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Psychometric properties of the Spanish version of the Edinburgh Handedness Inventory in a sample of Chilean undergraduates

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ABSTRACT

An individual's nervous and cognitive systems are lateralized, and handedness represents a behavioral manifestation of such organization. Therefore, accurately and reliably measuring handedness has repercussion on our understanding of both the human brain and cognition. The Edinburgh Handedness Inventory (EHI) is the most frequently used instrument to measure handedness both in clinical practice and research. We assessed the psychometric properties of the Spanish version of the EHI in a sample of 348 Chilean university students by confirmatory factor analysis. Cronbach's alpha and composite reliability were calculated to evaluate the internal consistency and reliability of the EHI, while the average variance extracted was estimated to evaluate its convergent validity. A 10-item unifactorial structure was confirmed, with factor loadings ≥ 0.50, showing excellent goodness-of-fit indicators, very high internal consistency and adequate composite reliability and convergent validity. Socio-demographic variables (sex, area of residence and belonging to an indigenous people or community) did not significantly modulate the EHI scores. Overall, by using this validated version of the EHI to accurately and reliably measure handedness in the greater Spanish population, researchers will be able to produce robust data to tackle the still open questions of lateralization in human cognitive and neural architecture.

1. Introduction

The concept of handedness refers to a person's consistent tendency or preference to use one hand instead of the other when performing a certain task (Adamo & Taufiq, 2011; Donaldson & Johnson, 2006). Handedness reflects the habitual preference of acting with one hand, but one's habitual preference to use one hand cannot be equated with a strong asymmetry in dexterity, the ability to perform skilled hand actions. Some individuals with a strong right-hand preference may perform a unimanual motor skill equally well with both hands (or even slightly better with the left non-dominant hand, Hervé, Mazoyer, Crivello, Perchey, & Tzourio-Mazoyer, 2005). For instance, a recent study on circle drawing confirmed that the asymmetry in dexterity and handedness for a given skill may vary substantially at the individual level (Angstmann et al., 2016).

Despite the study of genetic (de Kovel & Francks, 2019) and epigenetic factors (Espírito-Santo et al., 2017) and the ability to infer it pre-birth (Parma, Brasselet, Zoia, Bulgheroni, & Castiello, 2017), handedness - possibly the most studied asymmetry in basic and clinical research - does not produce a consensus on its origin (Scharoun & Bryden, 2014) or how to measure it. Indeed, throughout the years different tools have been developed to accurately evaluate handedness over time. Such tools rely on the assessment of the two main dimensions of motor asymmetry, namely direction and degree of handedness (Edlin et al., 2015). The direction of handedness identifies whether an individual habitually prefers to use their right or left hand for unimanual

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actions (Andersen & Siebner, 2018). Nearly 90% of the human population is estimated to be right-handed (Adamo & Taufiq, 2011; Jang, Lee, Lee, & Park, 2017; McManus, 2009) and the remaining 10% left-handed (Edlin et al., 2015). The second dimension - the degree of handedness - refers to how consistently (irrespective of direction) the preferred hand is employed (Lyle et al., 2017). Inconsistent handedness is more prevalent among left-handers (~80%) than right-handers (~40%; Christman & Prichard, 2016; Prichard, Propper, & Christman, 2013).

Although strictly dichotomous models have been proposed (McManus, 1985), measuring hand preference nowadays includes at least one intermediate category defined based on within-task (ambiguous handedness) and across-task variability (mixed handedness). The term ambiguous-handedness has been used to categorize people who may randomly use the left or the right hand in a given task, without necessarily highlighting differences in performance. Instead, the term mixed-handedness has been used to classify individuals who prefer to use one hand skillfully for a designated task, but would use the opposite hand skillfully for a different task (Fazio & Cantor, 2015).

Neuroscientists and psychologists have often acknowledged the importance that handedness plays in individual neural, behavioral and cognitive differences. Handedness is an important indicator of the lateralization of cognitive function (e.g., language, Knecht et al., 2000; approach motivation, Brookshire & Casasanto, 2018 and visuo-spatial cognition, Willems, Peelen, & Hagoort, 2010), whereas less clear results have been reported regarding its association with the lateralization of brain anatomy (for a review, see Papadatou-Pastou, 2018). Arning et al. (2013) advanced (although not conclusively, de Kovel & Francks, 2019) that such inconsistencies may be associated with tandem repeat variation in the PCSK6 gene, for which a role in the pathway for left-right cerebral asymmetry has been suggested. All in all, understanding handedness helps scientists explore the architecture of the human brain and cognition. As pointed out by Papadatou-Pastou (2018), confounding findings might be caused by the way handedness is conceptualized (e.g., direction vs. degree), measured (e.g., observation vs. self-report), and classified (e.g., dichotomous models vs. models including intermediate categories).

