Faking Handedness:

Individual differences in ability to fake handedness, social cognitions of the handedness of others, and a forensic application using Bayes' theorem

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Abstract

People usually describe their handedness honestly, but that need not necessarily be the case. A legal case is described of a murder said by the pathologist to be committed by a left-hander but the defendant claimed to be right-handed, and the first author assessed the defendant's handedness as an expert witness. We know of no previous work on faking handedness, and so we tested 30 right-handers and 25 left-handers on various handedness tasks, and then asked the participants to repeat the tasks while faking being of opposite handedness. Social cognitions of handedness were assessed from participants' knowledge of how other right- and left-handers would answer handedness questionnaires.

Fake handedness was best differentiated using cursive lower-case sentence writing, upper-case written letters being less good at distinguishing, as also were simple motor tasks. Participants differed in social cognitions of handedness, and those with more accurate social cognitions were better able to fake. Personality measures did not predict faking ability.

For forensic purposes a Bayesian analysis was carried out to evaluate the likelihood of right and left hand performance being true rather than faked, and the cursive lower-case writing provided strong posterior odds that, as claimed, the particular defendant was a true right-hander.

Introduction

Handedness is usually straightforward to assess, most obviously by asking someone their *writing hand*. For more sophisticated research purposes, relative *hand preference* can be assessed using various handedness questionnaires which ask about the preferred hand for a range of different tasks. Similarly, relative *hand skill* can be assessed using pegboards and other motor tasks such as the Tapley and Bryden (T&B) circle marking task (Tapley & Bryden, 1985). An assumption for any tests is that when participants are asked to perform as quickly or as accurately as possible then that is what they are doing. There are occasions however where a participant may wish to deceive, giving the impression of having the opposite handedness to their true hand preference.

The present study originated in a legal case, a couple of years previously, in which the first author (ICM) was an expert witness in a murder trial. The defendant, *D*, was accused of murdering the victim *V*. The pathologist who conducted the post-mortem on *V* reported that death was due to a single stab wound from behind into the left axilla severing the left subclavian artery, the intra-thoracic haemorrhage rapidly resulting in death. The pathologist gave the opinion that the murderer, *M*, must have held the murder weapon in the left hand, and therefore was probably left-handed. *D* however said that he was right-handed and had always been right-handed. ICM was asked by *D*'s legal team to act as an expert witness and to assess *D*'s handedness on behalf of the court. Time was short before the case was to be heard and ICM had only a single session to assess D's handedness, the limited testing taking place in the remand cells beneath the court and involving only pen, paper and stopwatch. ICM's testing, which involved questionnaires, an interview, hand writing with both hands, and skilled motor tasks with both hands, suggested that *D* was right-handed. However *D* was aware of the pathologist's report that *M* was left-handed and so, as ICM suggested in his report, there was necessarily a possibility that *D* was faking his handedness. At the trial *D* was found guilty of murder and given a sentence of life imprisonment. The present study represents a more considered and extended assessment of what might be involved in the faking of handedness.

The possibility of a person faking their handedness is rare, but in the present case there were clearly strong motivations had *D* wished to do it. In this paper we are also, of course, excluding from the definition of faking those cases of apparent right-handedness, rare nowadays in the UK, where left-handers have been forced, at school, to be right-handed for whatever reason. Faking more generally does occur in a range of psychological and medical situations (Domino & Domino, 2006). In job selection there are often fears that people are faking their answers to personality or aptitude questionnaires (so-called 'faking good' or giving responses that are deemed to be socially desirable) (Ziegler, MacCann, Roberts, & (editors), 2012; Ziegler, Schmidt-Atzert, Buhner, & Krumm, 2007). Similarly in medical contexts it is not unknown for patients to fake symptoms which appear to be serious, sometimes to gain access to pain-killers or hospitalisation, and sometimes that may be associated with so-called Munchausen's syndrome. All such cases are difficult to detect in ordinary medical practice as there is a presumption by doctors, nurses and other professionals of truth-telling by patients. Faking is probably more common in cases where there is a possibility of financial compensation or other rewards, perhaps for memory loss or pain incurred, and it is suggested that the 'Fake-Bad Scale' of the MMPI can be effective at detecting such behaviour (Lees-Haley, English, & Glenn, 1991; Nelson, Sweet, & Demakis, 2006). Within psychology there has long been an awareness that participants, for whatever reason, may lie so that questionnaires often include liedetector questions (Eysenck & Eysenck, 1975), although in more recent times it is argued that such 'lying' may instead be a form of social acquiescence or social desirability, in which participants try to present themselves in a more positive light, or try to help the researchers by providing answers that are implicitly requested via a demand characteristic. The most frequently used of scales for detecting faking is the Marlowe-Crowne Social Desirability scale (Crowne & Marlowe, 1960) ,for which there are also abbreviated versions (Reynolds, 1982). It has also been suggested that feigning poor memory on tests may be indicated by increased superior and medial prefrontal cortical activity (Kosheleva, Spadoni, Strigo, Buchsbaum, & Simmons, 2016). Although in recent years there have been many studies looking at when faking may occur in psychological tests, and in its detection while testing for legal and other purposes (Vrij, 2008), as far as we are aware there is no published previous research on the faking of handedness, particularly in a forensic situation where true handedness might have important evidential consequences.

'Faking' in general has a pejorative, negative tone, but that does not mean that faking is always bad, as can be seen in several examples. Actors are rewarded for their ability to fake the behaviour of other people, with performances that can be completely compelling, and magicians are also adept at faking movements to give the impression of carrying out a different action (Cavina-Pratesi, Kuhn, Ietswaart, & Milner, 2011). Likewise, when doctors are taught 'communication skills' there is a sense in which they are often faking their true feelings for a higher professional purpose. Similarly lawyers may argue strongly for cases in which they do not personally believe in a defendant's guilt when prosecuting or innocence when defending, their professional duty being to 'act', metaphorically and literally, to the best ends of prosecution or defence. To be successful, all such successful acting requires an actor to have acquired a sense of how other people behave in specific situations, with that behaviour presented to the watching public. It seems likely, therefore, that the more a person knows of how other people behave then the more successful they are likely to be at portraying the 'other'. Sociologists, following Erving Goffman, discuss how individuals with stigma can 'pass' as normal, characterised as, "a cultural performance whereby one member of a defined social group masquerades as another in order to enjoy the privileges afforded to the dominant group" (Leary, 1999) (p.85). Successful passing generally requires an accurate knowledge of the 'other', and therefore here we ask what right(left)-handers accurately know about the behaviour of left(right)-handers, and whether more accurate knowledge allows a more successful portrayal as left(right)-handers. We are therefore asking about *social cognitions* of handedness, an area for which there is little existing literature, although we do note a number of studies asking about the experience of handedness which are relevant (Masud & Ajmal, 2012; Misigo, 2015; Westmoreland, 2016).

To measure social cognitions of handedness we adapted a technique of Prelec (2004) in which participants are asked to answer a set of questions not for themselves but instead are asked to indicate what answers they think a typical set of 100 right-handers (or left-handers) would have given. Details are given later, but such data can be used to assess the accuracy of a person's understanding of the actual behaviour of right and left-handers as populations.

At the time of *D*'s trial there was insufficient opportunity to carry out further work on hand performance in control groups, and the urgency of the case required a very simple model of how faking handedness may be possible. In the intervening years, however, an opportunity arose to design an experiment which firstly re-used some of the tasks carried out by *D* in the remand cells, and secondly asked a reasonably sized group of right- and left-handers firstly to carry out tasks in the usual way, and then to try to fake being of the opposite handedness. Here we will briefly present the model of faking handedness which was developed for the use of the court, and then it will be reconsidered later in the light of the evidence from the present study.

The original model of faking. A straightforward assumption about faking is that it is always easier to fake bad than to fake good (and as Alice Heim said, many years ago, it is very easy to fake having a low IQ but very hard to fake having a high IQ, although it is worth considering an old but notorious case for the issues arising from that, as well as the vicissitudes of being an expert witness (Heim, 1982; Murray, 1983; Tunstall, Gudjonsson, Eysenck, & Haward, 1982a; Tunstall, Gudjonsson, Eysenck, & Haward, 1982b)). If faking bad is easier than faking good then it should be possible for, say, a right-hander to fake being left-handed by purposely slowing up the performance of their right hand. As long as only the relative difference between the two hands is considered such faking probably cannot be detected. However if the overall performance of right and left hands is available then a consequence is that the behaviour of the apparently dominant hand can be unrealistically slow. At the time that *D* was being tested ICM had access to the raw data from the large study of hand skill by Tapley and Bryden (1985) (see McManus et al (2016)). Figure 1 shows the separate performances of the right and left hands, with overall motor ability running along the ascending diagonal, and relative hand skill at right angles to motor skill (see the blue arrows at top right). Consider a participant at the green point, *X,* who is right-handed with a degree of handedness slightly above average and overall motor skill slightly above average for a right-hander. As the person slows down their right hand while keeping their left hand performance constant, they shift along the red line to the points X_1, X_2 or X_3. X_1 would be a rather weak left-hander while X_2 would have a weaker overall performance (but appear to be more strongly left-handed), and X_3 would apparently be very strongly left-handed while at the same time having a lower overall motor ability to the extent that such a pattern is not ever seen in this large population of left-handers. If a right-hander were to fake being left-handed as in figure 1 then some combinations of right and left hand performance become increasingly unlikely. In a more extreme case, such as *Y*, then no level of reduced right-hand performance is compatible with the actual behaviour of true left-handers. It should therefore, in principle, be possible to assess the likelihood that a particular 'left-handed performance' comes from a genuine left-hander or a right-hander faking left-handedness. It is that likelihood which is required for forensic purposes.

Terminology. There is much scope for confusion and we will refer to the natural, self-professed handedness of individuals as their true handedness, which we will indicate as R_T (true right-handers) or L_T (true left-handers). When individuals are faking we will refer to the outcome of that faking, so that when R_T fakes being left-handed they are a fake left-hander (L_F). And similarly left-handers faking right-handedness are R_F. R_T and L_F are therefore the same individuals as also are L_T and R_F. That will be made clearer in figure 2 (below).

Method

Two separate but related studies took place. In Study 1, run by GB and NH, groups of right and left-handed participants carried out a series of tasks, including producing writing specimens with the right and left hands, carrying out skilled motor tasks, and completing various handedness questionnaires, firstly in the normal way, and the secondly after being asked to fake their handedness after being given a cover story. The motor tasks and questionnaires were scored directly. However the hand writing samples could not be scored directly, and therefore in Study 2, run by AF, AN and FV, the various writing specimens were assessed for their quality by a set of judges who had not taken part in Study 1.

Study 1

Participants were tested in three blocks, A, B and C, for which A and B were similar in terms of the tests carried out. The instructions for Block A said that the experiment was a study of performance by the right and left hands. Once Block A had finished participants were given a briefing sheet explaining that for Block B they should try to give an impression that they were of the opposite handedness to their true handedness. The description of the tasks will be as for true right-handers, although half of the participants were true left-handers and in the descriptions left and right should be reversed throughout for them. Block C consisted of a series of questionnaires described below.

Testing procedure of Block A: Participants undertook a series of tasks:

1. *Writing tests*.
    a. *Alphabet*. On an A4 sheet, firstly with the right hand and then with the left hand, participants wrote as quickly and as neatly as possible, the 26 separate capital letters of the alphabet; the letters were printed at the top of the page to make the task clear. The task was timed with a stopwatch, and expressed as letters/second.
    b. *Sentence*. The participants wrote, as quickly and legibly as possible, and in cursive script, the sentence, "The quick brown fox jumps over the lazy dog". This standard sentence, often used for testing telegraphs or teaching typing, is a pangram or holoalphabetic sentence, containing all 26 letters of the alphabet in its 35 letters. The task was carried out firstly with the right hand and then the left. The task was timed, and expressed as letters/second.
2. *Circle marking tasks.*
    a. *Tapley and Bryden task.* Participants carried out the T&B task using sheets which were as similar as possible to the original task (Tapley & Bryden, 1985). The task was balanced: *Right hand starting at top left / Left hand starting at top left /Left hand starting at top right / Right hand starting at top right. Participants used a felt-tip pen with a standard 0.5mm tip diameter.* Participants were given 20 seconds for each task, and scoring counted the number of circles correctly filled with a dot. The 'circles' were actually ovals (the letter 'O'), with diameters of about 1.9 x 1.4 mms (McManus, Van Horn, & Bryden, 2016).
    b. *Van Horn circle-marking task*. Van Horn extended and developed the T&B circle-marking task (McManus et al., 2016; Van Horn, 1992). Participants carried out the Van Horn task with circles of 2.5 mm diameter.
3. *Handedness questionnaire*. Participants completed a modified Edinburgh Handedness Inventory (EHI) (Edlin et al., 2015), which had the original eight items, followed by an additional six items, and then single questions on the wrist for wearing a watch, footedness and eyedness. All items were scored on a five point scale.

Instructions before Block B. Before beginning Block B the participants read the Crime Scenario:

> "For this section we are looking at **faking handedness**. Imagine you have been arrested and accused of murder. The pathologist has concluded that someone who is **RIGHT**-handed stabbed the victim. The evidence is heavily stacked against you, and to be found innocent, you must fake being **LEFT**-handed."
>
> "We would like you to repeat the tests you have just completed, but this time faking which is your dominant hand."
>
> "(It might also help you to know that this is based on a real court case regarding which hand the suspect claimed to be their dominant hand)"

Testing procedure of Block B. The testing at the beginning of Block B was identical to that in Block A, with the alphabet, sentence, T&B and Van Horn tasks carried out in the same way but as if the participant were faking being left-handed (and instructions were reversed where necessary). Finally the questionnaire was completed as if the participant were left-handed.

Block C. After Blocks A and B there were the additional tasks of Block C:

1. Basic demographic data were collected, including age, occupation, ethnicity, nationality, birth language, problems with reading or writing, and familial handedness.
2. A measure of right-left confusion, with five questions, used in an earlier study (McManus et al., 2010) and based on the studies of Hannay (1990) and Jordan (2006).
3. Social cognitions of handedness. This questionnaire, which was completed firstly for right-handers and then for left-handers, was based on the method of Prelec (2004), as mentioned earlier. The items derived from the modified EHI used in Blocks A and B, but the rubric at the first presentation read: "Consider a group of 100 typical right-handers. If those right-handers were completing the handedness questionnaire, **what percentage do you think would answer each of the questions using the five possible answers**? Please try to make sure the answers in each row sum to 100%". Having carried out the task for right-handers it was then repeated for 100 typical left-handers.
4. A standardised measure of dyspraxia (Kirby, Edwards, Sugden, & Rosenblum, 2010).
5. The full version of the Marlowe-Crowne Social Desirability questionnaire (Crowne & Marlowe, 1960).
6. Big Five personality measures. The first questionnaire is the 15-item questionnaire used for the British Household Panel Survey https://www.iser.essex.ac.uk/bhps/documentation/pdf_versions/questionnaires/bhpsw15q.pdf (pp.168-171 of file). The second questionnaire consisted of 30 questions used in a previous study (McManus, Cook, & Hunt, 2010).

Participants: The study was carried out by 30 right handers (16 male/14 female) and 25 left-handers (11 male/14 female), who mostly were students at University College London. Handedness was defined as self-professed handedness, and invariably was consistent with further testing. Average age was 22.0 years (SD 6.40; range=18 to 51), and ethnicity by UK census classification was White (31), Indian sub-continent (4), Chinese (8), Other Asian(5), and Mixed (4). Participants were tested individually.

Study 2

Most of the measures used in Study 1 could be scored directly. However that was not possible for the writing specimens, and therefore a second, separate study, run by AF, AN and FV was carried out in order to rate the writing specimens for quality. Overall the 55 participants in Study 1 produced 440 writing specimens (55 participants x 2 hands x Faking-NotFaking) and in addition there were two alphabet specimens from *D.* A total of 442 writing specimens was too many for a single judge to assess, and therefore the specimens were divided into the 222 alphabet specimens and 220 sentence specimens, with judges in a session seeing one set or the other.

