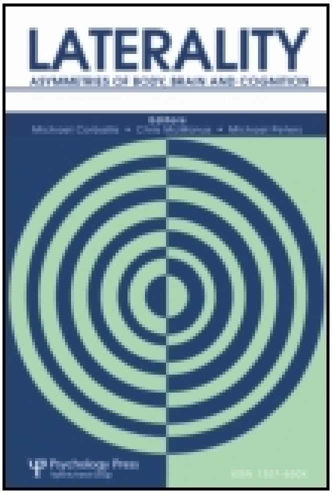

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Edinburgh Handedness Inventory - Short Form: A revised version based on confirmatory factor analysis

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Edinburgh Handedness Inventory – Short Form: A revised version based on confirmatory factor analysis

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While the Edinburgh Handedness Inventory has been widely used, there have been few studies assessing its factorial validity. There is evidence that the original instructions and response options are difficult to understand. Using simplified instructions and response options, the Edinburgh Handedness Inventory was administered on a sample of 1514 participants using an online questionnaire. In accordance with previous research, a model of the 10-item inventory had poor fit for the data. This study also detected model misspecification in the previously-proposed 7-item modification. A 4-item Edinburgh Handedness Inventory – Short Form had good model fit with items modelled as both continuous and ordinal. Despite its brevity, it showed very good reliability, factor score determinacy, and correlation with scores on the 10-item inventory. By eliminating items that were modelled with considerable measurement error, the short form alleviates the concern of the 10-item inventory over-categorising mixed handers. Evidence was found for factorial invariance across level of education, age groups, and regions (USA and Australia/New Zealand). There generally appeared to be invariance across genders for the 4-item inventory. The proposed Edinburgh Handedness Inventory – Short Form measures a single handedness factor with an inventory that has brief and simple instructions and a small number of items.

Keywords: Handedness; Edinburgh Handedness Inventory; Confirmatory factor analysis; Invariance testing; Psychometric properties.

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Handedness, or the preference to use one hand more than the other, is usually measured by questionnaire in the social sciences. The Edinburgh Handedness Inventory (Oldfield, 1971) is the most widely used of these questionnaires (Fazio, Coenen, & Denney, 2012). Oldfield's 1971 article currently has almost 11,000 citations in Scopus. To complete the Edinburgh Handedness Inventory, respondents endorse hand preference for 10 everyday tasks. In the original inventory participants are given a list of the tasks with adjacent "left" or "right" columns. They are asked write "+" in the appropriate corresponding column. If the preference is so strong that they "would never try to use the other hand unless absolutely forced to" they are to write "+ +" instead. If they are "really indifferent" they are instructed to put an "+" in both columns (Oldfield, 1971, p. 112).

Despite its widespread usage there have been few studies assessing the factorial validity of the Edinburgh Handedness Inventory. Such assessment is important because it tests whether the inventory measures the unidimensional handedness factor that it purports to measure. Studies that have been conducted have generally noted that some of the questionnaire items are problematic (Bryden, 1977; Dragovic, 2004; McFarland & Anderson, 1980; S. M. Williams, 1986). From exploratory factor analysis, Bryden found that three items (opening box, using broom, and striking a match) loaded onto a single factor "in which there was considerable disagreement among right-handers as to which hand was generally used, and items in which the subject had to think very carefully before giving an answer" (1977, p. 621). Also from exploratory factor analysis, McFarland and Anderson noted "poor" loading of the knife, broom, and box lid items on a single handedness factor. They reported evidence for factor loading stability across age and gender, and test–retest reliability for most of the items, but noted instability on the box, broom, match, and scissors items. McFarland and Anderson did not test whether allowing these factor loadings to differ between groups significantly improved the model fit and they did not test the equality of item intercepts or error variances, which are requirements for testing whether findings of group mean differences can be accounted for by measurement biases (Gregorich, 2006).

Confirmatory factor analysis is a powerful tool for assessing the factorial validity of a questionnaire. Advantages of confirmatory factor analysis are that it allows modelling of error variance, testing for item uniqueness, and testing for acceptable fit of the factor structure (Brown, 2006). Two studies have tested the Edinburgh Handedness Inventory using confirmatory factor analysis. From a community sample of 203, Dragovic (2004) found it was redundant to include both the writing and drawing items, as these were almost perfectly collinear, and that the broom and box-lid were modelled with a high proportion of error variance. He concluded that this high error variance was due to these items measuring another factor or ambiguity of item interpretation. Dragovic proposed a 7-item revised inventory with these three items removed. Milenkovic and Dragovic (2012) replicated these findings on a sample of 1224 high school students.

