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Precision in drawing and tracing tasks: Different measures for different aspects of fine motor control

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ABSTRACT

Drawing and tracing tasks, by being relatively easy to execute and evaluate, have been incorporated in many paradigms used to study motor control. While these tasks are helpful when examining various aspects relative to the performance, the relationship in proficiency between these tasks was not evaluated to our knowledge. Seeing that drawing is thought to be an internally cued and tracing an externally cued task, differences in performances are to be expected. In this study, a quantitative evaluation of the precision of circle drawing and tracing, and spiral tracing was made on 150 healthy subjects. Our results show that, while precision is correlated when repeating drawing circles, tracing spirals, or tracing circles as well as between tracing spirals and tracing circles; there is no correlation when subjects performed drawing circles and tracing spirals or between drawing and tracing of circles. These results suggest that this lack of correlation is task dependent and not shape dependent. We suggest that the evaluation of fine motor control should include both a tracing and a drawing task, taking in consideration the precision in each task. We believe that this approach could help not only to evaluate fine motor control more accurately, but also to identify subjects who are more reliant on either internal or external cueing and to what extent.

1. Introduction

Tracing and drawing tasks represent attractive tools for the evaluation of various aspects relative to motor control. As such, many paradigms designed to study motor control have incorporated them as part of their assessment. Most of these paradigms use simple shapes as their employment may be both easily executed and measured, while still providing valuable information of upper limb functioning as well as motor control (Smits et al., 2018). Specifically, the precision of performance in spiral tracing tasks has been incorporated as part of the neurologic examination for the evaluation of fine motor control (Cohen, Bravi, & Minciacchi, 2018; Hoogendam et al., 2014; Miralles, Tarongí, & Espino, 2006; San Luciano et al., 2016). On the other hand, circle drawing is widely incorporated in timing-based tasks in which the smooth and continuous motion of circle drawing has been used to compare discrete and continuous motor tasks for timing control (Repp & Steinman, 2010; Robertson et al., 1999; Spencer, Zelaznik, Diedrichsen, & Ivry, 2003; Studenka, Zelaznik, & Balasubramaniam, 2012). In this case, the drawn circles are not evaluated for precision, but for timing consistency between repetitive drawings of the shape. There are also examples in which the precision of the drawn circle was evaluated. It was shown that the area and roundness of the circles correlated with stroke severity and were suggested to represent outcome measures for stroke rehabilitation (Krabben et al., 2011). Also, precision in circle drawing was used to evaluate speed-

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accuracy tradeoff when temporal constraints are introduced (Gatouillat et al., 2017) as well as motor equivalence (i.e., the similarity of movements produced by different sets of motor commands, utilizing different muscle groups; Portnoy, Rosenberg, Alazraki, Elyakim, & Friedman, 2015).

Surprisingly, even though drawing and tracing tasks are widely used to evaluate fine motor control (Mergl, Tigges, Schröter, Möller, & Hegerl, 1999; Smits et al., 2018; Sülzenbrück, Hegele, Heuer, & Rinkenauer, 2010, 2011; Vuillermot, Pescatore, Holper, Kiper, & Eng, 2009), very few studies have investigated the relationship between drawing and tracing. Worth noting are the works of Gowen and Miall, in which the researchers have analyzed eye-hand interactions for both tracing and drawing of simple shapes; they have reported a tighter eye-hand coupling for the tracing task than the drawing task as well as more frequent pursuit eye movements for tracing than for drawing (Gowen & Miall, 2006). Following that, the researchers have further shown that different cerebral areas are activated when drawing was compared to tracing, suggesting the former to be a more cognitive task than the latter (Gowen & Miall, 2007). This is to be expected when also considering that tracing is an externally cued task and drawing is internally cued (Flanders, Mrotek, & Gielen, 2006; Sailer, Eggert, Ditterich, & Straube, 2000; Thut et al., 2000; van Donkelaar & Staub, 2000). In fact, it was shown that externally and internally cued performances may differ. Differences in performance were found when auditory synchronization (externally cued), measured as synchronized wrist oscillations to an auditory stimulus, was compared with auditory imagery (internally cued), measured as wrist oscillations synchronized to the recall of an auditory stimulus, with the auditory synchronization task being more precise than auditory imagery (Bravi et al., 2014, 2015). Specifically, based on autocorrelations of the performances, the auditory imagery task seemed to employ more emergent-based timing whereas the auditory synchronization task a more event-based timing. Also, it was suggested that internally and externally cued tasks may be used evaluate different aspects relative to motor control. This was shown in some auditory-motor paradigms involving finger tapping in which the synchronization phase (externally cued) was suggested as an estimator for anticipatory mechanisms (Repp, 2011; Repp & Moseley, 2012), whereas the continuation phase (internally cued) as an estimator for drift (Collier & Ogden, 2004). These observations not only reinforce the hypothesis that differences in performance for tracing and drawing tasks are to be expected, but also that the two tasks may be used to evaluate different aspects relative to fine motor control.

To our knowledge there is no study that evaluates whether the proficiency in one task correlates to the other. It was shown that substantial difference in precision may exist among individuals in certain types of tasks (Madison, 2004). Also, investigations of precision in an angle reproduction test, for which the results remain relatively constant for repetitions distant in time, have revealed that healthy subjects may be categorized according to their level of precision (Callaghan, Selfe, Bagley, & Oldham, 2002; Perlau, Frank, & Fick, 1995). Therefore, it appears that for certain types of tasks, when not subject to specific training, differences in precision may exist between individuals with some individuals being inherently more or less precise. It is possible to hypothesize that differences in precision among individuals may ensue also for both tracing and drawing tasks. It is also possible that, considering the differences between the tasks, no correlation in terms of performance precision would be found.

