EDINBURGH HANDEDNESS INVENTORY—SHORT FORM: A REVISED VERSION BASED ON CONFIRMATORY FACTOR ANALYSIS

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ABSTRACT

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 modeled 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 modeled with considerable measurement error, the short form alleviates the concern of the 10-item inventory over-categorizing 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.

KEY WORDS: 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 11000 citations in Scopus. To complete the Edinburgh Handedness Inventory, respondents endorse hand preference for ten 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 that the inventory measures the unidimensional handedness factor it purports to. 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 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" (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 for most of the items, but noted instability on the box, broom, match, and scissors item. However, 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 modeling 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 appeared to be almost perfectly collinear, and that the broom and box-lid were modeled 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. However, with 5-point Likert response options, an estimation technique for ordered-categorical data is also appropriate (Kline, 2011). These two previous studies administered the Edinburgh Handedness Inventory using the original instructions. These instructions have been criticized 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 a Likert scale adaptation of the Edinburgh Handedness Inventory could markedly improve instruction adherence.

METHOD

Participants

Participants were recruited for an internet-based study examining the development of gender identity and sexuality (Veale, Clarke, & Lomax, 2010) through lesbian, gay, bisexual, and transgender 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. 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.

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".

Table 1. Participants' demographics

Ethnicity	%	Residence	%	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

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. The former estimates and fit indices are adjusted to allow for missing data and variations of multivariate normality. The latter allows for ordinal categories, missing data, and uses a polychoric correlation matrix (Kline, 2011).

Model fit was assessed using absolute fit indices: Satorra-Bentler χ^2 likelihood ratio (SBχ^2), RMSEA, and SRMR and relative fit indices: CFI and TLI. Model misspecification was detected by a statistically significant p value less than .05 on the χ^2 test. CFI and TLI 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. 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). This 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 measures 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 thesis 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 conducted between those above and below the median age. Finally, invariance testing was conducted between males and females (participants with gender identities atypical to their biological sex are removed from this analysis).

Metric invariance and scalar invariance were tested by comparing these to a model where these invariance constraints were not imposed (the unconstrained model). A statistically significant change in scaled difference χ^2 likelihood ratio test may indicate scale noninvariance (Kline, 2011). However, because this test can be over-sensitive when sample size is large, Cheung and Rensvold's (2002) criterion of a decrease in CFI of greater than .01 is evidence for measurement noninvariance was also used.

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 ten 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 and TLI 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 χ^2 likelihood ratio using both estimation techniques and also the RMSEA when using WLSMV estimation, so a revised model was also tested.

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

Model	SBχ^2	*df*	*p*	CFI	TLI	RMSEA	SRMR	ρ	α	FSD
10 items	1144.19	35	< .001	.84	.79	.145	.05	.95	.95	.98
7 items	59.95	14	< .001	.99	.98	.047	.02	.95	.95	.98
4 items	0.40	2	.819	1.00	1.00	.000	.00	.93	.93	.97
4 items, parallel indicators	47.04	5	< .001	.98	.97	.075	.08	.93		.97

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

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	TLI	RMSEA
10 items	271.87	21	< .001	.99	1.00	.089
7 items	103.67	14	< .001	1.00	1.00	.065
4 items	1.97	2	.373	1.00	1.00	.000
4 items, parallel indicators	158.53	4	< .001	.99	1.00	.160

Note. N = 1514

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 modeled with significant error variance in the previous analysis and scissor use preference may be effected by practice with the tools available (i.e. many modern scissors are designed for right-handed use); and
- 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 for the on all fit tests using both estimation techniques. Constraining factor loadings to be equal amongst indicators (parallel indicators) resulted in a model with poor fit using both estimation techniques. Reliability and factor score determinacy estimates are also given in Table 2. Parameter estimates for the 4-item model are given in Table 4.

Table 4. Model estimates for the 4-item Edinburgh Handedness Inventory

Parameter	Unstandardized	*SE*	Standardized	Unstandardized	*SE*	Standardized
	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

Note. 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 $p < .001$.