There were limitations of these previous two confirmatory factor analysis studies. These studies used the maximum likelihood estimation technique that assumes indicators are continuous. An estimation technique for ordered-categorical data is also appropriate for 5-point Likert response options (Kline, 2011). These two previous studies also administered the Edinburgh Handedness Inventory using the original instructions. These instructions have been criticised as "somewhat lengthy and confusing" (Fazio et al., 2012, p. 71) and there is evidence that the majority of male inmates who were administered the inventory did not understand or follow them correctly (Fazio et al., 2012). Fazio et al. suggested that a Likert scale adaptation of the Edinburgh Handedness Inventory could markedly improve instruction adherence.

One of the aims of this research is to replicate the findings of previous confirmatory factor analyses using a large sample. To enhance our confidence that findings of group mean differences in handedness are based on actual group differences, this study also aims to test invariance of the Edinburgh Handedness Inventory measurement between genders, age groups, levels of education, and countries, using a stricter test than McFarland and Anderson (1980). This study also trials using simplified instructions and response options.

METHOD

Participants

Participants were recruited for an internet-based study examining the development of gender identity and sexuality (Veale, Clarke, & Lomax, 2010a) through lesbian, gay, bisexual, and transgender (LGBT) related online forums and mailing lists, Google online advertising, and a press release. The Edinburgh Handedness Inventory was completed by 1514 participants.

Participants' demographics are outlined in Table 1. While different educational attainments would be more common in different countries, the same scale was used for all participants. Participants could endorse multiple ethnicity categories. Age ranged from 16 to 81. A significant proportion of participants had gender identities not consistent with their biological sex (e.g., transsexual, transgender). For invariance testing between genders, 160 biological males and 266 biological females who did not report having gender-variant identities were used.

TABLE 1
Participants' demographics

Ethnicity	%	*Residence*	%	*Highest level of education*	%
White/Caucasian	92	USA	60	3 years high school	7
East Asian	3	New Zealand	18	4 years high school	10
Hispanic/Latino	3	Great Britain	8	5 years high school	11
Indigenous American	3	Canada	5	Diploma/trade qualification	20
Black/African	2	Australia	2	Bachelor's degree	31
South/other Asian	2	Other	7	Master's degree	14
Other	2			Doctoral degree	5

Measure

The Edinburgh Handedness Inventory (Oldfield, 1971) was administered with revised instructions and response options. The instructions given were "Please indicate your preferences in the use of hands in the following activities. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets." Response options given were "always right", "usually right", "both equally", "usually left", and "always left".

Data analysis

Confirmatory factor analysis of the Edinburgh Handedness Inventory was conducted using Mplus software version 5.1 (Muthén & Muthén, 2008). Some authors have suggested 5-point response scales be treated as ordinal (Kline, 2011), while others have suggested treatments as continuous (Blunch, 2008). Analyses for this article were conducted using both Yuan-Bentler robust maximum likelihood estimation and mean- and variance-adjusted weighted least squares (WLSMV) estimation. In the former, estimates and fit indices are adjusted to allow for missing data and variations of multivariate normality (Kline, 2011). The latter estimates z score thresholds underlying ordinal variables, from which a polychoric correlation matrix is calculated and then subjected to confirmatory factor analysis (Savalei, 2011). WLSMV analysis does not assume distributional form and, unlike traditional weighted least squares estimation, does not require very large sample (Kline, 2011).

Model fit was assessed using χ^2 likelihood ratio (using Satorra-Bentler adjustment with robust maximum likelihood estimation), RMSEA, SRMR, and CFI. Model misspecification was detected by a p value less than .05 on the chi-squared test. CFI values lower than .9, RMSEA values greater than .05, and SRMR values greater than .08 were also used as indicators that the proposed model did not fit the data (Kline, 2011).