In this study, we seek to evaluate whether the precision in drawing and tracing tasks is constant among subjects. If indeed the two tasks evaluate fine motor control, it would be expected that, in the population, precise individuals in one task would also be precise in the other. We consider the two most widely used tasks in literature, spiral tracing and circle drawing. We first assume that subjects may be ranked according to their level of precision in performing either task. Therefore, the initial step consisted in evaluating whether this ranking is persistent (i.e., repeatable) for each task. Following that, in order to compare the tasks, we consider the differences between them, mainly different task and different shape. Therefore, we have fragmented the comparison into two: task comparison for the same shape (i.e., circle drawing compared to circle tracing) and shape comparison for the same task (i.e., circle tracing compared to spiral tracing). Following that we have evaluated the case of a different shape and a different task (i.e., circle drawing and spiral tracing).

Our hypothesis is that tracing, by being being a different task compared to drawing, should not correlate with drawing, in terms of precision in the population. We expect that while subjects may be ranked according to their level of precision for both tracing and drawing, and that this ranking will remain relatively constant for all tasks regardless of shape, the precision in drawing compared to tracing among subjects would not correlate, again, regardless of shape. If our results go in line with our hypothesis, it should be possible to classify subjects as either drawers or tracers and to use this classification to accurately evaluate fine motor control.

2. Materials and methods

2.1. Participants

One hundred and fifty healthy adults were recruited for this study (age: 23.1 ± 2.6 years; 61 males). All participants were right handed (81.7 ± 17.5; laterality score from the Edinburgh Handedness Inventory; Oldfield, 1971). Participants were naive to the task and the purpose of the study, and free of documented visual, motor, and neurological impairments. All subjects reported to have a corrected-to-normal visual acuity. All subjects reported to not have any previous experience in using a graphic pen tablet. The participants were university students who volunteered for the study. Participants were not paid for their participation. The study protocol was approved by the Institutional Ethics Committee (Comitato Etico Area Vasta Centro AOUCareggi, Florence, Italy) and all procedures conformed to the code of ethics of the Declaration of Helsinki. All participants gave written informed consent.

2.2. Set up

The set up in this study is the same as the one used in Cohen et al. (2018) and is briefly summarized. The participants executed

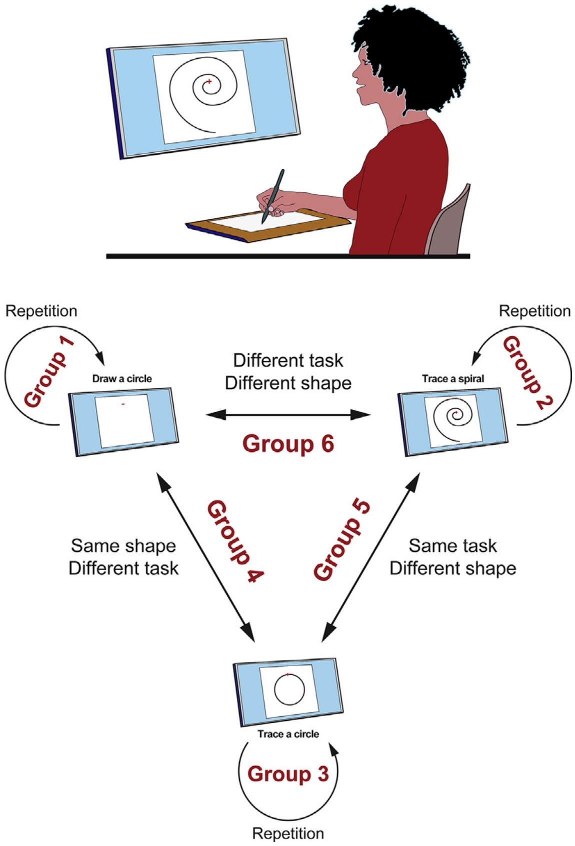

Fig. 1. Setup and experimental design. The upper panel illustrates the working setup used in the experimental session. The graphic pen tablet was placed in front of the screen, and the participants were asked to execute either the drawing or the tracing task, while seated, without the support of either wrist, arm, or elbow, in such a way that the only contact was made through the pen on the tablet. The lower panel illustrates the experimental design. Participants (n = 150) were randomly assigned to one of the six groups, each consisting of 25 subjects: Drawn Circles (Group 1), Traced Spirals (Group 2), Traced Circles (Group 3), Drawn Circles vs Traced Circles (i.e., same shape; Group 4), Traced Circles vs Traced Spirals (i.e., same task; Group 5), Drawn Circles vs Traced Spirals (i.e., different shape and different task; Group 6). Each participant performed 2 trials with a 1-minute interval between them. The trials were different according to the experimental group and consisted of: for Group 1 – draw a circle and repeat; for Group 2 – trace a spiral and repeat; for Group 3 – trace a circle and repeat; Group 4 – draw a circle and trace a circle, randomized order; for Group 5 – trace a circle and trace a spiral, randomized order; for Group 6 – draw a circle and trace a spiral, randomized order.

both tracings and drawings, projected on a monitor, while seated without the support of either wrist, arm, or elbow, in such a way that the only contact with the tablet was made through the pen (Fig. 1). All tasks were performed using graphic pen tablet (Wacom Intuos® CTH-690AK, Tokyo, Japan; active area: 216 × 135 mm).

Each participant was tested individually. Participants were randomly assigned to one of six groups (Fig. 1) composed of 25 participants each: Drawn Circles (Group 1; males = 9), Traced Spirals (Group 2; males = 9), Traced Circles (Group 3; males = 13), Drawn Circles vs Traced Circles (Group 4; males = 10), Traced Circles vs Traced Spirals (Group 5; males = 10), or Drawn Circles vs Traced Spirals (Group 6; males = 10).