To validly and reliably capture handedness, researchers have been moving away from mere dichotomous observations of direction of handedness and embracing the greater complexity that emerges from self-reports, behavioral performance, neural and genetic investigations. Importantly, both direction and degree of hand preference have been associated with variability in different (i) cognitive processes, such as memory (Lyle, Hanaver-Torrez, Hackländer, & Edlin, 2012), attention (Kourtis & Vingerhoets, 2016), cognitive flexibility (Gunstad, Spitznagel, Luyster, Cohen, & Paul, 2007) and approach motivation (Brookshire & Casasanto, 2018), and (ii) personal tendencies, such as anxiety (Lyle, Chapman, & Hatton, 2013), creativity (Badzakova-Trajkov, Häberling, & Corballis, 2011), extraversion (Grimshaw & Wilson, 2012) and risk-taking (Christman, Jasper, Sontam, & Cooil, 2007).

When looking at the neural correlates associated with handedness, both structural and functional differences have emerged. For instance, a recent study on large-scale brain tractography concluded that right-handers show greater intra-hemispheric clusterization in the topology of the white matter as compared to left-handers (Li et al., 2014). This pattern of results is mirrored at the functional level when considering the activation of the supplementary motor area (Pool, Rehme, Fink, Eickhoff, & Grefkes, 2014). These differences in inter-hemispheric interaction could be due to less prominent lateralization of manual abilities for left-handers (Andersen & Siebner, 2018). Although linking functional and structural differences in the corticospinal motor system to handedness has produced mixed outcomes, some recent studies demonstrate that both the direction and the degree of handedness produce effects measurable at the cortical level. For instance, the direction of handedness influences the cortical organization of upper limb muscles in M1, with right-handers showing wider and more postero-lateral representations in the non-dominant hemisphere than left-handers (Nicolini, Harasym, Turco, & Nelson, 2019). Additionally, the degree of handedness predicts whether electrically stimulating the frontal cortex via tDCS increases or decreases lateralized approach motivation, which manifests in opposite tendencies in left- and right-handers (Brookshire & Casasanto, 2018). When moving to structural observations, consistent handedness is associated with decreased callosal thickness (Luders et al., 2010), which may provide a reason why consistent right-handers show decreased functional interaction between processes lateralized in opposite hemispheres (Christman & Butler, 2011; Christman, Prichard, & Corser, 2015), while inconsistent handers show better coordination of hemispherically-segregated processing in the prefrontal lobes while performing demanding episodic retrieval tasks (Lyle, McCabe, & Roediger, 2008).

It becomes clear how any tool that informs reliably on hand preference is in the service of the greater endeavor of understanding the relationship between handedness and cognitive ability. Given the ease, speed and cost-effectiveness of their administration, self-reported questionnaires are the most common tool to determine handedness. Throughout the years different questionnaires measuring direction and degree of handedness have been created and optimized, with the Annett Questionnaire (Annett, 1970) and the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) being the most popular (Espírito-Santo et al., 2017; Williams, 1991).