Reliability was estimated using Cronbach's (1951) α and Raykov's (1997) factor ρ which is a composite reliability coefficient that is calculated as the ratio of variance explained by the factor to the total variance. An advantage of Raykov's ρ is that unlike Cronbach's α it does not assume all scale items equally contribute to a factor's variance and can allow for correlated error variances (Yang & Green, 2010). Factor score determinacy was also estimated by calculating the squared multiple correlation of the proposed indicators for predicting the handedness factor. This gives information about the extent to which the true factor score can be determined in the model (Grice, 2001). Such information is useful because while confirmatory factor analysis models with a small number of indicators may be more likely to fit the data, they are also more likely to have factor indeterminacy (Brown, 2006).

In accordance with Milenkovic and Dragovic's (2012) study, laterality quotients were calculated. These ranged from –100 (left-handed) to 100 (right-handed). Participants with a laterality quotient score between –60 and 60 (inclusive) were classified as mixed-handers. Testing for parallel indicators was also conducted to test whether each item measured the handedness construct equally. Such testing is desirable to understand whether summing scores on each item equally (as per the laterality quotient) will accurately estimate a person's handedness.

The inventory's stability across a number of groups was also assessed using factorial invariance testing. The majority of participants sampled in this study lived in two regions: the USA (60%) or Australia and New Zealand (20%). Invariance testing was conducted between these groups to test for differences in item meaning for participants living in these regions. The median age of participants was 37. Invariance testing was also conducted between those above and below the median age, between level of education groups (3 or 4 years of high school, 5 years of high school or diploma/trade qualification, and university degree), and between males and females (participants with gender identities atypical to their biological sex are removed from this analysis).

Cheung and Rensvold (2002) outlined different levels of measurement invariance that can be tested. First, metric invariance occurs when factor loadings of items on factors do not differ between groups, suggesting factors are manifested consistently between groups. A more stringent form of measurement invariance is scalar invariance, which occurs when as well as metric invariance, intercepts (when maximum likelihood estimation is used) or thresholds (when WLSMV is used) of items do not differ between groups. Metric invariance is required for meaningful comparison of factor relationships between groups, and scalar invariance is required for meaningful comparison of mean factor score differences between groups (Kline, 2011). Metric and scalar invariance were tested by comparing these to a model where these invariance constraints were not imposed (the unconstrained model). Using robust maximum likelihood estimation, a statistically significant change in scaled difference chi-squared likelihood ratio test may indicate scale variance across groups (Kline, 2011). Because this test is sensitive when sample size is large, Cheung and Rensvold's (2002) criterion of a decrease in CFI of greater than .01 as evidence for measurement variance was also used. Invariance testing was not conducted using WLSMV estimation because there have been relatively few studies that have conducted this type of analysis, no standards exist for comparing models on fit indices other than the chi-squared likelihood ratio (Sass, 2011), and it was not possible to calculate WLSMV between-gender invariance tests because of a not-positive definite correlation matrix, likely due to a low number of "both equally" and "usually left" response options to the writing variable.

Data were missing for 1% of responses. Analyses were conducted using Mplus's full information maximum likelihood method (Asparouhov & Muthén, 2010).

RESULTS

Model testing and selection

As outlined in Tables 2 and 3, confirmatory factor analysis using all 10 items of the Edinburgh Handedness Inventory elicited similar concerns to previous studies. The model had poor performance on all fit indices with the exception of the CFI using WLSMV estimation. There was collinearity between the drawing and writing items, $r = .97$, and high proportion of residual error for the broom (.64 using robust maximum likelihood, .44 using WLSMV estimation), knife (.54, .35), and lid opening (.54, .34) items. The covariance matrix for the 10 items is given in supplementary electronic data. Dragovic's proposed 7-item inventory, in which the drawing, broom, and box lid opening items are removed, had signs of model misspecification on the chi-squared likelihood ratio using both estimation techniques and also the RMSEA when using WLSMV estimation, so a revised model was also tested.

In selecting a revised model, the following were considered:

- As outlined above, previous research has noted problems with the knife, striking match, and scissors items;
- although this past evidence is more limited for the knife and scissors items, the knife item was modelled with significant error variance in the analysis and scissor use preference may be affected by practice with the tools available (i.e., many modern scissors are designed for right-handed use); and

TABLE 2
Fit statistics, and reliability and factor score determinacy estimates, for versions of the Edinburgh Handedness Inventory with robust maximum likelihood estimation

Model	$SB\chi^2$	*df*	*p*	*CFI*	*RMSEA*	*SRMR*	ρ	α	*FSD*
10 items	1144.19	35	<.001	.84	.145	.05	.95	.95	.98
7 items	59.95	14	<.001	.99	.047	.02	.95	.95	.98
4 items	0.40	2	.819	1.00	.000	.00	.93	.93	.97
4 items, parallel indicators	47.04	5	<.001	.98	.075	.08	.93		.97

$N = 1514$; ρ = Raykov's composite reliability; FSD = factor score determinacy.