Invariance Testing

Tables 5 and 6 outline the results of invariance testing results. These analyses showed no significant change towards poorer model fit in the χ^2 likelihood ratio test. While the change in this test for between-countries metric invariance achieved statistical significance ($\chi^2(3) = 8.13$, $p = .04$) when using WLSMV estimation, this represented an improvement in model fit. Although not detected by the χ^2 likelihood ratio 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 $\chi^2(1) = 4.08$, $p = .04$, suggesting toothbrush hand preference has a slightly higher factor loading in males. Unfortunately, WLSMV between-gender invariance testing could not be conducted 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.

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

Model	SBχ^2	*df*	*p*	χ^2_{SD}	Δ*df*	*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

Note. SD = scaled difference

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 ρ = .90 and r^2 = .94.

Results of assignment to handedness categories are given in Table 7. The level agreement of this categorization between the 10-item and 4-item inventories was kappa = .73.

Table 6. Invariance testing fit statistics for the 4-item Edinburgh Handedness Inventory using WLSMV estimation

Model	χ^2	*df*	*p*	$\chi^2_{\text{Difference}}$	Δdf	*p*	CFI	ΔCFI
Country: USA/Australia or New Zealand					*n* = 1214			
Unconstrained	48.82	9	< .001	-	-	-	.998	-
Metric invariance	45.33	10	< .001	8.13	3	.043	.998	.000
Scalar invariance	40.20	11	< .001	6.60	4	.159	.998	.000
Age median split					*N* = 1514			
Unconstrained	52.69	10	< .001	-	-	-	.998	-
Metric invariance	46.26	11	< .001	6.53	3	.089	.998	.000
Scalar invariance	45.28	12	< .001	8.37	4	.079	.998	.000
Level of education					*n* = 1446			
Unconstrained	35.23	17	.005	-	-	-	.999	-
Metric invariance	31.61	19	.035	4.91	5	.427	.999	.000
Scalar invariance	35.39	21	.026	11.68	9	.232	.999	.000

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 need to be retained. The simpler instructions and response options, and lower number of items mean the short form is notably less burdensome to participants.