All writing specimens were scanned and presented to the participants using Qualtrcs software (Qualtrics, Provo: Utah, https://www.qualtrics.com), with the order of specimens randomised separately for each judge. Although it was intended to record individual reaction times a technical failure meant this did not occur.

To help in anchoring the judgements exemplars were provided for Alphabet and Sentence specimens which were set at scores of 2, 5 and 8 (see Supplementary Figure S1 for the exemplars and further information).

Participants. Overall there were 28 judges (21 female, 7 male; mean age = 22.2, SD=2.42), all of whom were fluent in English and 54% of whom were native English speakers. 13 judges assessed the Alphabet specimens and 15 the Sentence specimens.

Data from D. As well as the data from the participants in Study 1, there was some data from *D*, the defendant in the legal case, and these clearly are of interest, since it was *D*'s case which was the reason that Study 1 had taken place. The data from *D* consisted of a single block of testing, with *D* tested as a self-professed right-hander:

1. *Writing tests*.
    a. *Alphabet*. *D* wrote the alphabet in the same way as in Study 1. The rate of writing the 26 letters was calculated, and also a quality judgement was available from Study 2.
    b. *Sentence*. For various reasons, the cursive sentence written by *D* was actually different from that in Study 1, and therefore a rate of writing in letters/second was available, but not a quality judgement from Study 2.
2. *Circle marking tasks.*
    a. *Tapley and Bryden task.* Tested as in Study 1 Block A.
    b. *Van Horn circle-marking task*. Tested as in Study 1 Block A, with 2.5 mm diameter circles.

Ethics. Studies 1 and 2 were approved by the Ethics Committee of the Research Department of Clinical, Educational and Health Psychology at University College London.

Statistics. Statistical analysis used SPSS v22.0.

Results

Scoring of the various measures.

Circle-marking tasks. Analysis of the circle-marking tasks is straightforward, simply being measured as number of circles marked per second. The writing tasks are however more complex as there are measures both of rate of writing (letters per second) and of quality of writing. The measures derived from the writing tasks will therefore be assessed before the main analyses.

Writing quality. The quality of writing was assessed by the judges in Study 2, in arbitrary quality units on a scale of 1 to 9, with 9 being high. For the judgements of the Alphabet specimens made by 13 judges, Cronbach's alpha was .969 (mean inter-judge correlation = .711, range .518 to .839). Factor analysis strongly suggested only a single factor (first six eigenvalues = 9.563, .543, .465, .417, .363, .276). Similarly, for the judgements of the Sentence specimens made by 15 judges, Cronbach's alpha was .970 (mean inter-judge correlation = .700, range .564 to .805), and factor analysis again suggested only a single factor (first six eigenvalues = 10.816, .554, .459, .415, .383, .347). Scores for each of the Alphabet and Sentence writing specimens were therefore calculated as the simple mean of the ratings of all the judges.

Writing speed, writing quality and their relationship. Writing quality in relation to hand used, handedness, and normal or faking condition, showed much variability (see Supplementary figure S4) with the normal handwriting of participants varying considerably in quality). Similarly there was considerable variation in normal speed of writing (see Supplementary figure S3 for the Alphabet and Sentence tasks). Participants slowed down by a large extent when faking handedness, with speed to some extent covarying with normal writing speed (see table 1). The strategy of participants also needs taking into account as normal writing with the dominant hand is both fast and legible, but for non-dominant writing and faked writing there is a speed-quality trade-off, a participant perhaps choosing either to write faster with lower quality, or write more slowly with higher quality. As a result we also calculated a measure of quality units/second, assessing the quality produced for each second of writing, so that if quality is higher because longer has been taken over the task, the quality measure is thereby down-rated (see Figure 3 for the Alphabet task and figure S5 for the Sentence task).

Comparison of normal and faking performance.

The main results of the study are complex, and analyses are possible at several different levels. In the first instance comparisons will be made between the performance of participants in the normal and the faking conditions since that is a primary interest of the study. The performance of *D* will be considered at the end of the Results section.

The circle-marking tasks. The results for the T&B task are shown in figure 2, and those for the Van Horn task in Supplementary figure S2. Figure 2 summarises performance in both normal and faking conditions of right and left-handers. The multiple dark green circles are the performance of right-handers in Block A, and as expected they are below the diagonal, as right-handers mark more circles/second with the right hand than the left. In contrast, the left-handers, the multiple dark red circles, are above the diagonal marking more circles/second with the left hand than the right hand. The paler diamonds indicate performance of the same participants when they are faking being of the opposite handedness, and hence the green diamonds are true right-handers faking being left-handed, and the pink diamonds are true left-handers faking being right-handed. The large circles and diamonds are means for the various groups, circles for normal handedness (R_T and L_T) and diamonds for faking the opposite handedness (R_F and L_F). Note that R_T is connected to L_F as they are the same individuals, as also L_T is connected to R_F.

The writing tasks. The writing tasks show a rather different pattern from the circle-marking tasks, and Figure 3, as an example, shows the rate for the alphabet writing task, and the other five measures are shown in supplementary figures S3, S4 and S5. The major difference for the writing tasks is that in general the faking conditions results in an approximately horizontal (or vertical shift), but that the lines end at about the diagonal whereas for circle-marking they cross the diagonal.

Normal performance on the tasks. Table 1 summarises the means and SDs of performance of the various groups and conditions for the different outcome measures. As can seen for the T&B task in figure 1 (and the other tasks in supplementary figures S2, S3 and S4) in the normal conditions (R_T and L_T) there is no difference in performance of the dominant hand of right-handers and left-handers, and that is confirmed by a t-test, both for the T&B task and the other seven measures (Table 2 row a). However performance by the non-dominant hand of left-handers in 4 of the 8 measures is statistically better for left-handers (table 2 row b), and the difference between Dominant and Non-Dominant hand performance is significant for 7 of the 8 measures, left-handers showing less difference than right-handers (table 2, row c). In view of the multiple significance testing a 'portmanteau' test was also carried out using MANOVA, which for all eight outcome measures simultaneously showed no difference between right- and left-handers for the dominant hand (Wilk's Lambda = .855, approximate $F(8,46)=.973$, $p=.469$), but there was a significant overall difference for the non-dominant hand (Wilk's Lambda = .715, approximate $F(8,46)=2.291$, $p=.037$), and a rather more significant difference between right-handers and left-handers for the difference between the dominant and non-dominant hands (Wilk's Lambda = .625, approximate $F(8,46)=3.444$, $p=.003$). Overall therefore left-handers are similar to right handers in dominant hand performance, but have better performance on their non-dominant hand, meaning that overall the difference between dominant and non-dominant hands is smaller. That has possible implications for the faking of performance.

Faking performance on the tasks. The simple model in figure 1 suggests that faking will mostly be carried out by slowing down the performance of the dominant hand while maintaining performance of the non-dominant hand, so that right-handers will shift along the horizontal line shown (and similarly, left-handers should shift down a vertical line). The actual data, in figure 2 for the T&B task suggests that indeed the green line for true right-handers is approximately horizontal while the red line for true left-handers is approximately vertical. Those possibilities can be tested by comparing performance of the right- and left hands of right- and left-handers across the normal and faking conditions. As expected, and using paired t-tests, dominant hand performance is much reduced, both for right-handers (Table 2, row d) and left-handers (table 2, row e) for all eight measures. However non-dominant hand performance, for right-handers (table 2, row f) and left-handers (table 2, row g) differs between the tasks. For the circle-marking tasks right-handers do not change their non-dominant hand performance (i.e. the line is horizontal), but left-handers show an increase in non-dominant hand performance (i.e. the line slopes down somewhat to the right). Left-handers can therefore improve right-hand performance if they need to during faking, whereas right-handers cannot. A similar picture is shown for the raw measures of writing quality (figure S4), but only the left-handers cross the main diagonal. The measures of letters/second and quality/second (figures S3 and S5) show for both right and left-handers that performance decreases in both the dominant hand and the non-dominant hand, the lines for both right- and left-handers sloping downwards to the left, which is very different from the pattern for circle-making (compare with Figure 2 and figure S2).

Summarising these results, on the circle-marking task it is possible to fake the reversed pattern of handedness seen in people of the opposite handedness, but that is far harder for the writing tasks of the alphabet or sentence.

Variation in ability to fake the opposite handedness. Although the picture for faking handedness is clear for the average scores of participants, it is also apparent that there is variation in the extent to which individuals can produce results which are similar to those of individuals of the opposite handedness. Here we assess how much individuals can fake handedness, and how that relates to social cognitions of handedness and measures of individual differences.

Social cognitions of handedness.

Individuals differ in how much they know about the handedness of others, and to assess that we collected four separate measures using a conventional 14-item handedness questionnaire.

- *Questionnaire 1:* In Block A the participants were asked about *their own handedness* using the fourteen items on a modified and extended Edinburgh Handedness Inventory
- *Questionnaire 2:* In Block B participants were asked to complete the questionnaire *as if they were faking the opposite handedness*.
- *Questionnaire 3:* In the first part of the assessment of social cognitions in Block C, each participant was asked to estimate how frequently 100 other people *of the same true handedness as themself,* would answer the five possible response categories for each question.
- *Questionnaire 4:* Finally, at the end of Block C, participants estimated how frequently 100 other people *of the opposite true handedness to themself*, would answer the various response categories for each item on the questionnaire.

An example set of answers by a right-handed participant to a single item in each questionnaire is shown in Table 3.

Comparison of right and left-handers. Scores for Questionnaires 1 and 2 were calculated in a standard manner, reversing two items for which the non-dominant hand would normally be the correct answer, and then calculating a laterality index. *LI*, in the range +100 (complete right-handedness) to -100 (complete left-handedness). For convenience, a separate score, LI_D, was also calculated in which scores for left-handers were reversed, so that a score of +100 indicates complete dominance (be it for right or left handedness).

Figure 4 shows LI for the true handedness questionnaire and the questionnaire when faking the opposite handedness (and the same data plotted for LI_D are shown in Supplementary Figure S10). As is typical of most studies, on questionnaire 1 the right-handers were more strongly lateralised and less variable in their lateralisation then left-handers (mean LI_D(SD): R_T 69.8 (18.6); L_T 19.1 (36.9); t=6.58, 53 df, p<.001; Levene's test, p<.001). In contrast there were no differences in mean (SD) of LI_D between fake right-handers and fake left-handers (mean LI_D (SD): R_F 58.7(25.4) L_F 59.8 (17.6); t=-2.1, 53 df, p=.839; Levene's test, p= .439). Participants also showed significant correlations between their LI_D for actual handedness and faked handedness (right-handers: r=.450, p=.013; left-handers, r= .485, p=.014). Although left-handers actually show lower and more variable LI_D scores, fake left-handers show LI_D scores which are higher and less variable, and very similar to actual right-hander LI_D

scores. In contrast, fake right-handers show LI_D scores similar to those of actual right-handers, suggesting that left-handers are aware that right-handers have a different distribution of laterality indices to left-handers but that right-handers are not aware that left-handers have a different distribution of laterality indices.

Measuring the accuracy of perception of the handedness of others. Consider the right-hander in table 3 who is asked to *estimate* how other right-handers will answer a question about throwing, and they estimate that the percentages answering *L++, L+, =, R+ and R++* are 0%, 0%, 20%, 30% and 50%. In fact, of the 30 actual right-handers in the study, who for this purpose are the *normative* sample, 0, 0, 1, 13 and 16 participants (0%, 0%, 3.3%, 43.3% and 53.%) gave those answers. For this item a laterality index for the *normative* sample can be calculated, scoring *L++, L+, =, R+ and R++* as -100, -50, 0, +50 and +100, as (-100x0 + -50x0 + 0x3 + 50x13 + 100x16)/30 =2250/30 =+75.0. In comparison the participant has an *estimate* that the laterality scores will be (-100x0 + -50x0 + 0x20 + 50x30 + 100x50)/100 = 6500/100 =+65.0. The participant with a score of +65.0 for this item has therefore slightly under-estimated the actual laterality for this item of+75.0, and the effect can be summarised as the difference between the normative score and the estimated score, i.e. (+75.0) – (+65.0) = +10.0. The same process can be carried out and summed across the participant's estimates for *all* 14 items. The results are complicated and potentially confusing, and therefore will be described step by step.

For the normative sample of 30 right-handers the mean(SD) LI on the 14-item Edinburgh questionnaire was 69.76 (18.59) [column 2], and the absolute values are the same as all of the right-handers had positive LIs [column 3]. The 30 right-handers estimated that in other right-handers the mean LI would be 61.74 [column 4], a little less lateralised than was actually the case in the normative sample (69.76), the average error of estimation being -8.02 [column 6], the normative sample being more lateralised than estimated. Finally the absolute error of estimation [column 8] for right-handers of other right-handers is 11.54 (so that right-handers with a perfect estimate of the handedness of other right-handers would score zero, and positive scores indicate less accuracy of estimation). The normative group of left-handers had a score of -19.15 (SD 36.91) [column 2 second row], the mean being fairly close to zero as some left-handers had positive laterality indices. Other left-handers estimated that left-handers would have a mean LI of -37.74 [column 5 row 2] , so that the error of estimation was -17.59 [Column 7 row 2], the negative score indicating that left-handers saw other left-handers as being more lateralised, i.e. more left-handed, than they actually are. Left-handers had an absolute error of estimation of 19.10 [column 9 row 2], which is larger than the equivalent figure by right-handers of other right-handers (11.54) in large part because the normative variability of right-handers is less than that or left-handers (18.59 vs 36.91).

The remaining cells in rows 1 and 2 of table 4 are shaded, and indicate the estimated scores of individuals of one handedness for individuals of the other handedness to themselves.

The reason for assessing social cognitions of the handedness of others, and in particular the perceived handedness of those of opposite handedness, is to assess whether a more accurate knowledge of the handedness of those of opposite handedness to oneself can help in faking the handedness of those of opposite handedness.

Faking handedness in relation to the social cognitions of the handedness of others. In order to fake successfully a person must act as much as possible like a typical person from the group whom they are trying to imitate. Figure 5 shows a scattergram of the right and left hand performance of true right-handers (black solid circles) and of left-handers faking being right-handed (red solid circles). The most typical true right-hander will be at the centroid of the black circles with scores at the mean performance of R_T for right-hand performance, *mean(RH:*R_T*)*, and the mean of left hand performance, *mean(LH:*R_T*)*. A particular left-hander faking right-handedness, R_F, will have scores of *RH:*R_F and *LH:*R_F, and hence the distance of this participant from the centroid of R_T, using Pythagoras's Theorem is $sqrt([RH{:}R_F\text{-}mean(RH{:}R_T)]^2+[LH{:}R_F - mean(LH{:}R_T)]^2) = FF$, where FF is a measure of *Faking Failure*, a value of zero indicating successful performance at the centroid of true right-handers, and high values indicating degrees of failure at faking, and failing to 'pass' as a right-hander. Faking failure measures were calculated for each of the eight performance measures in table 2, each being converted to a z-score to allow them to be combined into an overall measure of FF. The eight FF scores correlated 0.418 on average, resulting in Cronbach's alpha for a combined score of .852, suggesting that faking ability is reliable across the multiple tasks and measures. Factor analysis of the eight FF scores showed a strong first factor (eigenvalues: 4.16, 1.51, 1.06, .54, .38, .17, and .06, the first factor accounting for 52% of the total variance). The scree-plot suggested three possible factors, and a varimax rotation suggested that these related to the timed writing measures, the tapping score measures (T&B and Van Horn) and the writing quality measures.