2.3. Task

For all tasks we have specified to trace or draw the circles and trace the spirals as precisely as possible with no regard to the speed of execution. Before starting the task, each subject was asked whether the instructions were understood. Specifically, for the circle drawing task, instructions stated “draw a circle as precise as you can, meaning a circle having a constant radius”, if instructions were not understood, it was further specified to “draw a circle as round as you can”.

For Group 1, participants were asked to draw a circle counterclockwise starting at 12 o’clock. After a minute from conclusion, participants were asked to draw a circle again counterclockwise starting at 12 o’clock. No information was given regarding the dimensions of the circles. For Group 2, participants were asked to trace a spiral beginning from the center and going outward. After a minute the task was repeated. The spiral templates were designed for a medial to lateral performance of the dominant hand (i.e., counterclockwise for the right hand). For Group 3, participants were asked to trace a circle counterclockwise starting at 12 o’clock. After a minute from conclusion, participants were asked to trace a circle again counterclockwise starting at 12 o’clock.

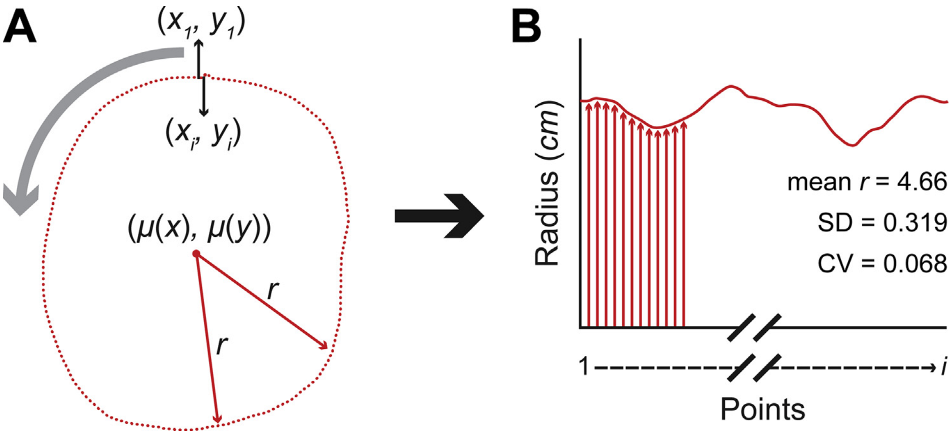

Fig. 2. Drawn circles analysis. An example of the calculation of the precision of a drawn circle. A. A drawn circle represented as points starting at point 1 (with the coordinates x_1, y_1) and going counterclockwise to the end point (with the coordinates x_i, y_i). The mean ($\mu(x)$) and mean ($\mu(y)$) values were considered as the centroid of the drawn circle, and the radius of each data point on the drawing (r) was calculated as the point's distance from the centroid. B. The measured radii of the consecutive points, from which the CV of the radii was calculated for each drawing. CV of the radii in this example was found to be 0.068. SD = standard deviation.

As Groups 4, 5 and 6 represent only different combinations of the tasks in the first three groups, the indications for performance of the specific tasks were identical to those in Groups 1, 2, and 3. Depending on the first task in Groups 4, 5 and 6, after a minute the participants were asked to perform the other task assigned to that group (Fig. 1). The order of either first task or second task was randomized so as to obtain an equal number of participants who started with either the former or the latter. The minute interval between trials was chosen seeing that it is considered to be well beyond the capacity of working memory (Siegel, 2002).

To exclude performance differences between genders, the results of both tracings and drawings were compared by using an unpaired two sample *t*-test. The comparison was made on the results of Groups 1, 2 and 3 (repetition groups) in which the measurements could be directly compared. The *t*-test did not reveal any significant differences between genders within groups for both the first and second tracings/drawings. Therefore, the results for each group were pooled together, regardless of gender.

2.4. Analysis

Using Matlab, we have developed an algorithm to measure the accuracy of the drawn circles. The algorithm consisted of first finding the centroid of the drawn shape. This was achieved by taking the mean value of all x and y coordinates, the result of which would provide a reference center, from which the actual center could be calculated. From the reference center, points were organized according to their angle and were then reduced to 360 points, having one point per angle. This was done in order to reduce the sensitivity to the way the shape was drawn (e.g., parts drawn slower will result in more points). After the point reduction, the mean value of all x and y coordinates were calculated on the remaining point, and the result was considered as the center of the circle. Following that, the distance of each point (prior to the reduction) of the drawing from the center was calculated (Fig. 2). These distances were considered as the radii for the drawn circle, the mean value of which would result as the radius of the corresponding perfect circle. Seeing that no indication was provided regarding the size of the circle, the coefficient of variation (CV) of the radii was considered as a measure of the precision of the drawn circle, bearing in mind that for a perfect circle the variability will be zero. The same algorithm was used also for CV analysis of the traced circles.

For spiral and circle tracing analysis the algorithm consists of serial angle-based calculation of the traced spiral or circle deviations from the template (Cohen et al., 2018). Points of the tracing (n = 6643 per traced spiral and n = 2984 per traced circle, normalized to the size of the template) were organized both according to their distance from the spiral center as well as according to the angle; for circles, the points were organized only according to the angle. Seeing that for the spiral there is no constant measurement (e.g., radius), the CV could not be used as a measure of accuracy in this case. For each point the residual difference (RD) between the tracing and the template was measured, considering the template as the expected value. Since we are interested only in deviations from the template, RDs were considered as absolute values. For each tracing (spirals and circles) the mean RD was calculated (Fig. 3).