Table 7. 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

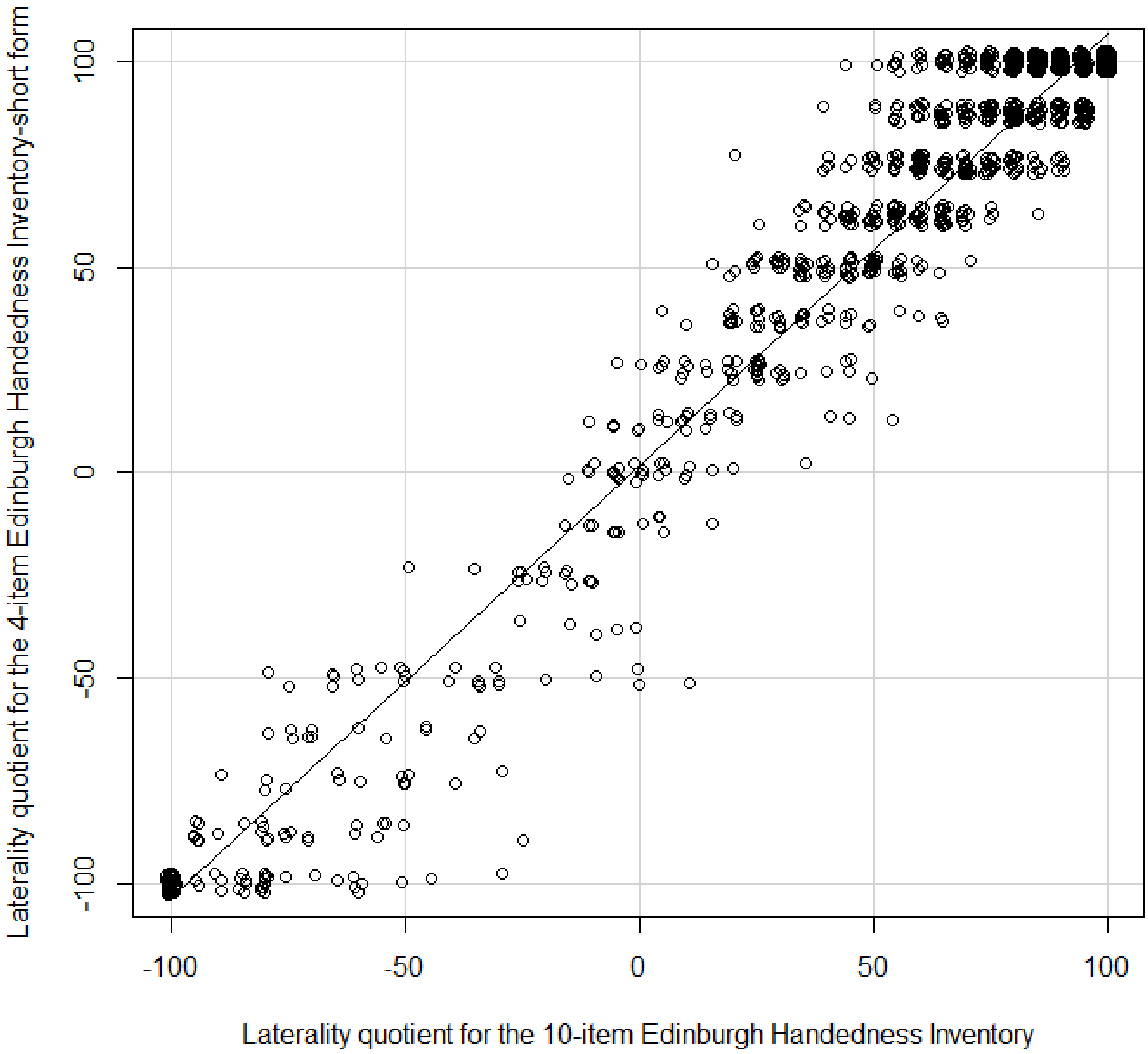

Figure 1. Scatter plot of laterality quotients for the Edinburgh Handedness Inventory and its short form

Note. *n* = 1396. Jitter function used to illustrate overlapping points.

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 previous studies using confirmatory factor analysis by Dragovic (2004; Milenkovic & Dragovic, 2012) that suggested a 7-item inventory, this study provided evidence that a 7-item inventory does not adequately fit the data. Although Dragovic (2004) 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 this misspecification on the χ^2 likelihood ratio test.

The 4-item inventory was proposed based on consideration of 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 modeled as both continuous and ordinal.

The 4-item Edinburgh Handedness Inventory—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). Also, 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 to more accurately assess handedness.

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 categorization of participants into left, mixed, and right handers between original and revised versions in this study (kappa = .73) was lower than in Milenkovic and Dragovic's study (kappa = .80), but this finding still suggests "substantial agreement" (Landis & Koch, 1977). Table 7 illustrates that the main source of disagreement in this study was participants categorized as mixed handers by the 10-item inventory were categorized as either left or right handers by the 4-item inventory. The percentage classified as mixed hander in the 10-item inventory was 31% and this decreased to 19% in the 4-item short form. 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 from 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 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 noninvariance for this item.

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 categorization. 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, and use biomarkers of handedness 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					

Scoring:

For each item: Always right = 100; Usually right = 50; Both equally = 0; Usually left = -50; Always
left = -100

To calculate the Laterality Quotient add the scores for the four items in the scale and divide this by four:

Writing score	
Throwing score	
Toothbrush score	
Spoon score	
Total	
Total ÷ 4 (Laterality Quotient)	

Classification:	Laterality Quotient score:
Left handers	-100 to -61
Mixed handers	-60 to 60
Right handers	61 to 100