Among the self-reported questionnaires, the EHI (Oldfield, 1971) is the most frequently cited instrument (Espírito-Santo et al., 2017; Veale, 2014; Yang, Waddington, Adams, & Han, 2017). As evidence of its popularity, in the past five years the citation index of the EHI (Oldfield, 1971) increased from ~11,000 (Veale, 2014) to more than 24,400 (as of September 2019, Scopus). The EHI has been used to evaluate handedness in the United Kingdom (Oldfield, 1971; Williams, 1991), Germany (Büsch, Hagemann, & Bender, 2010), Italy (Begliomini, Sartori, Di Bono, Budisavljević, & Castiello, 2018; Viggiano, Borelli, Vannucci, & Rocchetti, 2010), Portugal (Espírito-Santo et al., 2017), the Czech Republic (Komarc, Harbichová, & Tichý, 2014), Serbia (Milenkovic & Dragovic, 2012), Algeria (Nedjar, Touari, Mesbah, Lellouch, & Dellatolas, 1989), China (Yang et al., 2017), Korea (Kang & Harris, 2000), Australia (Dragovic, 2004b; McFarland & Anderson, 1980), Canada (Fazio & Cantor, 2015), the United States (Corey, Hurley, & Foundas, 2001; Fazio, Coenen, & Denney, 2012), Brazil (Brito, Brito, Paumgartten, & Lins, 1989), Mexico (Cuencas, Von Seggern, Toledo, & Harrell, 1990) and Chile (Camposano & Lolas, 1992; Letelier, Chabert, & Vielma, 2010), among others.

As pointed out by Edlin et al. (2015), many variations of the EHI have been used experimentally, resulting in the EHI including different items, response formats and classification rules of right-handed individuals across versions. The poor translation of an instrument, when not certified with the state-of-the-art back-translation (Sousa & Rojjanasrirat, 2011) and committee approaches (Furukawa, Driessnack, & Colclough, 2014), can lead to bias in the response pattern and reduce the comparability of findings across studies (Beaton, Bombardier, Guillemin, & Ferraz, 2000). This is the case of the currently available Spanish versions of the EHI, for which the translation process has not been thoroughly documented and a careful psychometric evaluation is lacking. Additionally, the role of socio-demographic influences on handedness (e.g., age and region of residence, Espírito-Santo et al., 2017) has not yet been evaluated in samples of Spanish speakers.

Given the lack of a valid and reliable Spanish version of the EHI, the aim of this study was to appropriately translate the EHI into Spanish and assess its psychometric properties (Oldfield, 1971). Based on previous research (e.g., Espírito-Santo et al., 2017; Fazio & Cantor, 2015), we expect to replicate a single factor structure via a confirmatory factor analysis in a sample of Chilean university students accounting for possible socio-demographic influences.

2. Method

2.1. Participants

A sample of 348 Chilean university students (mean age = 21 years old, *SD* = 3.7, age range = 19–34 years old) was selected using non-probability convenience sampling. This sample size is deemed to be adequate for the execution of a confirmatory factor analysis (CFA; N ≥ 300 according to Moshagen & Musch, 2014). The sample was composed of students from five Chilean universities enrolled in different programs. At the time of participation, 70.1% of the participants were enrolled in physiotherapy, 18.4% in nutrition and dietetics, 6% in psychology and 5.5% in business. The participants volunteered to participate in the study, without receiving any type of compensation. Participants took part in the study in large groups in the classroom. Those who volunteered to participate were provided a written informed consent as well as a paper version of the questionnaires. On average the procedure was completed in 10–15 min. This study was approved by the Science Ethics Committee of the Universidad de La Frontera and implemented according to its guidelines and based on the principles of the Declaration of Helsinki (World Medical Association, 2013).

2.2. Instruments

This study included a 10-item self-reported version of the Edinburgh Handedness Inventory (EHI, Oldfield, 1971). The EHI measures the participant's hand preference during certain tasks (see Table 1). In the present study, we used the instructions and response format proposed by Veale (2014). To obtain a measurement equivalent to this version of the EHI, the instrument was translated into neutral Spanish following a back-translation procedure (see Sousa & Rojjanasrirat, 2011) in line with recent validation studies of the EHI (Espírito-Santo et al., 2017; Yang et al., 2017). First, a translator not connected to the purposes of the study and a bilingual psychologist translated the instructions, items and response options on the EHI from English into Spanish. Both the English and the Spanish translations were then reviewed by a second bilingual psychologist, and minor observations were discussed with the investigators. Then, a second external translator and a third psychologist who was not part of the study back-translated the instrument into English. Finally, both the forward and back translations were compared to produce the final version of the instrument in Spanish, which was evaluated for clarity by native Spanish speakers from Chile and Spain. To evaluate possible issues with this Spanish version of the EHI, the instrument was tested on 12 university students (mean age = 19.7 years old, *SD* = 1.4). None of the participants indicated difficulties in completing the inventory during debriefing; these participants were not included in the final sample of this study.