The extent to which Social Cognitions were related to ability at faking was assessed by correlating FF with the overall mean absolute error of estimation (columns 8 and 9 in table 4). FF showed an overall correlation with the absolute error of estimation of the handedness of others of 0.483 (n=55, p<.001), those who were more accurate at predicting the questionnaire responses of individuals of opposite handedness to their own were also better at faking the performance of individuals of opposite handedness. The three separate performance faking factors correlated .195, .344 and .407 with absolute error of estimation of the handedness of others (p=.153, .010 and .002), but the three correlations did not differ significantly from one another (p=.256 (Meng, Rosenthal, & Rubin, 1992)).

Social cognitions as well as faking ability vary by handedness, and therefore figure 6 shows the relationship of FF and social cognitions separately for right and left-handers. The correlation is significant in right-handers (r=.379, n=30, p=.039) but not in left-handers (r=.195, n=25, p=.350), although the difference between the two correlations is not significant (p=.483).

Social cognitions, faking and personality. A range of personality measures was administered to the participants in the study. In particular there were two separate versions of the five scales of the Big Five, the Marlowe-Crowne Social Desirability scale, a measure of Right-Left confusion, and a measure of dyspraxia (see method section). Each personality measure as well as sex was correlated with the measure of social cognition (absolute error in predicting others handedness) and the measure of faking, the overall FF score. None of the 28 correlations reached significance at the .05 level, the most significant being p=.061 (without correction for multiple testing).

Bayesian analysis for D.

The analyses thus far have been in terms of a group of typical right and left-handed participants. However the impetus behind those studies was the case of the defendant *D*, who claimed to be right-handed, and indeed carried out the various tasks better with his right hand than his left hand. However there is a possibility that *D* is actually left-handed and, aware of the advantages of being perceived as right-handed, is faking being a left-hander, presumably by reducing his left-hand performance. What is required therefore is to compare *D*'s performance with true right-handers (R_T) and with true left-handers faking being right-handed (R_F), as for both groups the performance, as in *D*, would be better with the right-hand.

Figure 5 shows a scattergram on the T&B task of right-hand performance (horizontal) and left-hand performance (vertical), for R_T as black points and contours, and R_F as red points and contours, and it is clear that both right and left-hand performance are lower for R_F than for R_T, as expected from the model described earlier. The distributions for R_T and R_F both also approximate correlated bivariate normal distributions, so that the distributions can be considered as Gaussian, The large blue point in figure 5 is the data for *D*, and it is clear that his overall performance is a little below average for R_T but above average for R_F. The question therefore is whether *D*'s performance is more compatible with R_F or R_T, with a key forensic question being the relative odds of *D* being from R_T rather than R_F.

The problem can be expressed in Bayesian terms (and for a clear, straightforward, worked introduction to the univariate and multivariate cases see Shimodaira (2015)). Each participant is assessed with their right and left hands on a set of *t* tasks. In general let there be *n* measures, where n=2.t, each task being tested with each hand. For Figure 5, t=1 and n=2. The points for R_T have an (n x 1) vector of means, $\mathbf{m_T}$ and an (n x n) covariance matrix, $\mathbf{V_T}$. Similarly the points for R_F have an (n x 1) vector of means, $\mathbf{m_F}$ and an (n x n) covariance matrix, $\mathbf{V_F}$. R_F and R_T both have multivariate normal distributions, and a useful measure of the distance between the distributions is the Bhattacharyya distance (BD), which is a conceptual extension of the Mahalanobis distance, and is calculated here as sqrt[$(\mathbf{m_T}-\mathbf{m_F})*((\mathbf{V_T}+\mathbf{V_F})/2)^{-1}*(\mathbf{m_T}-\mathbf{m_F})$]. Note that BD is not merely the Euclidean distance between $\mathbf{m_T}$ and $\mathbf{m_F}$ but also takes into account the variances and covariances of the measures. BD can be regarded as similar to an effect size, expressing the distance between the means of two distributions, and when k=1 it is equivalent to Cohen's *d*.

D also has a (n x 1) vector, $\mathbf{x_D}$, of points corresponding to *D*'s performance on the various measures. The probability of $\mathbf{x_D}$ coming from distribution R_T, $P(\mathbf{x_D}|R_T) = k.L(\mathbf{x_D}|R_T) = k.\mathcal{N}(\mathbf{x_D}; \mathbf{m_T},\mathbf{V_T})$, where $\mathcal{N}(...)$ is the multivariate normal probability density function for $\mathbf{x_D}$ given means $\mathbf{m_T}$ and covariance matrix $\mathbf{V_T}$, and $L(\mathbf{x_D}|R_T)$ is the likelihood of $\mathbf{x_D}$ given R_T, which is the ordinate of the multivariate normal distribution; and similarly the probability that *D*'s data come from R_F is $P(\mathbf{x_D}|R_F) = k.L(\mathbf{x_D}|R_F) = k.\mathcal{N}(\mathbf{x_D}; \mathbf{m_F},\mathbf{V_F})$. *k* is a constant of proportionality, and for the same data will be the same in the two equations (and hence later will cancel out).

The analysis however requires an estimate not of the likelihood of the data given the distributions, but the posterior probability of the likelihoods that *D's* results are drawn from each of the distributions, given the data, which are $L(R_T|\mathbf{x_D})$ and $L(R_F|\mathbf{x_D})$. These likelihoods can be calculated from Bayes Theorem, so that, $L(R_T|\mathbf{x_D}) = P(\mathbf{x_D}|R_T).p(R_T)/p(\mathbf{x_D})$, where $p(R_T)$ is the prior probability in the population of an individual being $p(R_T)$. Likewise $L(R_F|\mathbf{x_D}) = P(\mathbf{x_D}|R_F).p(R_F)/p(\mathbf{x_D})$. Note that both equations have $p(\mathbf{x_D})$ as the divisor, and eventually this will cancel out, as is typical in many applications of Bayes' Theorem.

The odds ratio that the data come from R_T rather than from R_F can then be estimated as $P(\mathbf{x_D}|R_T).p(R_T) / [P(\mathbf{x_D}|R_F).p(R_F)]$, with the posterior probability of R_T being $[P(\mathbf{x_D}|R_T).p(R_T) / [P(\mathbf{x_D}|R_F).p(R_F)]]/[1+P(\mathbf{x_D}|R_T).p(R_T) / [P(\mathbf{x_D}|R_F).p(R_F)]]$.

There is no obvious basis on which to estimate the prior probability that an individual is faking their handedness rather than showing their true handedness. For a random member of the public it is almost certainly extremely low, but where there is a potential reward it could be very high. A neutral prior of 0.5 is probably therefore the most sensible. The sensitivity of the calculations to that assumption can be tested if required.

For the data shown in Figure 5, where k=2 and the first element is for the right hand and the second element for the left hand, $\mathbf{m_T}$ = [2.3900 1.5683]', $\mathbf{V_T}$ = [0.1163 0.0515; 0.0515 0.0942], $\mathbf{m_F}$ =[1.8660 0.9820]' and $\mathbf{V_F}$ = [0.1109 0.0470; 0.0470 0.1114]', with $\mathbf{x_D}$ = [2.4250 1.0500]'. As a result, $P(\mathbf{x_D}|R_T)$ = 0.2359 and $P(\mathbf{x_D}|R_F)$ = 0.3305. p(R_T) is given a neutral value of 0.5, therefore also p(R_F)=1- p(R_T) = 0.5. The odds ratio that the data come from R_T is then .2359/.3305 = .7137 (meaning that the odds are less than 1 that the data come from R_T and hence that R_F is a little more likely). Finally the posterior probability for R_T is calculated as .7137/(1+.7137) = .4165. Based on the T&B task there is a slightly higher chance that *D*'s data come from R_F rather than R_T.

Altogether there are six measures of motor skill for *D*, two measures of circle marking ability (T&B and Van Horn), and four measures of writing ability, three for writing the letters of the alphabet (letters per second, quality of writing, and quality of writing per second) and one for writing a cursive sentence (letters per second). Note that for D there was neither a quality measure nor a quality per second measure for the sentence as a different sentence had been used. Figures similar to figure 5 for all of the measures are available in the Supplementary Material, and table 5 summarises the various measures. Of the six measures, five do not show convincing evidence for or against *D* being R_T, the posterior probabilities for R_T varying from range .1607 (i.e. a little in favour of R_F) to .6912 (a little in favour of R_T). The exception is for speed of sentence writing which has an odds ratio of 4.24×10^5 and hence a posterior probability for R_T of >.9999. Although a multivariate analysis could have been carried out, the results did not provide any additional evidence of interest, and therefore are not included here.

Table 5 provides the Bhattacharyya distances (BDs) for each of the measures, both for the six measures on which *D* was tested, as well as the other two measures which were not available for *D*, and the calculations are also provided for left-handers. The timed measures for writing (characters/second and quality/second) generally have higher BDs, all being over 3, suggesting they are better at discriminating true from faked handedness compared with the circle-marking tasks. Writing quality measures on their own, without timing information, have low BDs, probably because of strategy differences between participants.

Discussion

A legal case involving possible faking of handedness, a topic on which we are unable to find any previous studies, was the initial stimulus to the present study. Providing a possible answer to that question required a more extensive study in groups of right- and left-handers who were tested firstly in the usual way, and then after being asked to fake being of the opposite handedness. In general opposite handedness was faked by reducing the performance of the dominant hand, so that the true non-dominant hand then performed better than the true dominant hand. Left-handers, but not right-handers, were also more able to improve the performance of their usually non-dominant hand. Comparing the various tasks it became clear that faking was most easily detected using a timed test such as cursive lower-case writing where in the faking condition the faked dominant hand wrote more slowly and less accurately. Simple motor tasks such as the Tapley and Bryden and Van Horn tasks were less good at distinguishing true handedness from faked handedness, perhaps because they are less skilled and less over-learned than cursive hand-writing, which is a highly skilled activity that children practice for many years at skill and adults often use extensively on a daily basis. Upper case letters are less good as tasks, as children and adults sometimes learn, and practice, writing upper cases letters with their non-dominant hand, be it for fun, curiosity, a party trick, or for other sometimes work-related purposes, and in addition upper case letters are often simpler with many straight lines than the fluidly curving letters of lower-case cursive writing. A simple statistical model, which was similar to that produced in the expert witness statement to the court (see Figure 1) provided a reasonable account of how motor tasks can be faked. A noteworthy part of the model is that conventional laterality coefficients of the form (R-L)/(R+L), which reduce hand performance to a single number, would be unable to detect faking, but plotting data in the two-dimensional space of right-hand performance vs left-hand performance makes faking clear as it is the dominant hand only which changes its performance. That conclusion is also consistent with our own recent re-analyses of data on the Tapley and Bryden and other tasks, where it is clear that simple laterality coefficients can be very misleading (McManus et al., 2016).

The case of D. The analyses show that in a forensic situation the various measures can be assessed using a Bayesian approach to assess the posterior probability of an individual being a true [right-]hander as opposed to a fake [right-]hander. For the particular case of *D*, the evidence was in favour of him being a true right-hander, although inevitably there must be provisos. The analyses require not only reasonably large control samples of both right- and left-handers, but those control groups also need to be carrying out the tasks both in the usual way and while trying to fake being of the opposite handedness. The control groups may not be entirely appropriate, not being matched to *D* in various ways. In particular, the control groups were mainly university undergraduates, whereas *D* did not attend university, and had relatively low educational attainment at school-leaving examinations, and that may reduce the generalisability of the conclusions. In future legal cases it may make sense to have educationally matched right- and left-handers, although cursive hand-writing is over-learned and heavily practised in most adults, and there was little evidence that *D* was an outlier in his performance (see supplementary figures S6, S7 and S8). Although we gave the current participants a cover story as to why they needed to fake, they only had a little time to consider that story and how to respond to it, whereas *D* both knew the potential importance of his handedness, was aware that he might be tested, and had a number of months in confinement to consider that possibility (although there was apparently no evidence that he had been practising at performing as a right-hander). *D* also could not have had any awareness that he might be presented with timed tests, nor of what those tests might be. Were the handedness of *D* to become important in the future then clearly more extensive and more detailed testing would be required, and the present study could help to clarify both the nature of those tests and the appropriate control participants who perhaps should be tested. Cases of possible faking of handedness for legal purposes are rare (and this is only the second one which the first author has encountered in his career, the previous case not eventually going to court), and so it is recommended that future cases use an *ad hoc* panel of known left and right-handers for comparison, using appropriate written sentences in the language of the defendant.

More generally, it is of interest that in the various tests, it was the hand-writing tests which were particularly important at suggesting that *D* was a true right-hander, and the motor tasks contributed relatively little. Motor tasks such as the T&B task (Tapley & Bryden, 1985) can undoubtedly separate right- and left-handers clearly, as McManus et al (2016) demonstrated. However they are relatively unskilled tasks, and therefore have not been over-learned, in contrast to hand-writing, which is a complex skill learned over many years, a skill which education emphasises from an early age, and a skill for which lower quality of performance is very apparent visually. It was the cursive hand-writing task which particularly provided the most robust evidence for *D* being a true right-hander, although there was a suggestion that quality of alphabet writing in particular is rather anomalous.

The Bhattacharyya distances (BD) for the tests are informative about their ability to distinguish true handedness from faking. The two circle-marking tests have lower BD scores, 2.000 and 1.532, than any of the other measures, probably reflecting them not being particularly over-learned as skills. The writing tasks mostly have higher BD scores, with alphabet quality being an exception with a BD of 1.300, and on an anecdotal basis it is possible that writing the upper case alphabet with the right hand is something that a number of left-handers have practised (and it is in contrast to the BD score for sentence quality score of 2.837, which for the particular sentence presented has probably not been practised). Rate of writing has BD scores of 3.019 and 3.815 for alphabet and sentences respectively, and quality of writing per second has BD scores of 3.722 for alphabet and 4.393 for sentences. Cursive sentences therefore distinguish better between R_T and R_F than do individual uppercase letters. The most compelling evidence for *D* being R_T came from the speed of lower-case cursive writing. However it is generally important that judgements of writing *quality* are collected, as well as only the quantitative measures of writing *speed*. There is inevitably a speed-accuracy trade-off, and without quality measures participants could have written very fast but utterly illegibly. It was unfortunate that the control participants could not be tested on the same sentence as *D* had written, but that reflected the lack of preparation time before *D* was tested, and in an ideal world the testing of the control participants would have taken place before *D* was tested. Nevertheless a clear prediction, given the high BD scores, is that the rate, quality and quality/second measures of cursive lower-case sentence writing would be the best measure for identifying faking of handedness, cursive writing being the most technically difficult and hence over-learned of all the skill. Finally, although the analysis has concentrated on R_T and R_F, since that is of interest for the particular case of *D*, table 5 also shows the BD scores for the case where it is L_T and L_F which are being distinguished. For the circle-marking tasks the BD scores are higher for left-handed performance, but that is not overall the case for the writing measures.

Cursive writing is better than simple motor tasks at detecting faking, but it has the practical problem that judgements of writing quality have to be made, which requires a series of trained judges. Writing tasks also have a speed-accuracy trade-off which participants handle differently, and as a result quality per second measures are the best measure for assessing faking. The judged quality of the writing specimens in our study, particularly using a large number of judges and hence having very reliable measures allows other conclusions about writing quality.

The handwriting of left-handers. There have been few studies of handwriting in left-handers, with the internet as ever making myriad contradictory claims, some suggesting that it is harder for left-handers to learn to write neatly, mainly because of mechanical constraints and a lack of proper educational input, but also that the handwriting of left-handers is typically no worse than that of right-handers. Of the few formal studies, one large study of children in grades 1-9 found that right-handers were slower at writing, but legibility was the same as for right-handers (Graham, Berninger, Weintraub, & Schafer, 1998). A further study looking at writing kinematics in 59 participants claimed no differences between right and left-handers, but with only four left-handers there was little power to find differences (Mergl, Tigges, & Schröter, 1999). An old study in Sweden compared 750 right-handed children with 136 children consistently writing with the left-hand (and many other left-handers had chosen or were made to use their right-hand for writing), and found significantly better writing in the consistent left-writing children (Trankell, 1956). Our study, with 55 adult participants, nearly half of whom were left-handed, and with formal, blind judgements of writing quality by multiple judges, found no difference in either speed of writing or quality of writing in the dominant hand of left- and right-handers. Few other studies have looked at writing by the non-dominant hand but our data clearly show that left-handers are better than right-handers at writing with their non-dominant hand. The equivalence of writing time and quality in right- and left-handers was also seen in two earlier, unpublished, studies (McManus & Rustell, 1982) (Appleyard, 1987), with evidence also in one of them for faster, higher quality writing by the non-dominant hand in left-handers than right-handers (Appleyard, 1987).