- the match and knife items are the only remaining items pertaining to tasks which require two hands—removing these will simplify the scale.

Given these considerations, the knife, striking match, and scissors items were removed. Tables 2 and 3 show the resultant 4-item model had adequate fit on all fit tests using both estimation techniques. Constraining factor loadings to be equal among indicators (parallel indicators) resulted in a model with poor fit using both estimation techniques, as shown on all fit indices except the CFI. Reliability and factor score determinacy estimates are also given in Table 2. Parameter estimates for the 4-item model are given in Table 4.

Invariance testing

Table 5 outlines the results of invariance testing using robust maximum likelihood estimation. These analyses showed no significant change towards poorer model fit in the scaled difference chi-squared test. Although not detected by the chi-squared test, change in CFI for between-genders invariance testing was notable. This can be explained by constraining the toothbrush item between genders, resulting in a significant scaled difference chi-squared test, $\chi^2(1) = 4.08$, $p = .04$, suggesting toothbrush hand preference had a slightly higher factor loading in males.

TABLE 3
Fit statistics, and reliability and factor score determinacy estimates, for versions of the Edinburgh Handedness Inventory with WLSMV estimation

Model	χ^2	*df*	*p*	*CFI*	*RMSEA*
10 items	271.87	21	< .001	.99	.089
7 items	103.67	14	< .001	1.00	.065
4 items	1.97	2	.373	1.00	.000
4 items, parallel indicators	158.53	4	< .001	.99	.160

$N = 1514$.

TABLE 4
Model estimates for the 4-item Edinburgh Handedness Inventory

Parameter	*Unstandardised*	*SE*	*Standardised*	*Unstandardised*	*SE*	*Standardised*
	MLR factor loadings			*WLSMV factor loadings*		
Writing	1.00[a]	–	.89	1.00[a]	–	.97
Throwing	0.83	.03	.82	0.89	.01	.87
Toothbrush	0.94	.02	.88	0.95	.01	.92
Spoon	1.00	.02	.91	0.97	.01	.94
	MLR factor variance			*WLSMV factor variance*		
Handedness	32.29	2.23	1.00	0.95	.01	1.00

SE = standard error. MLR = robust maximum likelihood. [a]This parameter is fixed because this item is used as a marker variable, therefore it is not tested for statistical significance. All other estimates were statistically significant $p < .001$.

Laterality quotient

Figure 1 plots participants' laterality quotient scores on the 10-item inventory and the 4-item short form. Participants with any missing data were excluded from this analysis. The relationship between these two scales was Spearman's $\rho = .90$ and $r^2 = .94$.

TABLE 5
Invariance testing fit statistics for the 4-item Edinburgh Handedness Inventory using robust maximum likelihood estimation

Model	$SB\chi^2$	*df*	*p*	χ^2_{SD}	Δdf	*p*	*CFI*	ΔCFI
Country: USA/Australia or New Zealand					$n = 1214$			
Unconstrained	2.14	4	.710	–	–	–	1.000	–
Metric invariance	2.82	7	.901	0.30	3	.960	1.000	.000
Scalar invariance	10.94	10	.362	4.88	6	.560	.999	.001
Age median split					$N = 1514$			
Unconstrained	4.14	4	.388	–	–	–	1.000	–
Metric invariance	7.17	7	.412	1.24	3	.744	1.000	.000
Scalar invariance	15.54	10	.114	6.31	6	.389	.997	.003
Gender					$n = 426$			
Unconstrained	6.48	4	.166	–	–	–	.994	–
Metric invariance	16.27	7	.023	4.61	3	.203	.977	.017
Scalar invariance	22.54	10	.013	8.45	6	.207	.968	.026
Level of education					$n = 1446$			
Unconstrained	3.96	6	.683	–	–	–	1.000	–
Metric invariance	11.88	12	.455	3.21	6	.782	1.000	.000
Scalar invariance	19.91	18	.338	6.46	12	.891	.999	.001

SD = scaled difference.