The original instructions of the EHI ask the participant to mark the symbol "+" for each item in one of two columns assigned for left- or right-hand preference. When the preference is so strong that the other hand would never be used unless forced, the participant is asked to mark "++" in one of the columns. If they are indifferent, they are asked to mark "+" in both columns. Some activities require the use of both hands. In these cases, the part of the task or object for which the determination of hand preference is to be made is indicated in parentheses. It has been previously shown that these instructions frequently lead to misinterpretation by the participants (Espírito-Santo et al., 2017; Fazio et al., 2012; Fazio, Dunham, Griswold, & Denney, 2013). To improve adherence to the instructions (following Christman et al., 2015; Fazio et al., 2012; Veale, 2014) we changed the response format to a 5-point Likert-type response scale (1 = *always right*, 2 = *usually right*, 3 = *both equally*, 4 = *usually left*, 5 = *always left*) as in Veale (2014), who obtained reliable data in line with previous research (Fazio et al., 2012). The instructions, items and response format of the Spanish version of the EHI are shown in Table 1.

To determine the role of socio-demographic variables on handedness as measured by the new version of the Spanish EHI, a brief socio-demographic survey was included to characterize the sample in terms of sex, area of residence (rural vs. urban), belonging to an indigenous people or community (yes or no, if yes, which one?) and university program.

2.3. Data analysis

A laterality quotient (LQ) was estimated based on the following calculation: LQ = (R − L)/(R + L) × 100, assigning two points to L or

Table 1
Spanish Version of the Edinburgh Handedness Inventory.

Instrucciones. Por favor, indica tus preferencias en el uso de las manos en las siguientes actividades. Algunas de las actividades requieren de ambas manos. En estos casos, la parte de la tarea u objeto para la cual se busca la preferencia manual, se indica entre paréntesis.
[*Instructions. 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.*]

Items	Siempre derecha [*Always right*]	Usualmente derecha [*Usually right*]	Ambas por igual [*Both equally*]	Usualmente izquierda [*Usually left*]	Siempre izquierda [*Always left*]
Escribir [*Writing*]	1	2	3	4	5
Dibujar [*Drawing*]	1	2	3	4	5
Lanzar [*Throwing*]	1	2	3	4	5
Tijeras [*Scissors*]	1	2	3	4	5
Cepillo de dientes [*Toothbrush*]	1	2	3	4	5
Cuchillo (sin tenedor) [*Knife (without fork)*]	1	2	3	4	5
Cuchara [*Spoon*]	1	2	3	4	5
Escoba (mano superior) [*Broom (upper hand)*]	1	2	3	4	5
Encender un fósforo (fósforo) [*Striking a match (match)*]	1	2	3	4	5
Abrir una caja (tapa) [*Opening a box (lid)*]	1	2	3	4	5

Table 2
Socio-demographic characterization of the sample.

Variables	Total (N = 348)	Handedness		
		Right-handed (n = 286)	Ambiguous (n = 46)	Left-handed (n = 16)
Sex				
Female	68.1%	84.4%	11.0%	4.6%
Male	31.9%	77.5%	18.0%	4.5%
Area of residence				
Rural	11.2%	79.5%	20.5%	0.0%
Urban	88.8%	82.5%	12.3%	5.2%
Belonging to an indigenous people or community				
Yes	19.3%	88.0%	7.5%	4.5%
No	80.7%	80.8%	14.6%	4.6%

Note: The participants who indicated they belonged to an indigenous people or community identified as Mapuche.