Social cognitions of handedness. Although right and left-handedness are well known in society, knowledge about the handedness of others is little considered in general. Right-handers are not all identical in their patterns of right-handedness and left-handers are probably more variable in the nature of their left-handedness. We don't know of any previous studies which have attempted to assess social cognitions of handedness, and the method adapted from that of Prelec (2004), see table 3, is well suited to the purpose. The results are compl`icated, but there is clearly variation in perception of the handedness of others, right-handers thinking that other right-handers are less lateralised than they actually are, and left-handers thinking that other left-handers are more lateralised than they actually are. How individuals learn about the handedness of others is far from clear, and it may be by observation, or, say, left-handers may talk about their particular patterns of left-handedness to other left-handers. Such knowledge is not merely theoretical, it has to be emphasised, since both right- and left-handers who were better at faking opposite handedness had greater social cognitive knowledge about the handedness of those they were faking than did those who were less good. The understanding of the behaviour of others is always difficult, and particularly difficult is an understanding of the lived experience of others which might then allow one to enter into the mental world of the other. At its most extreme, of course, such insight is probably impossible, as Nagel emphasised in his classic paper which asked 'What is it like to be a bat?' (Nagel, 1974), with an understanding of what it is to behave like and to feel like a right-hander or a left-hander somewhere along that continuum.

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Table 1. Comparisons of R_T, L_T, R_F and L_F

In the top eight rows the values in bold are those that should have the better performance (i.e. Right hand for R_T and R_F and Left hand for L_T and L_F). For the bottom four rows (shaded) the values in bold are those for which the right hand should be faster (R_T and R_F) and have positive values, whereas for the other two rows the values should be negative, the left hand being faster.

				Circle-marking tasks		*Writing tasks*					
	Hand		N	T&B circle/sec	Van Horn circles/sec	Alphabet (letters/sec)	Alphabet (quality)	Alphabet (quality/sec)	Sentence (letters/sec)	Sentence (quality)	Sentence (quality/sec)
Right-handers, R_T	**Right**	**R_{T-RH}**	**30**	**2.390 (.341)**	**1.858 (1.419)**	**1.357 (.337)**	**7.080 (.999)**	**.364 (.086)**	**2.154 (.489)**	**6.307 (1.094)**	**.385 (.095)**
	Left	R_{T-LH}	30	1.568 (.307)	1.274 (.204)	.635 (.165)	3.772 (1.216)	.090 (.033)	.850 (.237)	3.324 (1.133)	.082 (.042)
Left-handers, L_T	Right	L_{T-RH}	25	1.664 (.334)	1.419 (.204)	.766 (.238)	4.499 (1.078)	.132 (.054)	.980 (.319)	3.664 (.822)	.101 (.037)
	Left	**L_{T-LH}**	**25**	**2.232 (.368)**	**1.859 (.216)**	**1.318 (.382)**	**7.062 (.869)**	**.355 (.103)**	**2.045 (.585)**	**6.013 (.863)**	**.351 (.111)**
Right-handers faking Left, L_F	Right	L_{F-RH}	30	.849 (.330)	.859 (.305)	.552 (.273)	3.800 (1.695)	.086 (.070)	.796 (.381)	3.493 (1.367)	.084 (.060)
	Left	**L_{F-LH}**	**30**	**1.648 (.384)**	**1.315 (.234)**	**.521 (.141)**	**4.997 (3.711)**	**.099 (.039)**	**.693 (.198)**	**4.209 (1.524)**	**.081 (.034)**
Left-handers faking Right, R_F	**Right**	**R_{F-RH}**	**25**	**1.866 (.333)**	**1.532 (.223)**	**.578 (.187)**	**5.579 (1.341)**	**.120 (.039)**	**.777 (.259)**	**3.661 (1.423)**	**.101 (.037)**
	Left	R_{F-LH}	25	.982 (.334)	1.015 (.328)	.564 (.218)	3.711 (1.197)	.081 (.043)	.864 (.371)	4.616 (1.119)	.090 (.049)
Right-handers, R_T	Right-Left	**R_{T-RH} - R_{T-LH}**	**30**	**.822 (.328)**	**.583 (.149)**	**.722 (.272)**	**3.308 (1.196)**	**.274 (.083)**	**1.304 (.441)**	**2.982 (1.250)**	**.302 (.086)**
Left-handers, L_T	Right-Left	L_{T-RH} - L_{T-LH}	25	-.568 (.247)	-.440 (.193)	-.552 (.279)	-2.563 (1.186)	-.223 (.085)	-1.066 (.452)	-2.349 (.962)	-.249 (.097)
Right-handers faking Left, L_F	Right-Left	R_{F-RH} – R_{F-LH}	30	-.799 (.359)	-.456 (.293)	-.020 (.204)	1.197 (1.830)	.014 (.061)	.103 (.288)	-.716 (1.625)	.003 (.050)
Left-handers faking Right, R_F	Right-Left	**L_{F-RH} – L_{F-LH}**	**25**	**.884 (.358)**	**.517 (.266)**	**-.014 (.239)**	**1.868 (1.683)**	**-.038 (.049)**	**-.087 (.349)**	**-.955 (.1535)**	**.011 (.043)**

Table 2. Comparisons for data in table 1, expressed as first minus second as in the table (e.g. for R_T vs L_T or equivalent). Cells with p<.05 are shown in bold, +ve (shaded light grey) indicates $R_T > L_T$, -ve indicates $R_T < L_T$ (or equivalent). Note that tests with 53 df are unpaired t-tests, whereas tests with smaller degrees of freedom (29 or 24) are paired tests within right-handers or left-handers.

Row	Hypothesis being tested	df	T&B circle/sec	Van Horn circles/sec	Alphabet (letters/sec)	Alphabet (quality)	Alphabet (quality/sec)	Sentence (letters/sec)	Sentence (quality)	Sentence (quality/sec)	Handedness inventory
a	Dominant hand skill: R_{T-RH} vs L_{T-LH}	53	t= .1.65 p=.105	t=-.027 p=.979	t=.401 p=.690	t=.070 p=.944	t=.358 p=.722	t=.750 p=.457	t=1.087 p=.282	t=1.220 p=.228	
b	Non-dominant hand skill: R_{T-LH} vs L_{T-RH}	53	t= -1.106 p= .274	***t=-2.62 p=.011***	***t=-2.403 p=.020***	***t= -2.323 p=.024***	***t=-3.495 p=.001***	t=-1.726 p=.090	t=-1.248 p=.217	t=-1.773 p=.082	
c	Dominant-NonDominant skill difference: R_T vs L_T	53	**t=3.186 p=.002**	**t=3.101 p=.003**	**t=2.276 p=.027**	**t=2.309 p=.025**	**t=2.248 p=.029**	t=1.973 p=.054	**t=2.075 p=.043**	**t=2.152 p=.036**	
d	Dominant hand change in right-handers faking left: R_{T-RH} vs L_{F-RH}	29	**t=19.09 p<.001**	**t=20.20 p<.001**	**t=12.13 p<.001**	**t=10.42 p<.001**	**t=15.74 p<.001**	**t=13.87 p<.001**	**t=9.52 p<.001**	**t=15.26 p<.001**	
e	Dominant hand change in left-handers faking right: L_{T-LH} vs R_{F-LH}	24	**t=13.28 p<.001**	**t=13.93 p<.001**	**t=9.32 p<.001**	**t=11.96 p<.001**	**t=13.40 p<.001**	**t=9.93 p<.001**	**t=5.56 p<.001**	**t=13.95 p<.001**	
f	Non-dominant hand change in right-handers faking left: R_{T-LH} vs L_{F-LH}	29	*t=-1.711 p=.098*	t= -1.142 p=.263	**t=3.946 p<.001**	**t= -5.37 p<.001**	t=-1.55 p=.133	**t=4.08 p<.001**	**t=-5.73 p<.001**	t=.224 p=.824	
g	Non-dominant hand change in left-handers faking right: L_{T-RH} vs R_{F-RH}	24	**t= -4.195 p<.001**	**t= -3.554 p=.002**	**t=-4.20 p<.001**	**t=-3.55 p<.001**	**t=5.22 p<.001**	**t= -4.97 p<.001**	t=.010 p=.992	t=.110 p=.913	

Table 3: Example results for the four versions of the hand preference inventory by a right-handed participant for the 'throwing' question. The versions are presented in the order in which they would have been presented during testing.

Block A:

Please indicate your *hand preference* for the following activities by putting a tick in one of the columns

	Always use left	Usually use left	Use both equally	Usually use right	Always use right
Throwing				**X**	

Block B:

[Faking condition] Please indicate your *hand preference* for the following activities by putting a tick in one of the columns

	Always use left	Usually use left	Use both equally	Usually use right	Always use right
[Faking condition] *Throwing*			**X**		

Block C:

Consider a group of 100 *typical RIGHT-handers*. If those right-handers were completing the handedness questionnaire, what percentage do you think would answer each of the questions using the five possible answers?

	Always use left	Usually use left	Use both equally	Usually use right	Always use right
Throwing	**0%**	**0%**	**20%**	**30%**	**50%**

Consider a group of 100 *typical LEFT-handers*. If those left-handers were completing the handedness questionnaire, what percentage do you think would answer each of the questions using the five possible answers?

	Always use left	Usually use left	Use both equally	Usually use right	Always use right
Throwing	**50%**	**20%**	**20%**	**5%**	**5%**

Table 4. Social cognitions of handedness. The rows show either actual laterality indices or estimates of laterality indices for right and left-handers. Columns 2 and 3 show mean (SD) for LI and LID for the normative sample of right-handers and left-handers. The remaining columns, 4 to 9, show the estimated scores of right- and left-handers either for others of the same handedness (normal font) or opposite handedness (bold font and grey shading). Columns 4 shows the estimated LIs made by right-handers for other right-handers and left-handers, and column 5 shows the estimated LIs made by left-handers for other right-handers and left-handers. Columns 6 and 7 show the mean errors in the estimates made by right and left-handers, and columns 8 and 9 the absolute errors of estimation made by right and left-handers. The table can be confusing, but the Ns indicate who is doing the judging since there are 30 right-handers and 25 left-handers making judgements.

Actual/predicted group	Normative sample for true right and left-handers		Mean estimates made by true right-handers	Mean estimates made by true left-handers	Mean error of estimation made by true right-handers	Mean error of estimation made by true left-handers	Mean absolute error of estimation made by true right-handers	Mean absolute error of estimation made by true left-handers
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mean (SD)	LI	LI_D	LI	LI	LI	LI	LI_D	LI_D
Right-handers , R_T	69.76 (18.59) N=30	69.76 (18.59) N=30	61.74 (12.09) N=30	**65.22** **(12.62)** **N=25**	-8.02 (12.09) N=30	**-4.53** **(12.62)** **N=25**	11.54 (8.65) N=30	**10.24** **(8.47)** **N=25**
Left-handers, L_T	-19.15 (36.91) N=25	34.00 (23.23) N=25	**-51.71** **(16.26)** **N=30**	-37.74 (17.76) N=25	**-32.57** **(-4.53)** **N=30**	-17.59 (17.76) N=25	**32.70** **(15.97)** **N=30**	19.10 (16.05) N=25

Table 5. Summary of Bayesian analyses of posterior probability of the measures for *D* being derived from the R_T population rather than the R_F population. See text for further details.

Row	Measure(s)	Bhattacharyya distance R_T vs R_F (L_T vs L_F)	$\mathbf{m_T}$	$\mathbf{V_T}$	$\mathbf{m_F}$	$\mathbf{V_F}$	$\mathbf{x_D}$	$L(\mathbf{x_D}\mid R_T)$	$L(\mathbf{x_D}\mid R_F)$	Odds ratio	Posterior probability for R_T
a)	Tapley and Bryden task circles/second	2.000 (2.456)	2.3900 1.5683	.1163 .0515 .0515 .0942	1.8660 .9820	.1109 .0470 .0470 .1114	2.452 1.050	.2359	.3305	.7137	.4165
b)	Van Horn test 2.5 mm circles/second	1.532 (2.666)	1.8575 1.2742	.0406 .0300 .0300 .0418	1.5320 1.0150	.0498 .0432 .0432 .1077	1.775 .975	1.2210	.9501	1.2851	.5624
c)	Alphabet letters/sec	3.019 (2.941)	1.3570 .6348	.1139 .0334 .0334 .0271	.5776 .5641	.0350 .0126 .0126 .0474	.912 .539	1.4533	.6492	2.2385	.6912
d)	Alphabet quality rating	1.300 (1.764)	7.0795 3.7718	.9971 .5232 .5232 1.4779	5.5785 3.7108	1.7989 .2002 .2002 1.4331	5.00 3.08	.0156	.0812	.1914	.1607
e)	Alphabet quality rating/second	3.722 (3.401)	.3642 .0900	.0075 .0009 .0009 .0011	.1195 .0814	.0015 .0005 .0005 .0018	.175 .064	5.2709	24.9489	.2113	.1744
f)	Sentence letters/second	3.815 (3.416)	2.1540 .8499	.2400 .0507 .0507 .0563	.7771 .8642	.0670 .0415 .0415 .1376	1.925 .679	1.1578	$2.73\text{x}10^{-6}$	4.24×10^{5}	>0.9999
	Measures not available for D										
g)	Sentence quality rating	2.837 (1.514)	6.3067 3.3244	1.1987 .4652 .4652 1.2842	3.6613 4.6160	2.0237 .4601 .4601 1.2516	n/a	n/a	n/a	n/a	n/a
h)	Sentence quality rating/second	4.393 (3.439)	.3847 .0823	.0089 .0017 .0017 .0018	.1010 .0900	.0013 .0010 .0010 .0024	n/a	n/a	n/a	n/a	n/a

Figure captions

Figure 1: Data from the Tapley and Bryden (1985) circle-marking task as re-analysed by McManus et al (2016). The horizontal and vertical axes show the number of circles marked by the right and the left hand respectively. Open and solid circles are self-professed right-handers and left-handers. The blue arrows show the axes of overall motor ability (on the major diagonal) and handedness, at right angles, running down at 45 degrees, with right-handers below the main diagonal and left-handers above. For other details see the text.

Figure 2: Performance of the right hand (horizontal) and the left hand (vertical) of individual participants on the Tapley and Bryden task. Solid dark green circles are for true right-handers (R_T), and pale green lines link those points to the pale green diamonds where true right-handers were faking being left-handed (L_F). Solid red circles are for true left-handers (L_T), and their points are connected to the pale red diamonds when those individuals were faking being right-handed (R_F). Large circles and large diamonds indicate mean performances.

Figure 3: Performance of the right hand (horizontal) and the left hand (vertical) of individual participants on the Alphabet writing task expressed as quality units/second. For colour coding etc see the caption for Figure 2.

Figure 4: Laterality index on the modified Edinburgh Handedness Inventory for true right-handers (green squares) and true left-handers (red circles) when they are describing their true handedness (horizontal) and when they are faking being of the opposite handedness (vertical).

Figure 5: Performance on the Tapley and Bryden task of true right-handers (R_T) shown as solid black circles, and left-handers faking being right-handed (R_F) shown as solid red circles. Ellipses in black and red indicate 5,10,20,30,40,50,60,70,80,90 and 95th percentiles for fitted bivariate normal distributions. The solid blue point marked *D* is for the defendant. For other tasks and measures see the supplementary information.