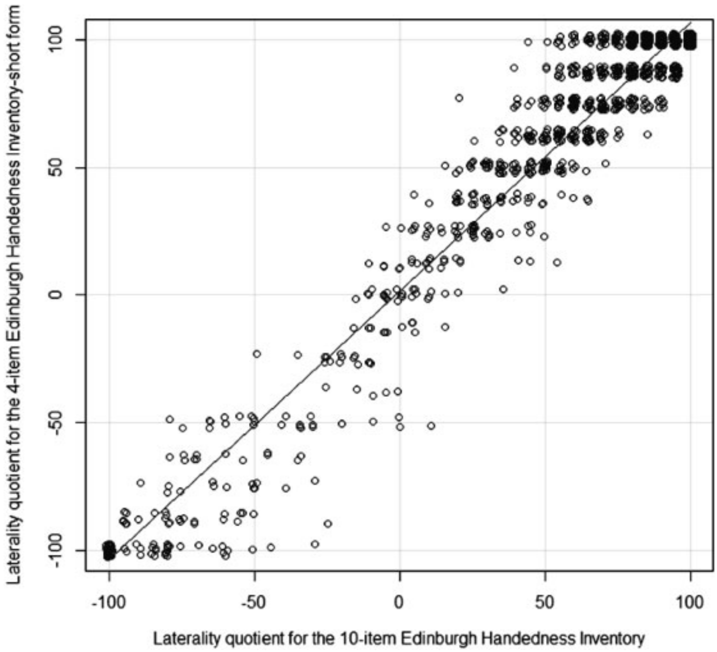

Figure 1. Scatter plot of laterality quotients for the Edinburgh Handedness Inventory and its short form. $n = 1396$. Jitter function used to illustrate overlapping points.

Results of assignment to handedness categories are given in Table 6. The level agreement of this categorisation between the 10-item and 7-item inventories was kappa = .84, and between the 10-item and 4-item inventories it was kappa = .72.

TABLE 6
Assignment of categorical handedness groups in the original and short form Edinburgh Handedness Inventories

		Original version (10-items)			
		Left n *(%)*	*Mixed* n *(%)*	*Right* n *(%)*	*Total* n
Short form (4-items)	Left	87 (95)	28 (6)	0 (0)	115
	Mixed	5 (5)	259 (60)	4 (0)	268
	Right	0 (0)	146 (34)	867 (100)	1013
Total		92	433	871	1396

DISCUSSION

This is the first study to use confirmatory factor analysis to examine the validity the Edinburgh Handedness Inventory when using simplified instructions and a response scale. The proposed Edinburgh Handedness Inventory – Short Form, including instructions and response scale, is reproduced in the Appendix. Because the remaining items relate to tasks that only require one hand, only simplified instructions are retained. The simpler instructions and response options, and lower number of items, mean the short form is notably less burdensome to participants.

In accordance with previous research, this study found that the 10-item Edinburgh Handedness Inventory did not adequately measure a single underlying handedness factor. Unlike a previous study using confirmatory factor analysis (Dragovic, 2004) that suggested a 7-item inventory, this study provided evidence that a 7-item inventory does not adequately fit the data. Although Dragovic did not find evidence for model misspecification for the 7-item inventory, this is likely to be because this study's sample size ($N = 203$) lacked the power detect this. This can be surmised because the two later studies with larger samples (Milenkovic & Dragovic, 2012, and the present study) found evidence for misspecification of the 7-item model on the chi-squared likelihood ratio test.

The 4-item Edinburgh Handedness Inventory – Short Form was proposed based on consideration of the items' face validity, performance of items in this study's initial analysis, and the findings previous factor analyses (Bryden, 1977; Dragovic, 2004; McFarland & Anderson, 1980; Milenkovic & Dragovic, 2012). This inventory passed the requirements of all of the fit tests and indices when indicators were modelled as both continuous and ordinal.

The 4-item short form performed well on further validation analyses. Despite it being a short scale, it showed very high reliability on measures of factorial composite reliability and Cronbach's alpha (Cicchetti, 1994). The estimate of the quality of factor scores, factor determinacy, was also high. This is noteworthy because this is an area which can be of concern when using a low number of indicators for factor estimation (J. S. Williams, 1978). Because the findings of this and another recent study (Milenkovic & Dragovic, 2012) indicated that the inventory does not have parallel indicators, researchers may prefer to calculate factor scores, rather than simply sum item scores, to more accurately assess handedness.