2.5. Statistics

In order to evaluate whether a correlation exists between performances in terms of precision, the Pearson correlation coefficient was used on CVs for circle drawing and tracings and on mean RDs for the spiral and circle tracings. Specifically, the Pearson correlation coefficient was calculated for Group 1 using CVs of the drawn circles; for Group 2 using mean RDs of the traced spirals; for Group 3 using both CVs and mean RDs (independently and in combination) of the traced circles; for Group 4 using CVs of the drawn and traced circles; for Group 5 using mean RDs of the traced spirals and circles, and CVs of traced circles; for Group 6, using CVs of the drawn circles and mean RDs of the traced spirals.

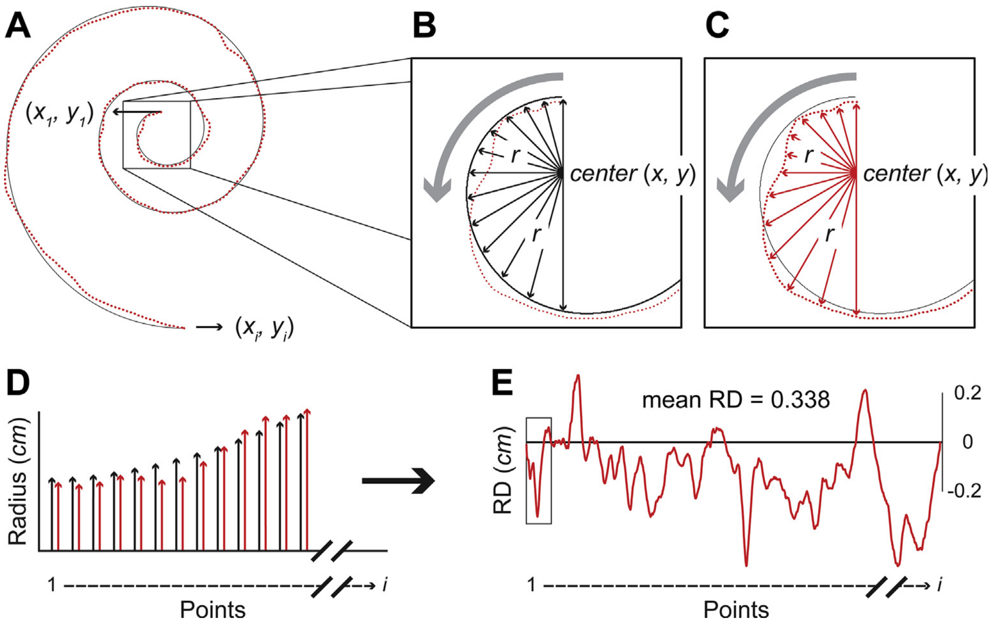

Fig. 3. Spiral tracing analysis. An example of the calculation of the precision of a traced spiral. A. Both the spiral template (in black) and one example of tracing (in red points) are illustrated. B, C. The distance from the spiral center (i.e., *r*, radius of the spiral; center with the coordinates *x*, *y*) was calculated for each point of the template (B) and of the tracing (C) from the template's center. D. RDs were calculated as differences between the radius of each point of the template (black) and the radius of the corresponding data point of the tracing (red). E. The red graph indicates the RDs of the example of tracing with respect to the template (black line). The small box represents the example illustrated on B, C, and D. The mean RD in this example was found to be 0.388 cm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.6. *Classification approach*

A support vector machine (SVM) algorithm was used for classification of the subjects in two groups (drawers and tracers). The SVM algorithm finds an optimal separating line in the data, with a maximum margin, to separate the two groups. SVM models are simple to implement and have the added advantage that the data sets do not need to present a particular class of distributions, moreover, they are also flexible and allow to expand the model by adding more parameters if needed (Noble, 2006).

As the training data for the SVM model, a randomly generated dataset was created containing hypothesized cases of ideal and univocal drawers and tracers. This was done by first considering normalized data in which maximum precision for a task is considered as 0 and minimum precision as 1. Following that, a series of virtual subjects ($n = 1000$) was randomly generated (i.e., training data), who are proficient in one specific task but not in the other (where proficiency is considered as values between 0 and 0.2, non-proficiency as values between 0.8 and 1). In this study a linear kernel function was used for data fitting, which was cross validated 10-fold. In addition, the posterior probability was calculated for each subject, expressing the data as statistical probability of effectively belonging to one group or the other (values range from -1 to 1). The model tested on normalized data from groups 4 and 6.

3. Results

Subjects were ranked in descending order in terms of precision (i.e., increase in CV for Drawn Circles; increase of mean RD for Traced Spirals) of the first performance. The Pearson coefficient revealed a significant correlation between the first and second drawing of circles for Group 1 (i.e., Drawn Circles), with an R-value of 0.96 and p-value < 0.001 (Fig. 4). The same trend was shown for Group 2 (i.e., Traced Spirals), with an R-value of 0.97 and p-value < 0.001 (Fig. 4).

Group 3 (i.e., Traced Circles) also demonstrated the same trend as Groups 1 and 2 (Fig. 4). The Pearson coefficient in this case was calculated in several ways. First, the CVs of the first and second tracings were compared, resulting in an R-value of 0.97 and p-value < 0.001. Second the mean RDs of the first and second tracings were compared, resulting in an R-value of 0.96 and p-value < 0.001. Then the CVs of the first tracings was compared with the mean RDs of the second tracings, resulting in an R-value of 0.95 and p-value < 0.001. Finally, the mean RDs of the first tracings was compared to the CVs of the second tracings, resulting in an R-value of 0.97 and p-value < 0.001. Finally, the correlation between CVs and mean RDs for the first tracings and the CVs and mean RDs of the second tracings were calculated, both resulting in an R-value of 0.99 and p-value < 0.001.