Figure 6: The relationship of ability at faking in relation to social cognitions of handedness of those of opposite handedness. The horizontal axis shows the error in predicting how opposite handers would answer the Edinburgh Handedness Inventory, with low scores indicating lower error and hence better prediction. The vertical axis shows a summary of accuracy on performance tasks of faking the behaviour of a person of opposite handedness, with lower error scores indicating better performance as an opposite hander, and hence better faking.

Figure 1

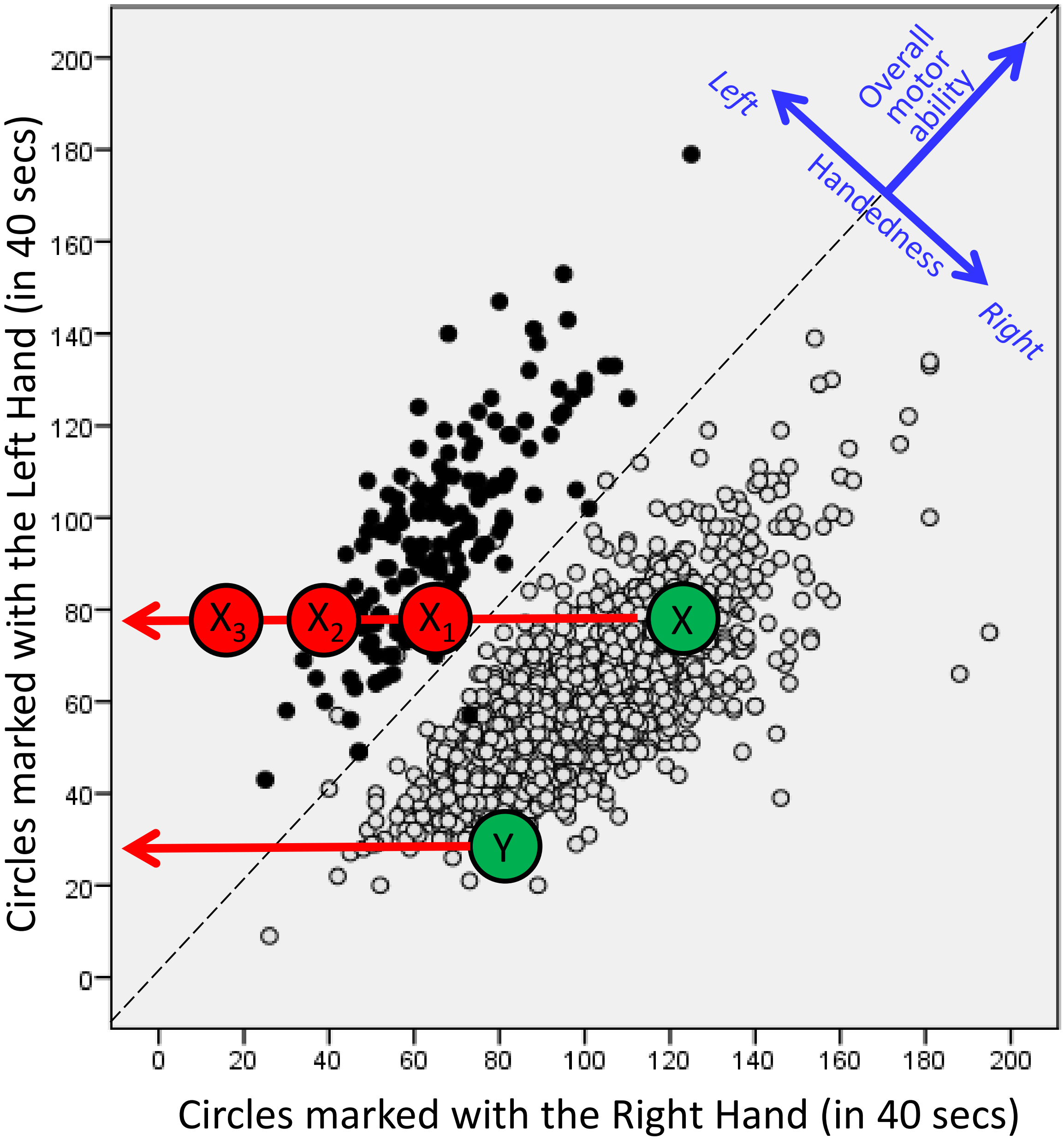

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Figure 2

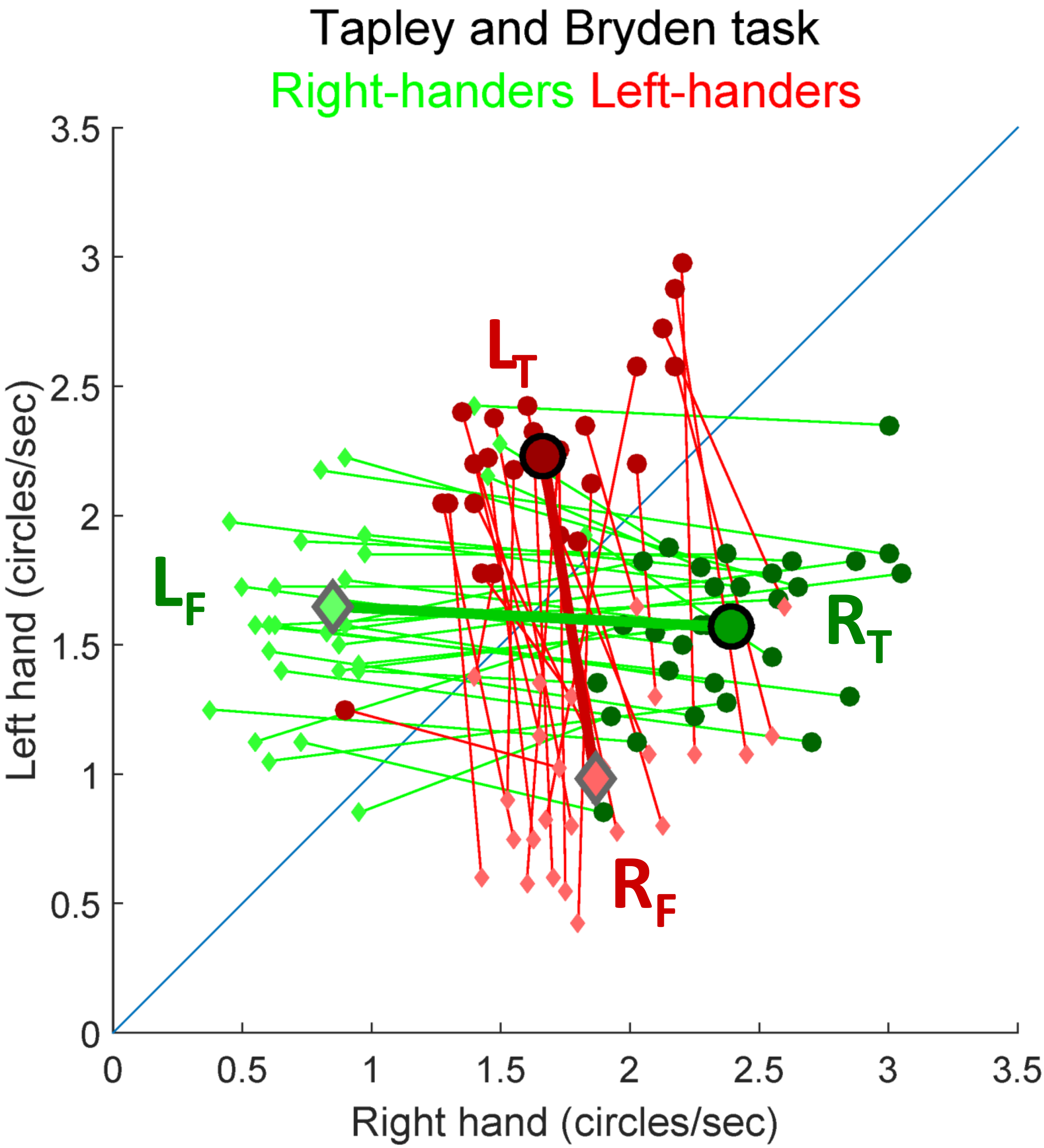

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Figure 3

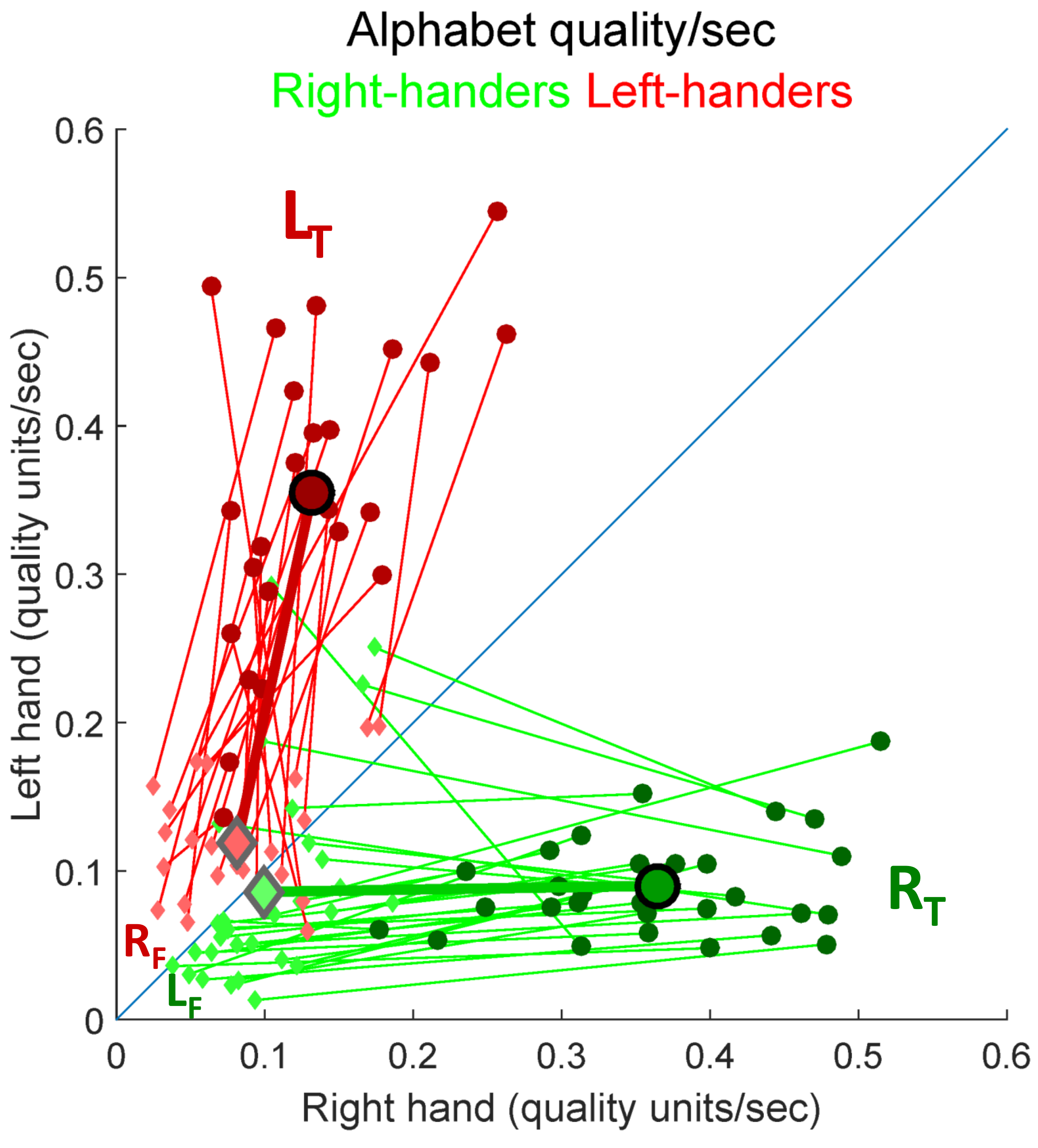

Figure 3: Performance of the right hand (horizontal) and the left hand (vertical) of individual participants on the Alphabet writing task expressed as quality units/second. For colour coding etc see the caption for Figure 2.

Figure 4

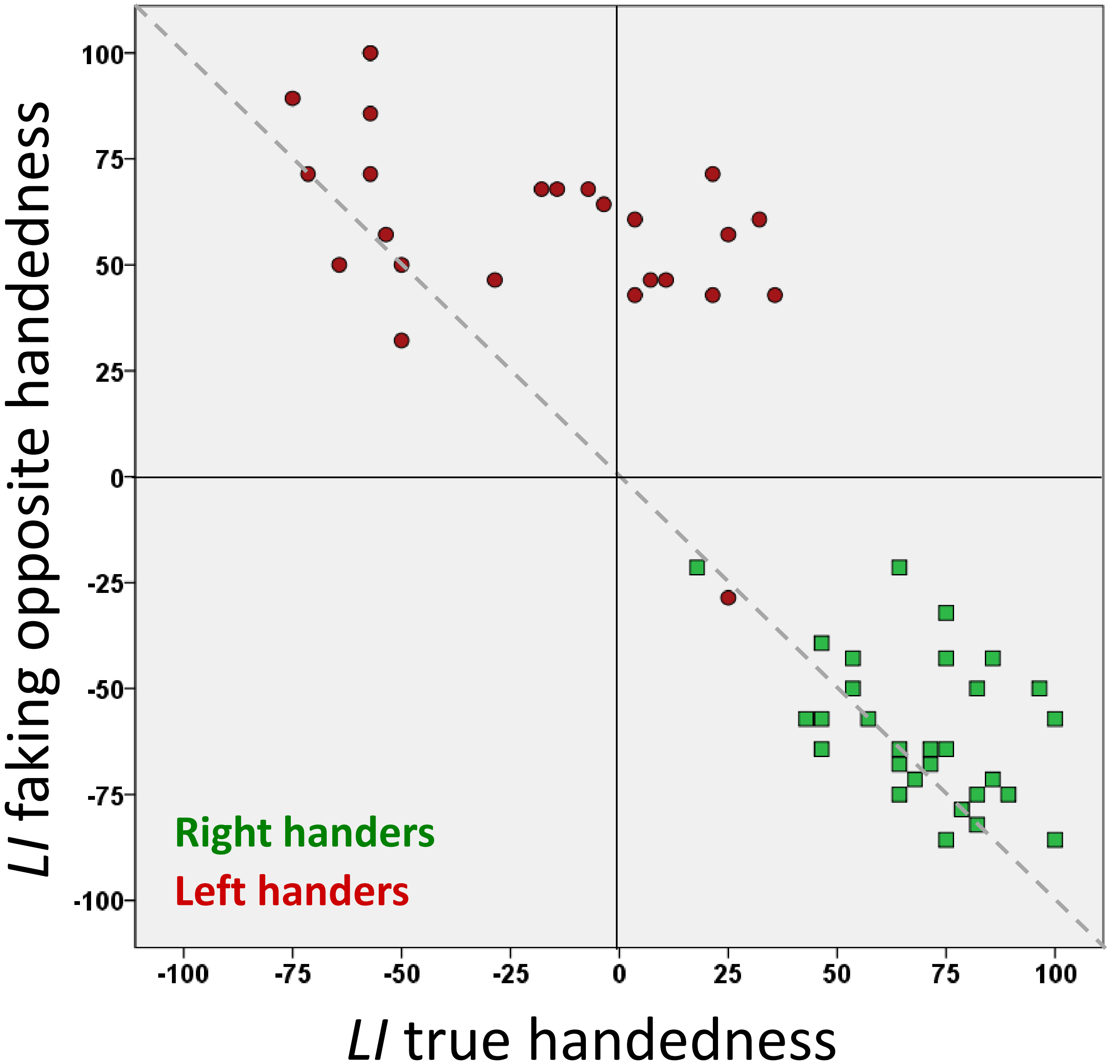

Figure 4: Laterality index on the modified Edinburgh Handedness Inventory for true right-handers (green squares) and true left-handers (red circles) when they are describing their true handedness (horizontal) and when they are faking being of the opposite handedness (vertical).

