agreeableness	-0.01	0.11	0.04	-0.15	0.10	0.02	0.09	0.04	-0.24	-0.20	0.20	0.13	0.04	0.17
Openness	-0.09	-0.14	-0.16	-0.07	0.27	0.23	-0.17	0.29	-0.14	-0.001	-0.01	0.35	-0.12	0.12
Conscientiousness	-0.33	-0.31	-0.01	-0.10	0.42	0.16	0.05	-0.06	-0.19	-0.29	0.10	0.17	-0.23	0.29
Drawing Slopes														
Observational drawing	-	0.50	-0.11	0.19	0.03	-0.05	0.05	-0.06	-0.19	0.04	0.06	-0.11	0.06	-0.36
Limited-Line Tracing	-	-	0.05	0.20	-0.03	0.002	0.16	0.06	-0.22	-0.04	-0.03	0.02	-0.12	-0.43
ATTA Total	-	-	-	-0.27	-0.14	0.02	0.15	0.23	0.07	0.01	-0.35	-0.11	0.04	-0.15
Visuospatial Slopes														
MRT RT	-	-	-	-	0.41	-0.06	0.22	0.07	-0.25	-0.18	0.09	0.14	-0.20	0.04
MRT Accuracy	-	-	-	-	-	0.12	0.31	-0.07	-0.37	-0.39	0.07	0.27	-0.35	0.26
EFT RT	-	-	-	-	-	-	0.12	-0.23	-0.16	0.14	0.14	0.25	-0.01	-0.06
EFT Accuracy	-	-	-	-	-	-	-	-0.10	-0.12	-0.12	-0.16	0.01	-0.43	0.11
Out of focus	-	-	-	-	-	-	-	-	-0.25	-0.03	-0.39	0.08	0.15	-0.01
Muller-Lyer Error	-	-	-	-	-	-	-	-	-	0.30	0.01	-0.03	0.12	-0.02
Rod-frame Error	-	-	-	-	-	-	-	-	-	-	0.05	0.04	0.26	-0.09
Ebbinghaus Error	-	-	-	-	-	-	-	-	-	-	-	0.10	-0.07	0.24
Bistable Switch	-	-	-	-	-	-	-	-	-	-	-	-	-0.02	0.24

Navon Global RT Interference	-	-	-	-	-	-	-	-	-	-	-	-	-0.17