For Group 4 (i.e., Drawn Circles vs Traced Circles), subjects were ranked in descending order, in terms of precision of the drawn circles. In this case, no correlation was found between the performances with R-value of 0.106 and p-value > 0.05 (specifically, 0.61;

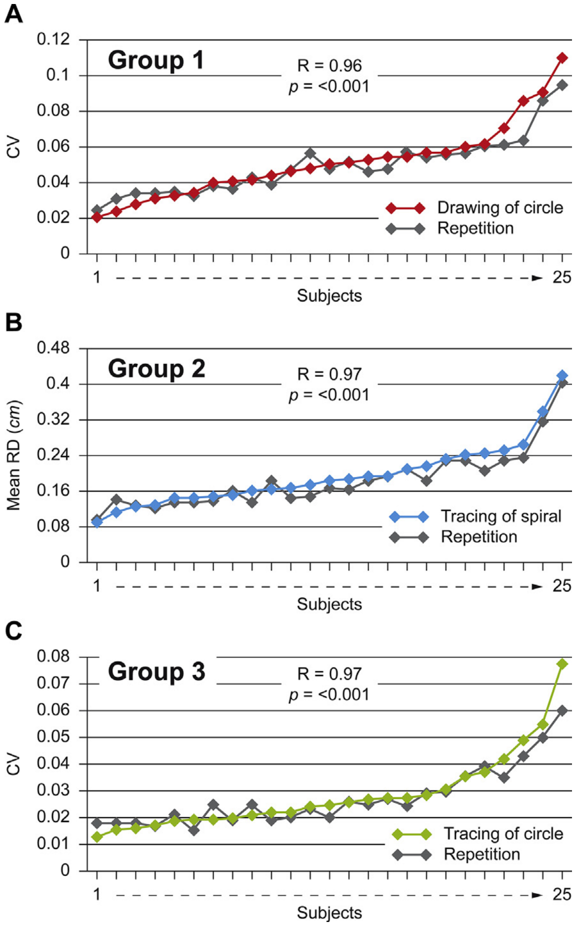

Fig. 4. Results Groups 1–3. A. The results for Group 1 (i.e., Drawn Circles) for the first (red) and second (grey) drawing are shown. Subjects (n = 25) are ranked in descending order in terms of precision (i.e., increase in CV) of the first drawing. It is possible to see a high correlation between the two drawings, meaning that those who were precise in the first were also precise in the second. B. The results for Group 2 (i.e., Traced Spirals) for the first (blue) and second (grey) tracing are shown. Subjects (n = 25) are ranked in descending order in terms of precision (i.e., increase in mean RD) of the first tracing. It is possible to see a high correlation between the two tracings, meaning that those who were precise in the first were also precise in the second. C. The results for Group 3 (i.e., Traced Circles) for the first (green) and second (grey) tracing are shown. Subjects (n = 25) are ranked in descending order in terms of precision (i.e., increase in CV) of the first tracing. It is possible to see a high correlation between the two tracings, meaning that those who were precise in the first were also precise in the second. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 5).

For Group 5 (i.e., Traced Circles vs Traced Spirals), subjects were ranked in descending order in terms of of precision the traced spirals (i.e., increase in mean RD). When comparing the CVs with the mean RDs of the traced circles a very high correlation was found, with an R-value of 0.99 with a p-value < 0.001. A significant correlation also was found between the traced circles and traced spirals when comparing mean RDs of the two, with an R-value of 0.91 and p-value < 0.001. An even higher correlation was found when comparing the CVs of the traced circles with the mean RDs of the traced spirals, with an R-value of 0.95 and p-value < 0.001 (Fig. 6).

For Group 6 (i.e., Drawn Circles vs Traced Spirals), subjects were ranked in descending order, in terms of precision of the traced spirals. In this case, similarly to Group 4, no correlation was found between the performances with R-value of 0.26 and p-value > 0.05 (specifically, 0.21; Fig. 7).

The SVM model separated the data from Group 4 and Group 6 into two groups, drawers and tracers (Fig. 8), along with the posterior probability for each subject, expressing the data as statistical probability of effectively belonging to one group or the other (values range from -1 to 1) (Fig. 9). It is possible to notice that while some subjects could be considered as ideal tracers or ideal drawers, there are also subjects that have an equal probability of belonging to either group.

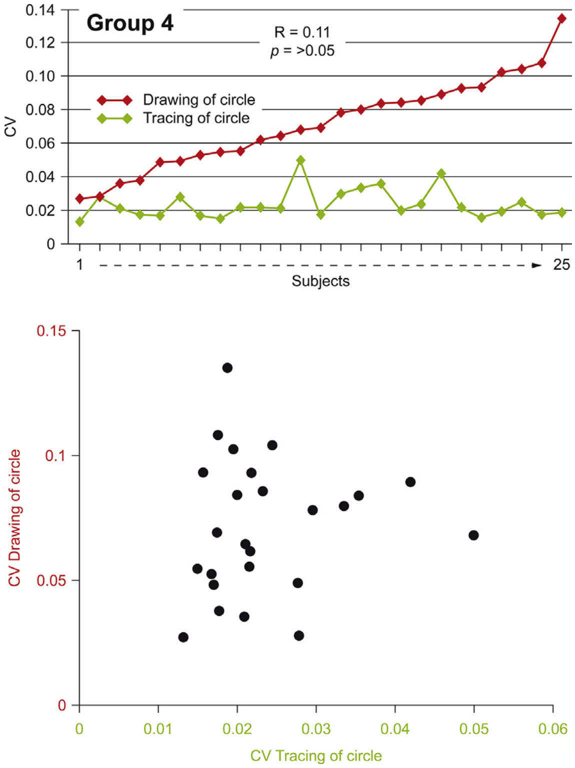

Fig. 5. Results Group 4. A. Results for Group 4 (i.e., Drawn Circles vs Traced Circles; n = 25). Subjects are ranked in descending order in terms of precision (i.e., increase in CV) of the drawn circles (red). Corresponding CV values of the traced circles (green) are reported. It is possible to see that there is no correlation (R-value of 0.11 and p-value $>$ 0.05) between the precision in drawing and in tracing circles. B. Scatter plot of the results for Drawn Circles and Traced Circles, each dot represents a subject.