Figure 5

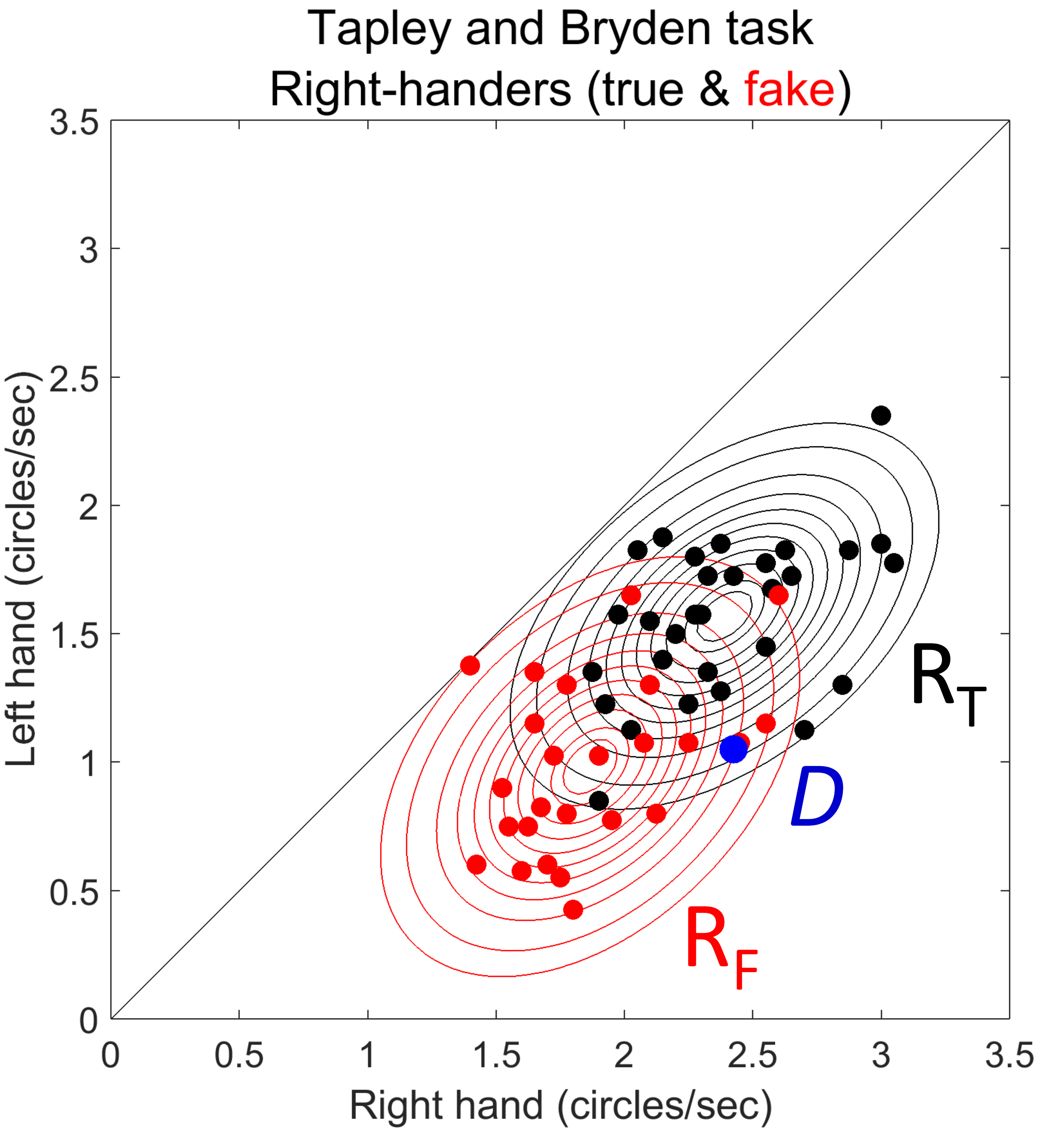

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Figure 6

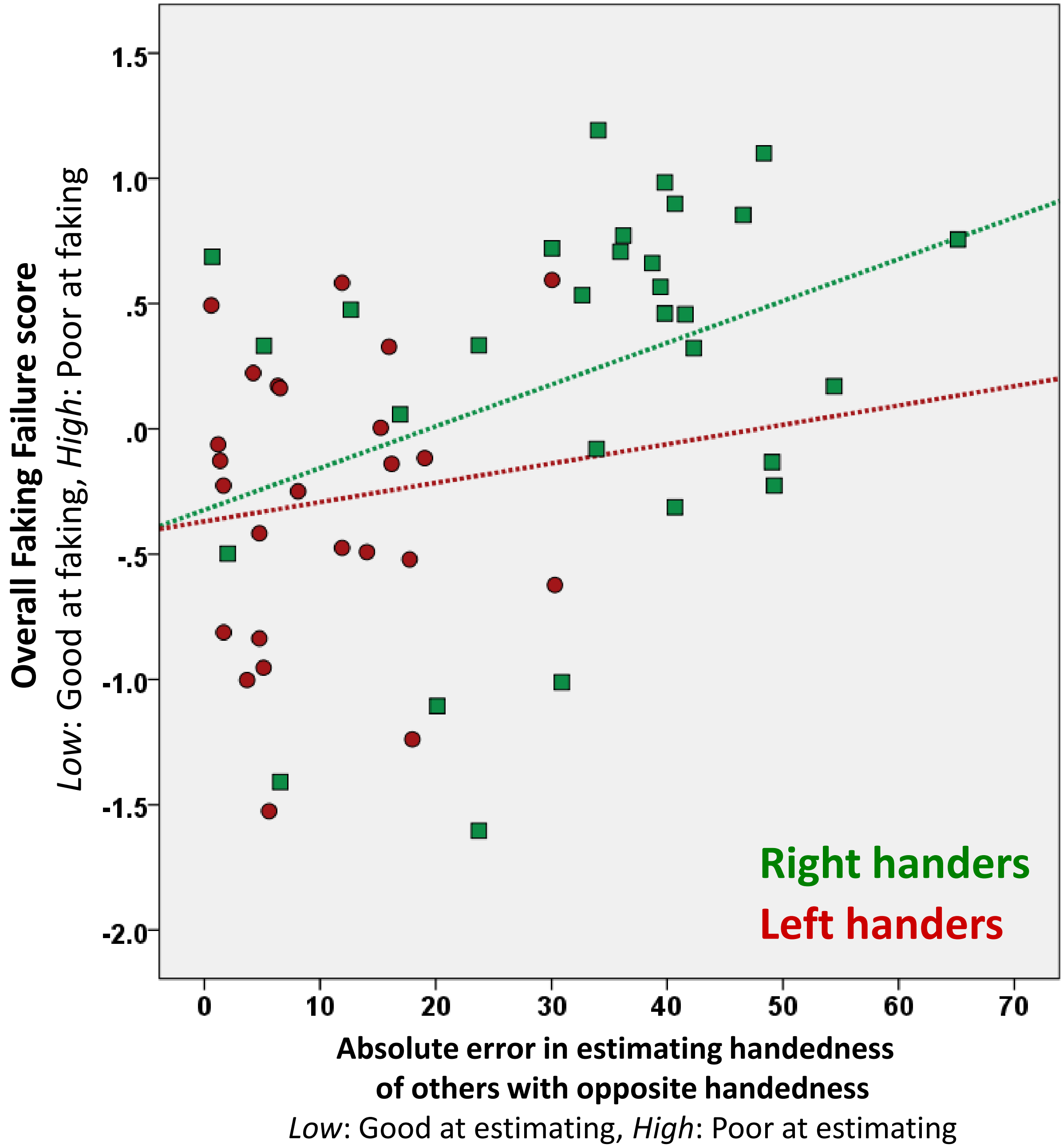

Figure 6: The relationship of ability at faking in relation to social cognitions of handedness of those of opposite handedness. The horizontal axis shows the error in predicting how opposite handers would answer the Edinburgh Handedness Inventory, with low scores indicating lower error and hence better prediction. The vertical axis shows a summary of accuracy on performance tasks of faking the behaviour of a person of opposite handedness, with lower error scores indicating better performance as an opposite hander, and hence better faking.

Supplementary Information

Exemplars for rating writing specimens

Participants were asked to rate each of the writing specimens on a scale from 1 (very poor) to 9 (very good). In order to help participants get a sense of the scale they were provided with three examples of good, medium and poor writing specimens which the researchers had pre-rated as 8, 5 and 2. The exemplars were chosen after discussion between the researchers after looking at a large number of specimens, and they seemed to summarise the broad range of quality in the specimens. The exemplars were printed and stayed in front of the judges throughout the study. It was explained that if a specimen was about as good as one of the exemplars they should rate it as 2, 5 or 8, if it was better than any of them they should rate it as 9, if it was worse than any of them they should rate it as 1, and if it was between 2 and 5 or 5 and 8 they should interpolate to 3 or 4, or to 6 or 7. Figure S1 (top) shows the exemplars for the Alphabet specimens and figure S1 (bottom) shows the exemplars for the Sentence specimens.

It should be noted that although comparisons can be made between writing specimens within the various sets of alphabet and sentence specimens, the scores of the two sets of specimens cannot meaningfully be compared since judges did not rate both sets of specimens, and the two sets of specimens were arbitrarily anchored to the scores of 2, 5 and 8. That is however of no consequence for the purposes of the present experiment.

Comparison of right and left-handers on faking

Figures S2 to S5 show individual and group mean performance of right and left-handers for the two circle-marking tasks (figure S2) and the two writing tasks (figure S3: letters/second; figure S4: quality of writing; figure S5: quality of writing/second). The figures are complicated and are explained in more detail in the captions and in the text of the main paper. Note that the circle-marking tasks and the speed of writing tasks are all expressed comparably as circle/second or letters/sec, so that higher scores are better performance. The quality measures are also scored as higher values are better performance, and the quality/second scales, of quality measure divided by time/letter, also have higher scores indicating better performance (i.e. more quality is delivered per second of time).

Faking compared with real handedness.

A Bayesian analysis of hand performance data for assessing whether an individual is actually of their professed handedness or is faking the opposite handedness to their true handedness uses the same data as in figures S2 to S5 show, but conceptually is simpler to visualise if the apparent right-handers (normal and left-handers faking right-handedness) and apparent left-handers (normal and right-handers faking left-handedness) are shown separately for each measure and apparent handedness. Thus in the top row of figures S6 to S9 the black points are for those who are truly right-handed, whereas the red points are for those who are actually left-handed but are faking being right-handed (and therefore in general the performance of the right-hand is better than performance with the left-hand). The bottom row shows the converse, with true left-handers (in black) and right-handers faking being left-handed in red. Note that the circle-marking tasks and the speed of writing tasks are all expressed comparably as circle/second or letters/sec, so that higher scores are better performance. The quality measures are also scored as higher values are better performance, and the quality/second scales, of quality measure divided by time/letter, also have higher scores indicating better performance (i.e. more quality is delivered per second of time).

Figure S1: The exemplars of writing specimens which had been pre-rated by the researchers as at scale points 2, 5 and 8. Judges were provided with the exemplars on a printed sheet which was available throughout the experiment.

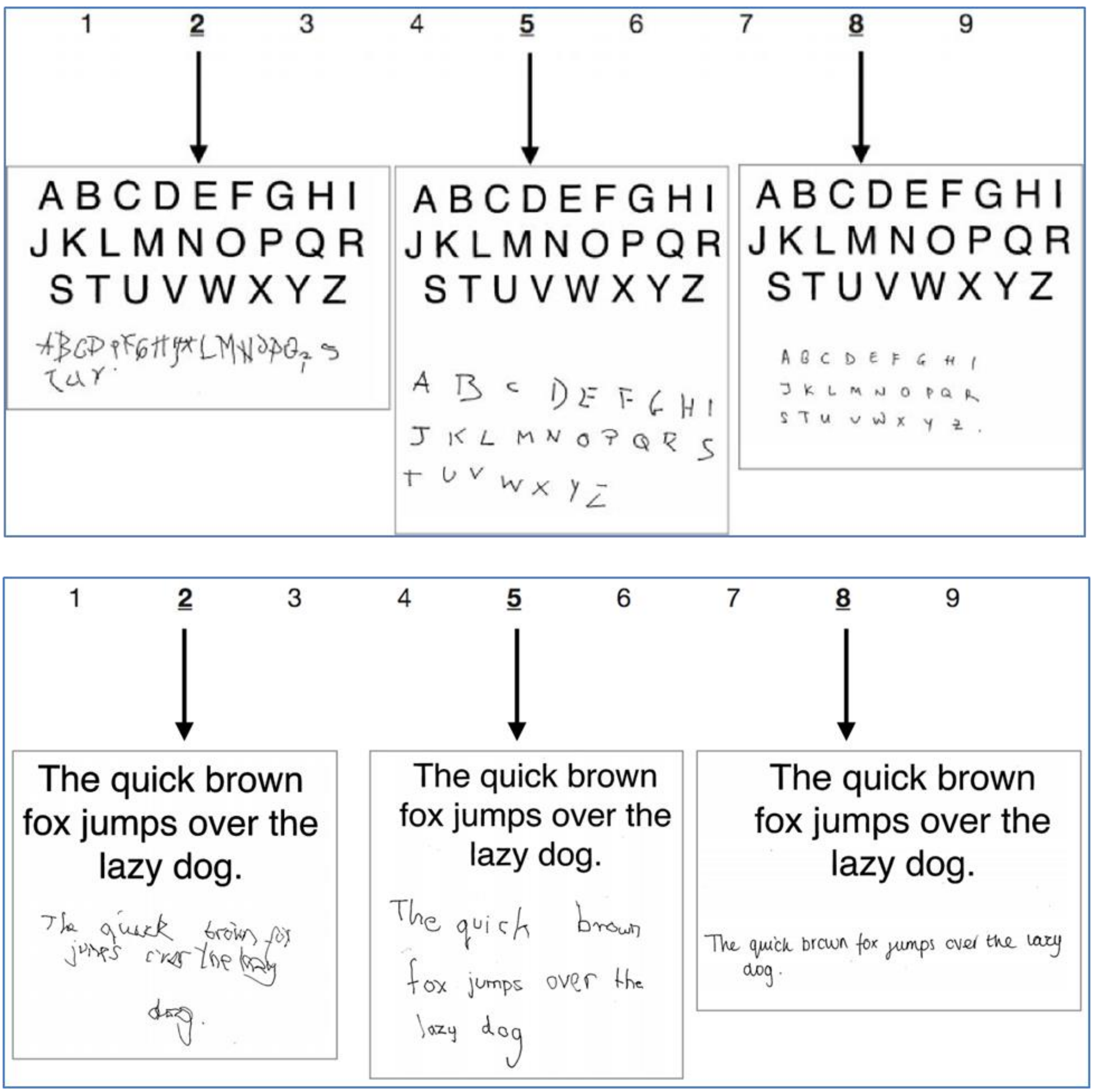

Figure S2: Performance of participants in circles per second when using right hand (horizontal axis) and left hand (vertical axis) on the Tapley and Bryden task (top) and the Van Horn task (bottom). Right-handers are shown in green and left-handers in red. The larger dark green and dark red points are for normal hand usage, with right-handers below the diagonal and left-handers above the diagonal. The pale green and pale red diamonds are right-handers and left-handers faking opposite handedness, and are linked to normal performance by thin green lines (running horizontally) and thin red lines (running vertically). Means are shown as the large black edged circles and diamonds, using the same colour scheme. For further details see the main text.