The model testing the 4-item short form had only two degrees of freedom. A greater number of degrees of freedom would be preferred as this is indicative of a more parsimonious model with more elements in which the model can possibly be rejected, and one that is more likely to be replicated from samples in the same population (Kline, 2011). Despite this, the 4-item model showed superior performance compared to the 7- and 10-item models on the parsimony-adjusted RMSEA index. Models outlined in Table 5 also show the 4-item model was replicable across a number of different subgroups within the sample and showed acceptable model fit in models with as many 18 degrees of freedom. Also, as mentioned above, the results of this study were comparable to previous factor analyses of the Edinburgh Handedness Inventory, suggesting these findings were not the result of idiosyncrasies of these particular data.

When laterality quotients were calculated, the short form also predicted a large proportion (94%) of the variance of the 10-item inventory. This is around the same proportion that Milenkovic and Dragovic (2012) found from the same analysis with the 7-item inventory. The level of agreement of categorisation of participants into left-, mixed-, and right-handers between original and short form versions in this study (kappa = .72) was lower than the agreement between the 10-item and 7-item versions in this study and in Milenkovic and Dragovic's study (kappa = .80), but this finding still suggests "substantial agreement" (Landis & Koch, 1977). Table 6 illustrates that the main source of disagreement in this study was participants categorised as mixed handers by the 10-item inventory were categorised as either left- or right-handers by the 4-item inventory. The percentage classified as mixed-handers in the 10-item inventory was 30%, and this decreased to 24% in the 7-item scale and 18% in the 4-item short form (cf. Milenkovic & Dragovic, 2012). With recent evidence that the Edinburgh Handedness Inventory overestimates the proportion of mixed-handers (Büsch, Hagemann, & Bender, 2010; Dragovic, Milenkovic, & Hammond, 2008), it seems that by eliminating items with notable measurement error, the short form inventory alleviates this concern.

This was the first study to test between-group factorial invariance for the Edinburgh Handedness Inventory using confirmatory factor analysis. Both metric and scalar invariance was found between those older than and younger than age 37, those with different levels of education, and those living in the USA versus Australia and New Zealand. This can be interpreted as evidence for the same factor structure across these groups, further supporting the validity of the short form. These level of education findings are especially important given recent work suggesting that a notable proportion of inmates, who are likely to have lower levels of education on average, did not understand or follow the original Edinburgh Handedness Inventory correctly. There was some indication that the toothbrush item loaded higher on the factor in males than females. Because this difference was of marginal significance, only detected on one of the two fit indices, and there is no obvious theoretical explanation for this finding, replication of this finding would be prudent before attempting to interpret it. Nevertheless, researchers interested in the study of gender differences in handedness should be aware of the possibility of factorial non-invariance for this item.

The sample in present study differed from previous samples on which the Edinburgh Handedness Inventory has been validated, in that it had a high proportion of LGBT participants. These groups are more likely to be non-right-handed (for reviews see Rahman & Wilson, 2003; Veale, Clarke, & Lomax, 2010b). Although it would not be expected, it is possible that the factor structure of handedness differs between heterosexual and LGBT groups. This would need to be tested with empirical evidence, which was beyond the scope of this study.

This was the first confirmatory factor analysis study to validate the Edinburgh Handedness Inventory using simplified instructions and response options. This was also the first study to model the response options as ordinal and test factorial invariance statistically. Results of the analyses suggested the revised 4-item Edinburgh Handedness Inventory – Short Form had very good reliability, factor score determinacy, and model fit. It also appeared to have enhanced performance in handedness categorisation. This short form will be of interest to researchers wanting to measure a single handedness factor with an inventory that has brief and simple instructions and a small number of items. This research was conducted using an online questionnaire; future research could assess the Edinburgh Handedness Inventory – Short Form using pen-and-paper format. Biomarkers of handedness could also be used to further assess its validity.

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APPENDIX

Edinburgh Handedness Inventory – Short Form

Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
Writing	☐	☐	☐	☐	☐
Throwing	☐	☐	☐	☐	☐
Toothbrush	☐	☐	☐	☐	☐
Spoon	☐	☐	☐	☐	☐