4. Discussion

From this study it is possible to see that spiral tracing, circle tracing, and circle drawing provide reliable results for motor precision (measured as CVs for circles and as mean RDs for spirals and circle tracing). This is made evident by the constant relationship between tasks repetitions (high correlations between repetitions for Group 1, Group 2, and Group 3; Fig. 4). The results also indicate that subjects who are precise in one task remain precise in said task, at least beyond the capacity of working memory (Siegel, 2002). This trend is to be expected considering that differences in precision were shown to occur for different tasks among individuals (Callaghan et al., 2002; Madison, 2004; Perlau et al., 1995).

Furthermore, it is also evident by the results that drawing and tracing are, as expected, in fact different, as shown by the lack of correlation between tasks in Group 4 and in Group 6 (Drawn Circles vs Traced Circles and Drawn Circles vs Traced Spirals, respectively; Figs. 5 and 7). Specifically, when we consider the lack of correlation in Group 4 (i.e., same shape and different task) with the high correlation in Group 5 (i.e., same task and different shape), it seems the the lack of correlation in Group 6 (i.e., different shape and different task) is effectively task dependent rather than shape dependent. Moreover, while the comparison between drawn circles and traced circles (i.e., comparison between tasks for the same shape) did not reveal any correlation, it is still possible that the use of the same shape in the two tasks may be considered as repetition; as such, it could be subject to repetition priming or learning effect between trials (Patel et al., 2017; Siniscalchi, Cropper, Jing, & Weiss, 2016). Also, as no indications were made regarding the drawn circles' size, the use of a circle template for the tracing task could cause a visual conditioning of the subjects when drawing the circles (Renaux, Rivière, Craddock, & Miller, 2017). Taking these factors into consideration, it is possible that the correlation between the two tasks may be even lower than that reported here.

These results raise some interesting questions as both drawing and tracing tasks are used for evaluation of fine motor control (Cohen et al., 2018; Mergl et al., 1999; Smits et al., 2018; Sülzenbrück et al., 2010, 2011; Vuillermot et al., 2009), however, their usage appears not to be interchangeable. Though this may suggest that using solely one of the tasks for evaluation of fine motor control may produce inconsistent results, it is still not sufficient in explaining what do these tasks effectively evaluate as well as what could be inferred from performance differences in the two tasks.

In an attempt to respond to these questions, we begin by noticing that, when examining the results of this study (specifically those of Group 4 and 6), there are certain individuals who appear to be better drawers than tracers and vice-versa. Let us simplify the situation by first considering a population consisting of either drawers or tracers, which are mutually exclusive. Let us further assume that for each of these groups, precision in the specific task in which they are proficient in, is a good estimator for fine motor control.

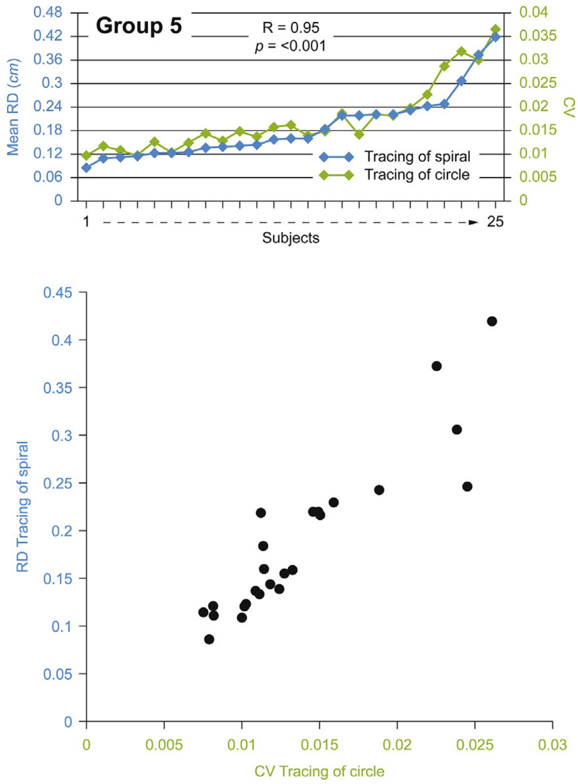

Fig. 6. Results Group 5. A. The results for Group 5 (i.e., Traced Circles vs Traced Spirals) are shown. Subjects (n = 25) are ranked in descending order in terms of precision (i.e., increase in mean RD) of the traced spiral (blue). On the right side corresponding CV values of the traced circles (green) are illustrated. It is possible to see a high correlation between the two tracings, meaning that those who were precise in tracing a spiral were also precise in tracing a circle. B. Scatter plot of the results for Traced Circles and Traced Circles, each dot represents a subject. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Considering all that is known regarding these tasks in literature, the main difference between the tasks is the presence or absence of a template, or in other words the cueing (internal or external; Flanders et al., 2006; Gowen & Miall, 2006, 2007; Sailer et al., 2000; Thut et al., 2000; van Donkelaar & Staub, 2000). Applying this notion to the proposed population of drawers and tracers, we can deduce that drawers are more reliant on internal cueing whereas tracers are more reliant on external cueing. In addition, it was previously shown that drawing tasks also employ different neural areas than tracing tasks; in particular, a greater activation in the cerebellar crus I, pre-supplementary motor cortex, dorsal premotor cortex (Gowen & Miall, 2007). Conversely, the striate and extrastriate areas, as well as the anterior intraparietal sulcus were shown to be more active during the tracing task (Gowen & Miall, 2007). Therefore, it would not be entirely incorrect to assume that dissimilarities in brain activity could account for the differences between drawers and tracers.