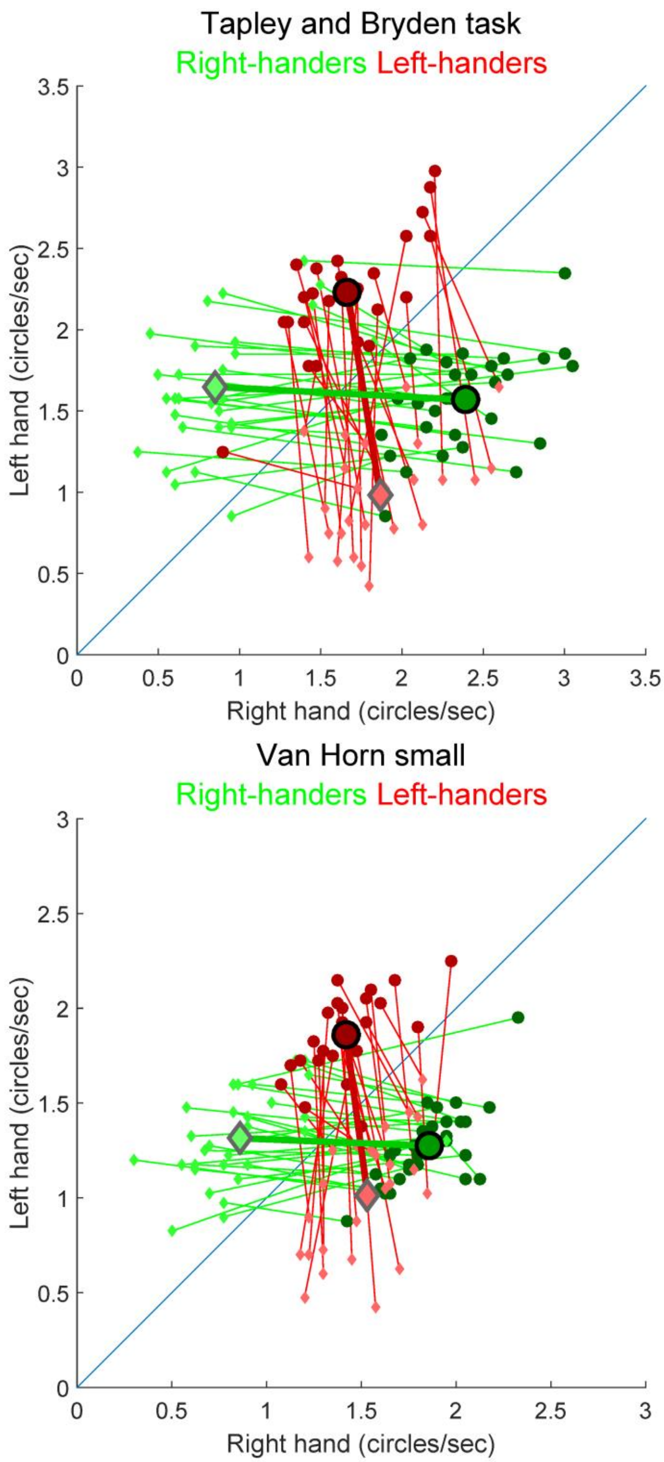

Figure S3: Performance of participants in letters per second when using the right hand (horizontal axis) and left hand (vertical axis) on the Alphabet task (top) and the Sentence task (bottom). Right-handers are shown in green and left-handers in red. The larger dark green and dark red points are for normal hand usage, with right-handers below the diagonal and left-handers above the diagonal. The pale green and pale red diamonds are right-handers and left-handers faking opposite handedness, and are linked to normal performance by thin green lines (running horizontally) and thin red lines (running vertically). Means are shown as the large black edged circles and diamonds, using the same colour scheme. For further details see the main text.

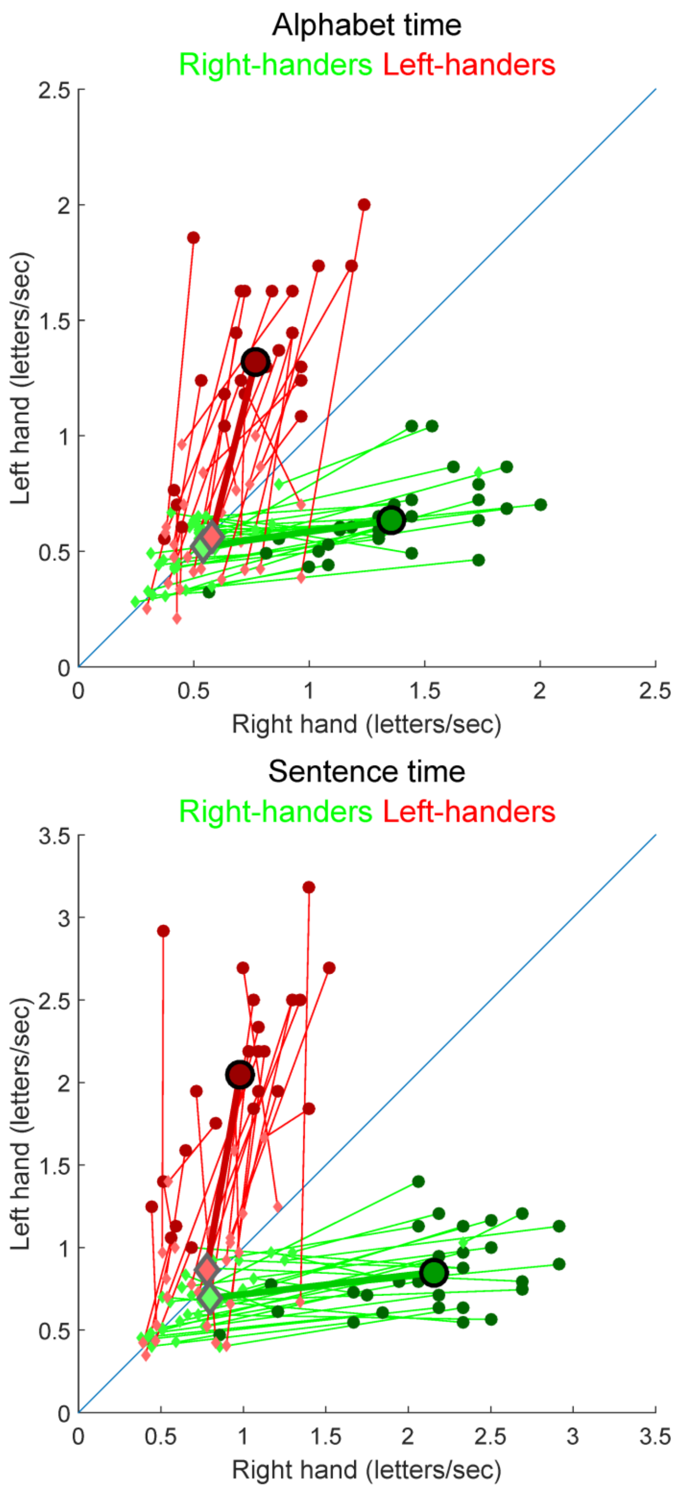

Figure S4: Performance of participants in quality units when using the right hand (horizontal axis) and left hand (vertical axis) on the Alphabet task (top) and the Sentence task (bottom). Right-handers are shown in green and left-handers in red. The larger dark green and dark red points are for normal hand usage, with right-handers below the diagonal and left-handers above the diagonal. The pale green and pale red diamonds are right-handers and left-handers faking opposite handedness, and are linked to normal performance by thin green lines (running horizontally) and thin red lines (running vertically). Means are shown as the large black edged circles and diamonds, using the same colour scheme. For further details see the main text.

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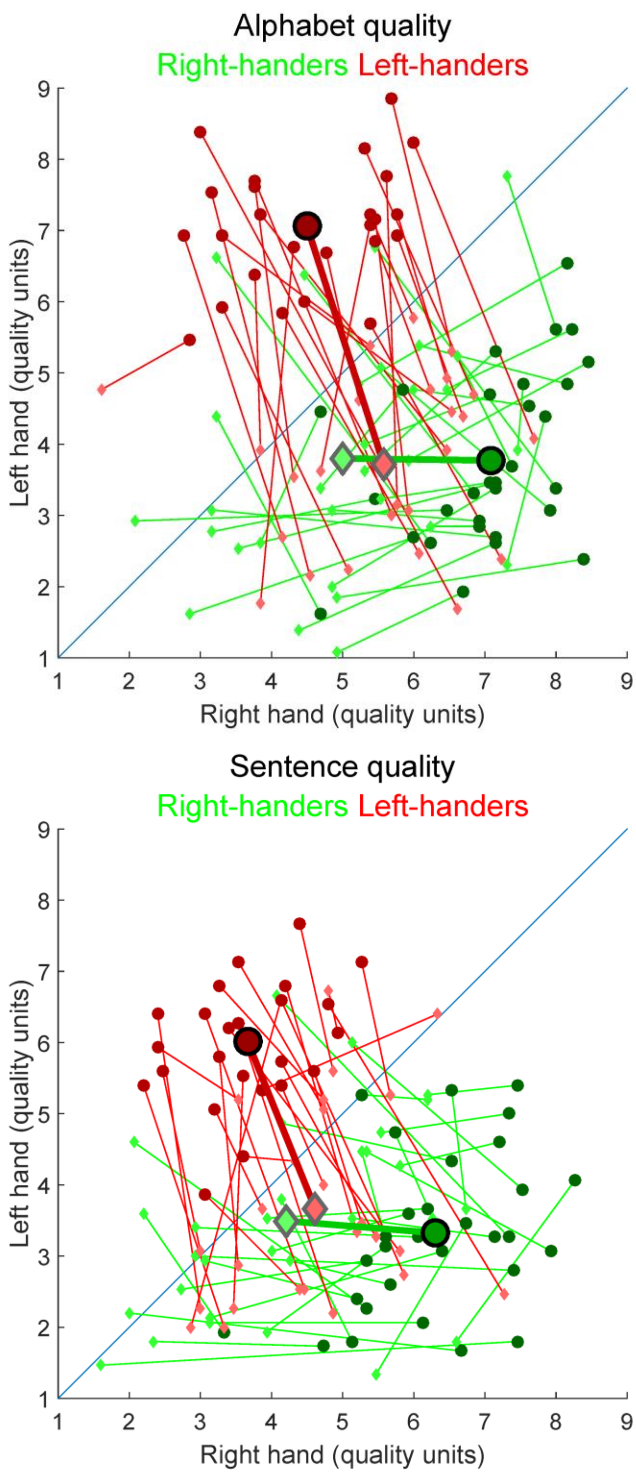

Figure S5: Performance of participants in quality units per second when using the right hand (horizontal axis) and left hand (vertical axis) on the Alphabet task (top) and the Sentence task (bottom). Right-handers are shown in green and left-handers in red. The larger dark green and dark red points are for normal hand usage, with right-handers below the diagonal and left-handers above the diagonal. The pale green and pale red diamonds are right-handers and left-handers faking opposite handedness, and are linked to normal performance by thin green lines (running horizontally) and thin red lines (running vertically). Means are shown as the large black edged circles and diamonds, using the same colour scheme. For further details see the main text.

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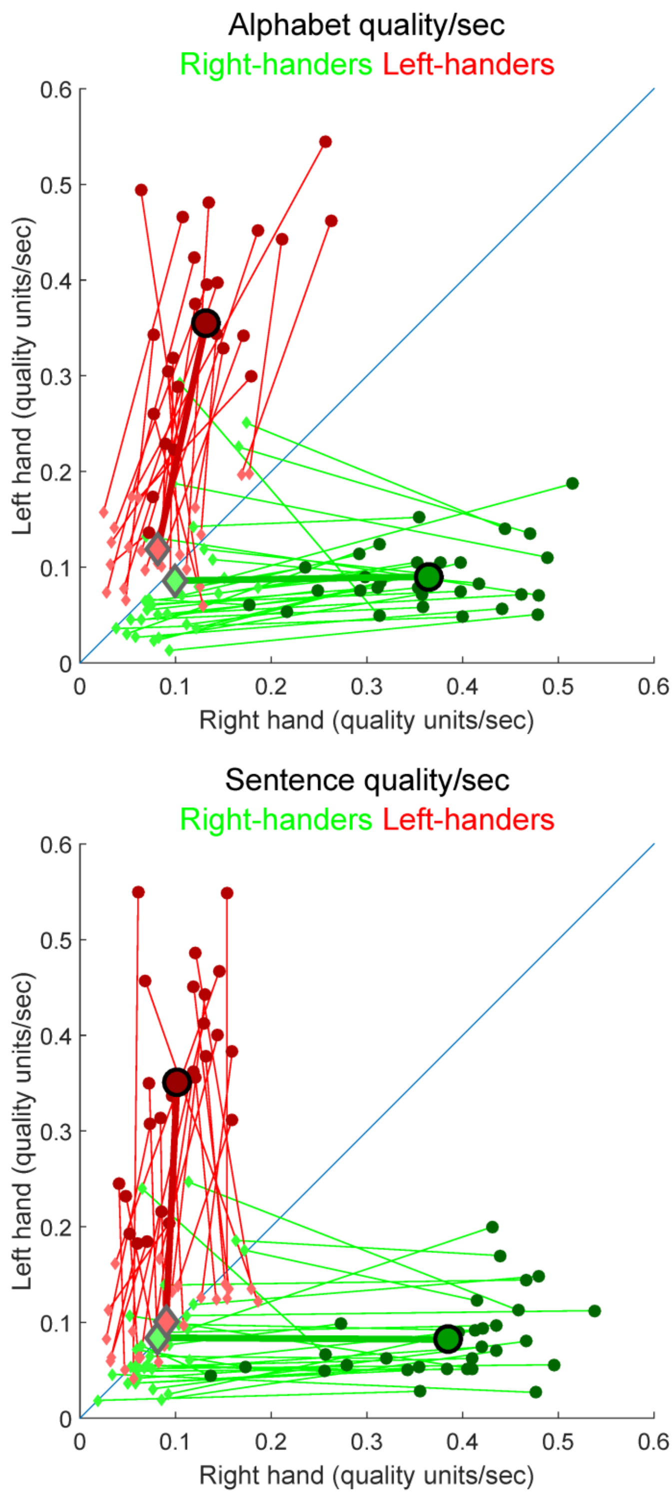

Figure S6: Performance of participants using the right hand (horizontal) and left hand (vertical axis) at the two circle-marking tasks. Right-handers are shown in the top row (*a* and *b*) and left-handers in the bottom row (*c* and *d*). Handedness refers either to true handedness (in black) or participants of the opposite handedness faking that handedness (shown in red). Contours are plotted at 95%, 90% through 10% in 10% steps, and 5% for a bivariate normal distribution. The blue points (right-handers only) are for the defendant, *D*.