At this point, the task in which the subjects are less proficient in, could not serve as a quantifier for fine motor control, as our *a priori* knowledge suggests that the performance in said task does not evaluate the full potential of the subject (which we know is either a drawer or a tracer); moreover, the performance in the less proficient task is not correlated with the performance in the other task. Therefore, the less proficient task must evaluate a different aspect, which could very well be the reliance or functioning of the weaker cueing modality. For example, precision in a drawing task for a tracer would quantify his reliance on internal cueing. As the reliance on the weaker cueing modality is already known to employ activation of different cerebral areas, the performance in less proficient task could also be considered as a measure of the functionality of these areas.

If we apply this concept to the data in this study, we first assume that certain individuals in the population are drawers and others are tracers, and classify the population of groups 4 and 6 in these terms. However, it is clear that such a net distinction is inaccurate, as not all of our cases were ideal drawers and tracers. To overcome this, we may examine the results of the posterior probability, which expresses the statistical probability of a subject as effectively belonging to one group or the other.

When observing the data in this way (Fig. 9), it is clear that the there are some subjects who could be considered as ideal drawers or ideal tracers, neither drawers or tracers, as well as intermediate cases. This sort of dispersion does not only have a descriptive purpose, as we have already discussed, there are some practical implications. In fact, more than the sole evaluation of fine motor control, the two tasks give also information regarding the reliance on external or internal cueing. Therefore, as fine motor control in a task is also dependent on the subject’s propensity towards external or internal cueing, evaluation of effective fine motor control must consider these factors. As such, a more accurate way of quantifying fine motor control would be by using the product of the precision

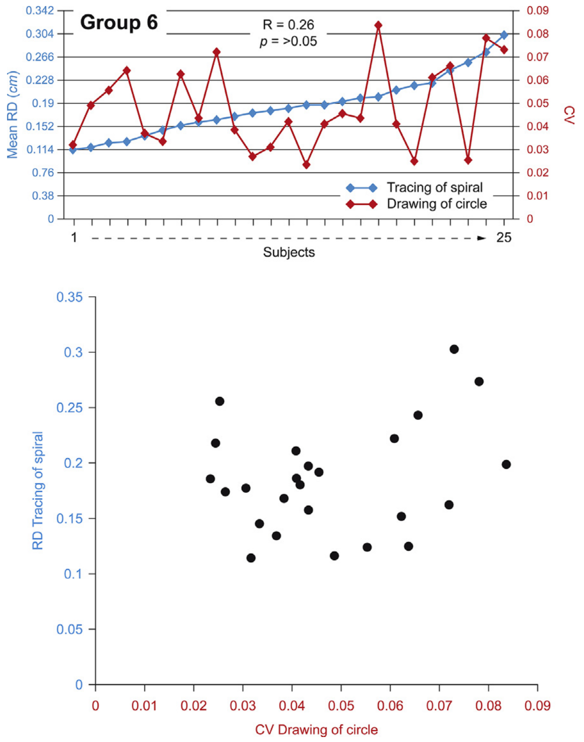

Fig. 7. Results Group 6. A. Results for Group 6 (i.e., Drawn Circles vs Traced Spirals; n = 25). Subjects are ranked in descending order in terms of precision (i.e., increase in mean RD) of the traced spirals (blue). On the right side are reported corresponding CV values of the drawn circles (red). It is possible to see that there is no correlation (R-value of 0.26 and p-value > 0.05) between the precision in tracing spirals and drawing circles. B. Scatter plot of the results for Traced Spirals and Drawn Circles, each dot represents a subject. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

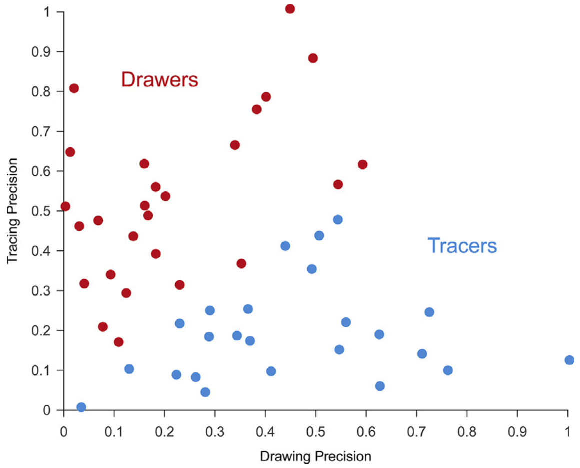

Fig. 8. SVM Classification. The figure shows a scatter plot of pooled results from Group 4 (Drawn Circles vs Traced Circles) and Group 6 (Drawn Circles vs Traced Spirals). Results for each group were normalized considering the maximum precision for each task as 0 and minimum precision as 1. The SVM classification divided the results into two mutually exclusive groups, tracers (in blue) and drawers (in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in the tracing and drawing task. An example for this is shown in Fig. 9.