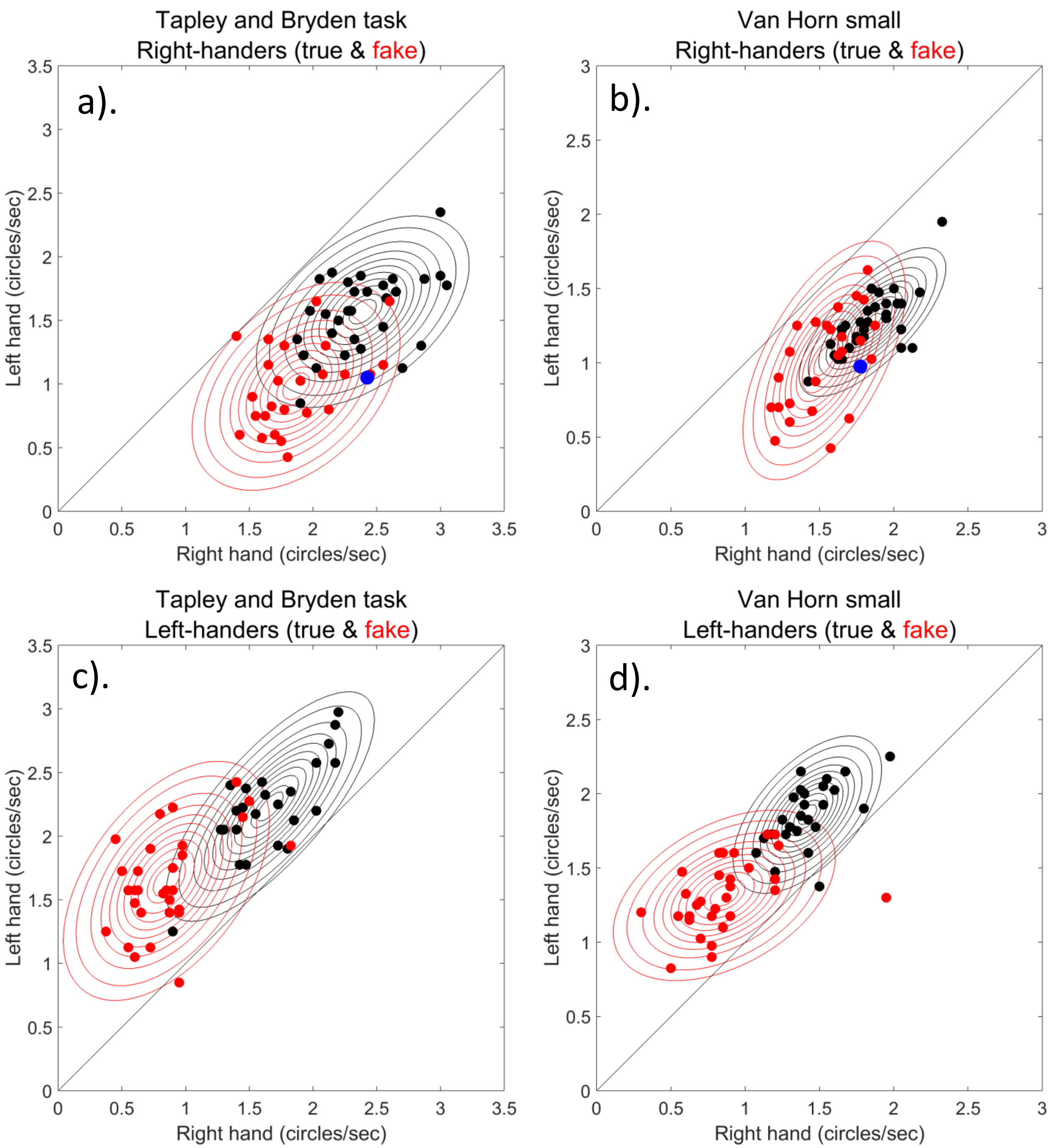

Figure S7: Performance of participants using the right hand (horizontal) and left hand (vertical axis) for the time taken on the two writing tasks, the alphabet (*a* and *c*), and the cursive sentence (*b* and *d*). Right-handers are shown in the top row (*a* and *b*) and left-handers in the bottom row (*c* and *d*). Handedness refers either to true handedness (in black) or participants of the opposite handedness faking that handedness (shown in red). Contours are plotted at 95%, 90% through 10% in 10% steps, and 5% for a bivariate normal distribution. The blue points (right-handers only) are for the defendant, *D*.

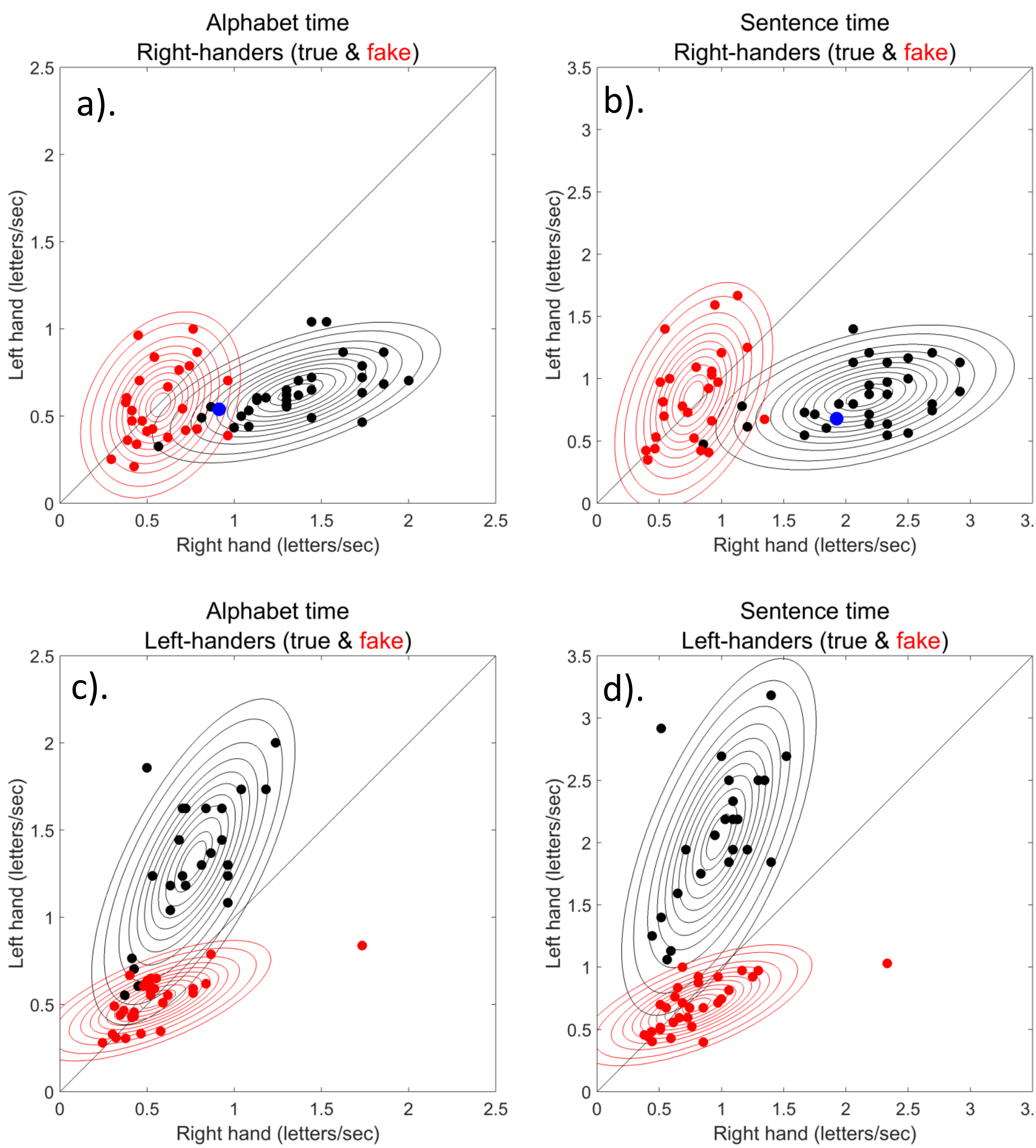

Figure S8: Performance of participants using the right hand (horizontal) and left hand (vertical axis) for the measures of quality on the alphabet task, with the quality measure in figures *a* and *c*, and the quality/second measure in *b* and *d*. Right-handers are shown in the top row (*a* and *b*) and left-handers in the bottom row (*c* and *d*). Handedness refers either to true handedness (in black) or participants of the opposite handedness faking that handedness (shown in red). Contours are plotted at 95%, 90% through 10% in 10% steps, and 5% for a bivariate normal distribution. The blue points (right-handers only) are for the defendant, *D*.

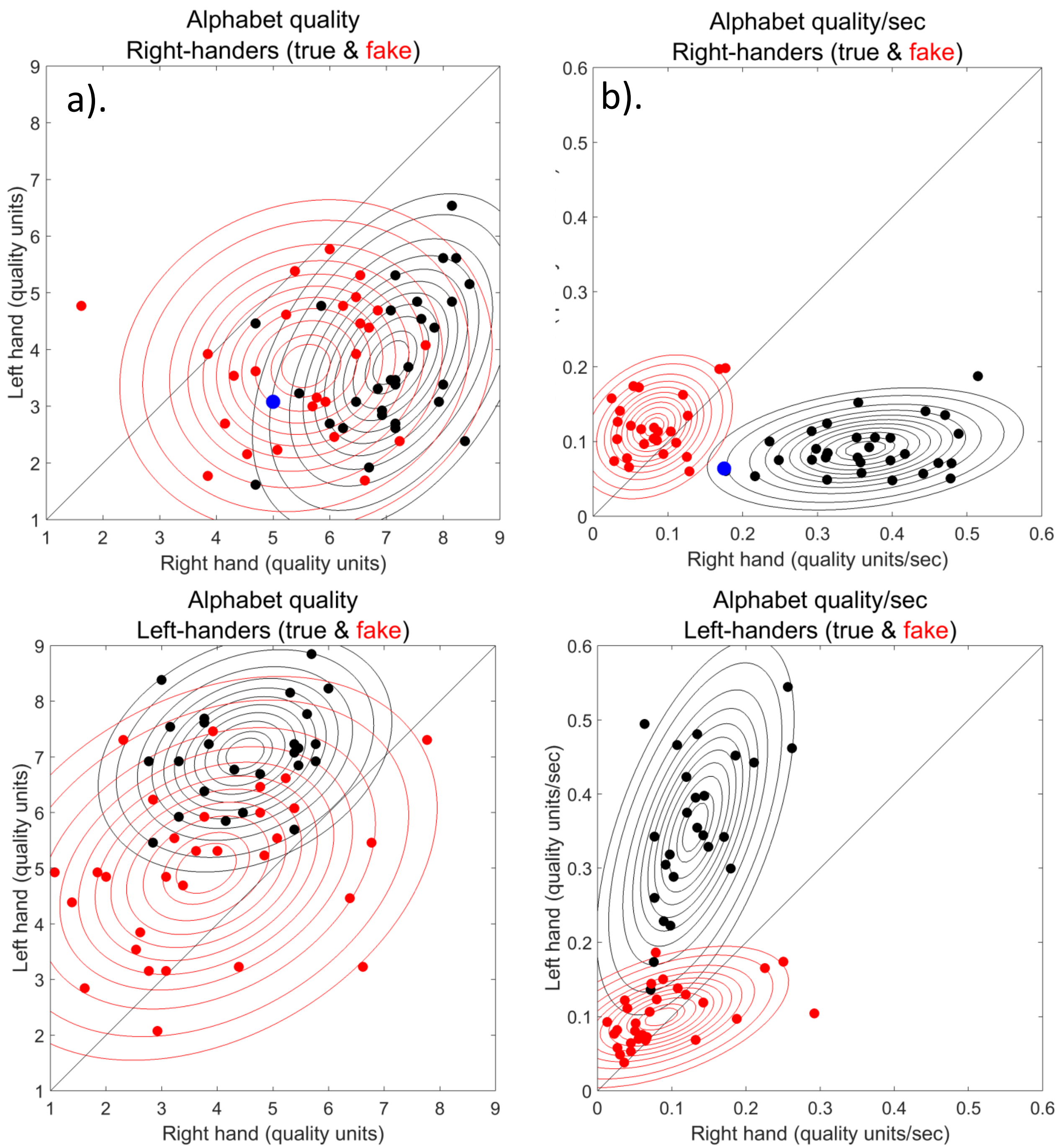

Figure S9: Performance of participants using the right hand (horizontal) and left hand (vertical axis) for the measures of quality on the sentence, with the quality measure in figures *a* and *c*, and the quality/second measure in *b* and *d*. Right-handers are shown in the top row (*a* and *b*) and left-handers in the bottom row (*c* and *d*). Handedness refers either to true handedness (in black) or participants of the opposite handedness faking that handedness (shown in red). Contours are plotted at 95%, 90% through 10% in 10% steps, and 5% for a bivariate normal distribution. Note that these measures were not available for the defendant, *D*.

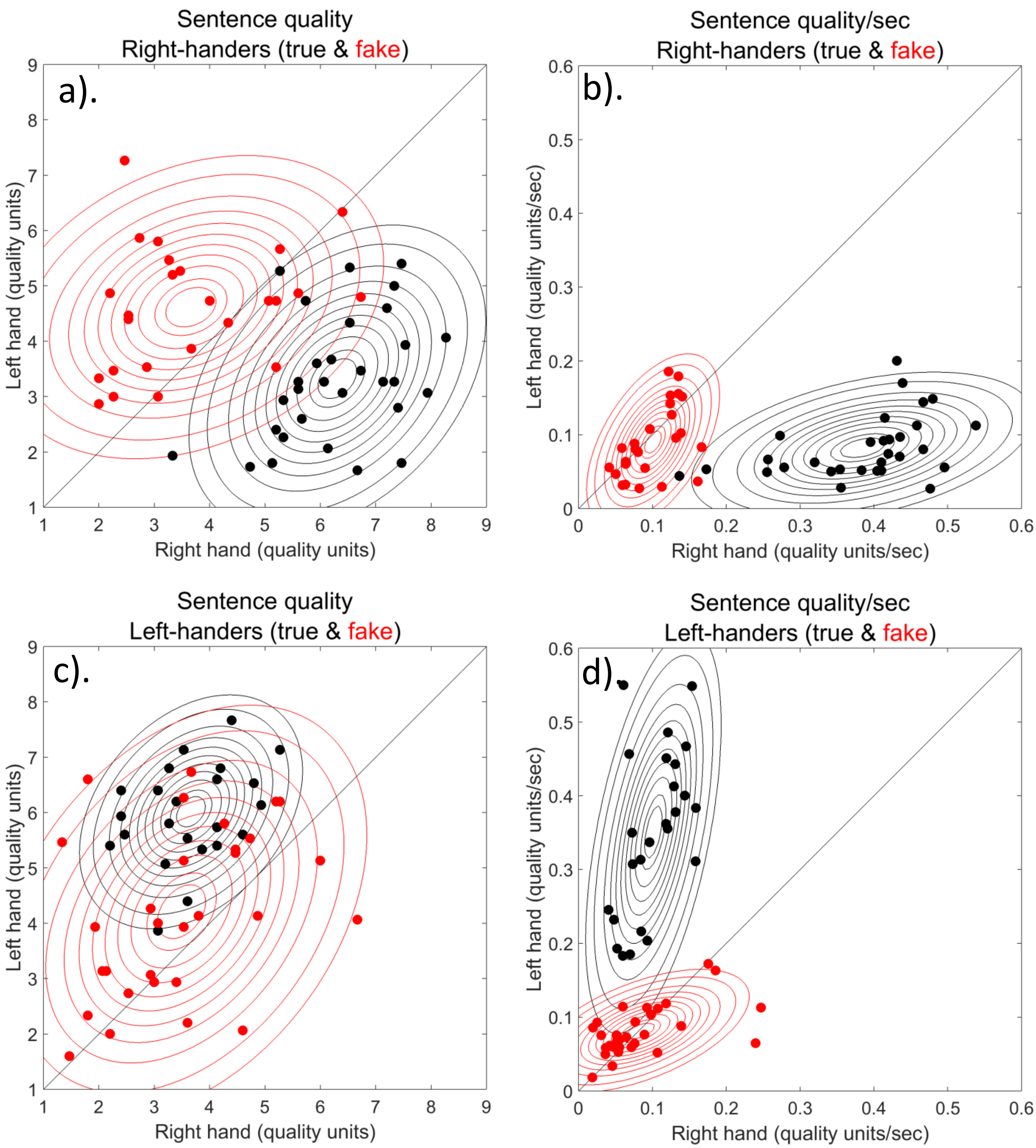

Figure S10: Absolute laterality index on the modified Edinburgh Handedness Inventory for true right-handers (green squares) and true left-handers (red circles) when they are describing their true handedness (horizontal) and when they are faking being of the opposite handedness (vertical). For comparison to figure 4 in the main text.