Some issues regarding this study should be mentioned. The first is the comparison between the measurements of Group 6 (Drawn Circles vs Traced Spirals), in which two different types of values are used (i.e., mean RDs and CVs). However, seeing that these values are used only to represent indicators of task precision, and considering the high correlation between the two types of values for the traced circles (i.e., mean RDs vs CVs in Group 3 and in Group 5), the use of them by extension to compare the correlation between precision of traced spirals (measured as mean RDs) and of drawn circles (measured as CVs), is justified. Also, various combinations

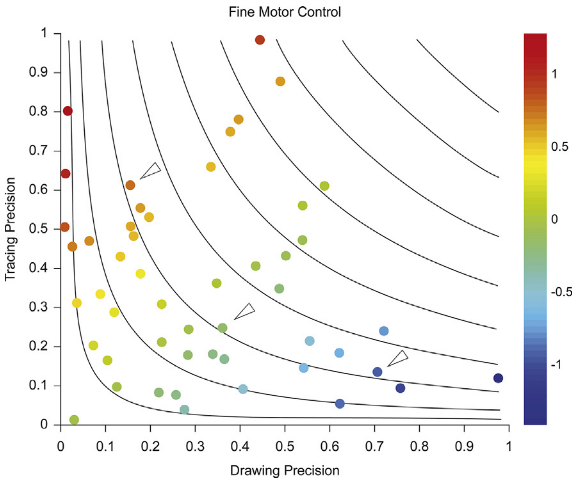

Fig. 9. Posterior Probability and Fine Motor Control Quantification. The figure shows a scatter plot of pooled and results from Group 4 (Drawn Circles vs Traced Circles) and Group 6 (Drawn Circles vs Traced Spirals). Each dot represents a subject, and the color of the dot represents the posterior probability of that subject as being either a tracer or a drawer (color gradient on the right side; values ranging from −1 to 1). As fine motor control in a task is also dependent on the subject's propensity towards external or internal cueing (tracing or drawing), when quantifying fine motor control, these factors should be taken into consideration. This is illustrated by the curved lines in the figure which delimitate similar subjects, in terms of fine motor control, by considering the product of the precision in the two tasks. Therefore, a good tracer having 0.1 precision in the tracing task and 0.9 in the drawing task, would be equivalent to a good drawer (0.1 in drawing and 0.9 in tracing), which would also be equivalent to a non-tracer non-drawer with 0.3 and 0.3, as 0.1 × 0.9 is equal to 0.3 × 0.3. In the figure the arrowheads indicate three similar cases. The orange subject is a good drawer (0.15 drawing precision * 0.61 tracing precision = 0.0915 effective fine motor control), the green subject is neither a drawer nor a tracer (0.36 drawing precision * 0.25 tracing precision = 0.09 effective fine motor control), and the blue subject is a good tracer (0.7 drawing precision * 0.13 tracing precision = 0.091 effective fine motor control). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

were used to compare CVs and mean RDs in Group 3 (see Results), all of them revealing very high correlations. Even though the measurements are not equal, the differences in terms of correlation due to the use of different measurements did not go beyond 4% (found between CVs of Traced Circles and RDs of Traced Spirals in Group 5, see Results). Therefore, the use of different measurements is not expected to affect the data in this study as the correlations found were all sufficiently strong.

Another issue is the exclusion of the spiral drawing task. Quantitative evaluation of spiral drawing presents several limitations. Considering the complexity and the different ways that exist to draw a spiral, it would not be possible to test the precision of the drawn spirals across subjects as it is very unlikely that the same shape would be drawn. While precise instructs could help reduce this variability, they are also not as readily understandable as those for circle drawing, rendering the spiral drawing task much more complex than the other conditions. The only paper to our knowledge that has quantitatively compared precision of drawn spirals is that of Longstaff and Heath, 2006. However, in that study, a spiral was presented to the subject before the trial, and furthermore, subjects performed a training period in order to obtain relatively comparable drawings before comparing the results to an ideal spiral. The addition of these constraints, while rendering possible the comparison of drawn spirals, does not go in line with our experimental paradigm, which seeks to avoid learning of the task. On the other hand, the elimination of these constraints results in a variability between shapes that would render the comparison meaningless. Moreover, other papers who addressed spiral "drawing" quantitatively, have effectively evaluated a spiral tracing task (Hoogendam et al., 2014; Miralles et al., 2006). Therefore, in adhering with the current literature we have limited our study to spiral tracing. Also, the original premise of the study was to evaluate the differences between spiral tracing and circle drawing. By fragmenting it to comparisons for shape and for task, and by considering the previous studies comparing tracing and drawing as well as externally and internally cued tasks (Bravi et al., 2014, 2015; Collier & Ogden, 2004; Gowen & Miall, 2007; Repp, 2011; Repp & Moseley, 2012) it is licit to generalize our results to other shapes, in accordance with models of analytic generalization and case-case transfer (Firestone, 1993). As such, we may infer that spiral drawing would be equivalent to circle drawing, considering that our results suggest that ranking in terms of precision is task dependent and not shape dependent.

It should be also noted that this study was concentrated only on differences in terms of precision between the tasks. In light of the results, we believe that some differences in the strategy employed for each task (e.g., speed-accuracy trade-off, pen pressure during execution, posture, etc.) may also exist. Though it would be interesting to examine the differences between the subjects and groups from a biomechanics point of view, it goes beyond the scope of the present study.

5. Conclusions

In this study we have shown that there is no correlation between precision in a drawing task compared to a tracing task. Further, we have demonstrated that the lack of correlation between the two is effectively task dependent and not shape dependent. We argue that evaluating fine motor control by using a single task may produce inconsistent results. To overcome this limitation, we suggest that the evaluation of fine motor control should include both a tracing and a drawing task, taking in consideration the precision in each task separately and in combination. This study also demonstrates that there is no difference in precision between tracing of circles and of spirals. Therefore, for a widespread implementation, we suggest that fine motor control evaluation would be better tested by using circle drawing and circle tracing tasks. In both tasks it is possible to use the same measurement (i.e., CV), which is already independent of other factors (such as size of circle, and number of points etc.). This way, results from different studies could be more readily compared. We believe that the approach presented here could help not only evaluate fine motor control more accurately, but also identify subjects who are more reliant on either internal or external cueing and to what extent. Using this knowledge, it would be possible to taylor specific strategies in both clinical or professional settings, dependent on subjects reliance on a specific modality of cueing, to improve fine motor control.

Declarations of interest

None.

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