R for each item marked *always left* or *always right*, respectively, one point for L or R for those indicated as *usually left* or *usually right* correspondingly, and one point for both L and R for each item where both *equally* was indicated. The LQ were compared across sex (female vs. male), area of residence (urban vs. rural) and belonging to an indigenous people or community (indigenous vs. non-indigenous) by means of Kruskal-Wallis tests following assessment of the non-normality of LQ via the Kolmogorov-Smirnov test ($p < 0.001$). The frequency of the hand preference categories was contrasted using a one-way chi-square test. Considering a cutoff score of 60, the LQ was used to classify the hand preference of each participant as left-handed (−100 to −61), ambiguous (−60 to 60) or right-handed (61–100) in line with previous studies that have evaluated the performance of the EHI (Espírito-Santo et al., 2017; Fazio et al., 2012; Milenkovic & Dragovic, 2012). As pointed out by Dragovic (2004a), a cutoff value between 50 and 70 provides the greatest agreement with classification based on statistical criteria, whereas cutoffs below 50 and greater than 70 were progressively lower in agreement with statistical criteria, producing a higher number of misclassifications. On the other hand, in order to determine whether participants were categorized as ambiguous due to a high proportion of "either" responses or due to a contrast between "left" or "right" responses, we distinguished between ambiguous-handedness and mixed-handedness. Although the methodology to determine these categories has not yet reached a consensus, based on Espírito-Santo et al. (2017) we classified participants as follows: truly ambiguous (i.e., five or more "either" responses), mixed-handed (i.e., 0–1 "either" and 0–9 "left" or 0–1"right" responses, with at least one "left" and one "right), right-handed (i.e., 6–10 "right" and 0–4 "either" or 0–1 "left" responses) and left-handed (i.e., 6–10 "left" and 0–4 "either" responses). Cramer's V was used to test the association between the two types of handedness categorization (i.e., the one based on the cutoff score of 60 and the one that distinguishes between ambiguous and mixed-handed).

To confirm the factorial structure of the EHI [a first-order latent factor (handedness) and 10 indicators (inventory items)], we ran a CFA, considering the following goodness-of-fit indicators: chi-squared (χ^2), the comparative fit index (CFI ≥ 0.95), the Tucker-Lewis index (TLI ≥ 0.90), the root mean square error of approximation (RMSEA ≤ 0.06) and the standardized root mean square residual (SRMR ≤ 0.08) according to the cutoff scores established by Hu and Bentler (1999). If in case of statistical significance of Mardia's multivariate normality test, the maximum likelihood estimation was used with the Satorra-Bentler robust correction (Satorra & Bentler, 1988).

From a perspective centered on the comparison of models (McElreath, 2016), the Akaike information criterion (AIC) was estimated to account for the model with the best fit of the data (i.e., lowest relative AIC). The internal consistency of the instrument was also evaluated using Cronbach's alpha coefficient, while composite reliability (CR ≥ 0.7) and the average variance extracted (AVE ≥ 0.5) were estimated to assess the reliability and convergent validity of the instrument, respectively, according to the guidelines of Fornell and Larcker (1981). The statistical analyses were performed using the STATA 14.1 MP software (StataCorp, 2015).

3. Results

Adopting a cutoff score of 60 for the LQ of the EHI (mean = 73, SD = 42), 82.2% of the sample was characterized as right-handed, 13.2% as ambiguous and 4.6% as left-handed, not being equally distributed, $\chi^2(2) = 377.586$, $p < 0.001$. Considering the pattern of responses to distinguish between truly ambiguous and mixed-handed individuals, 75% of the sample was characterized as right-handed, 3.7% as left-handed, 4.9% as truly ambiguous and 16.4% as mixed-handed. Following this classification, the individuals categorized as ambiguous based on the cutoff of 60, 56.5% were truly ambiguous and 43.5% mixed-handed. As the two types of handedness categorization were significantly associated, $\chi^2(6) = 442.963$, $p < 0.001$, Cramer's V = 0.798, the description of the sample is shown in Table 2 based on the established cutoff criteria.

No significant differences were found when considering area of residence, $\chi^2(1) = 1.131$, $p = 0.288$ and belonging to an indigenous people or community, $\chi^2(1) = 0.151$, $p = 0.698$. However, sex provides a trending result: $\chi^2(1) = 3.520$, $p = 0.061$, with women being more frequently right-handed than men. The mean and standard deviation (SD) of the socio-demographic variables by LQ are shown in Table 3.

The following results are derived via maximum likelihood estimation with the Satorra-Bentler robust correction (Satorra & Bentler, 1988). The standardized factor loadings of the indicators of a unifactorial model including the 10 items of the EHI (see Fig. 1) varied between 0.38 and 0.98 (all values $p < 0.001$). However, considering that the goodness-of-fit indicators of this model were not within the selected criteria (Hu & Bentler, 1999; see upper row of Table 4), and given the presence of collinearity between items one and two (*writing* and *drawing*, respectively; $r = 0.97$), a second model was estimated.

As can been seen in Fig. 2, model 2 was comprised of a latent factor and 10 indicators, with only one covariance having been added between the error variances of the items *writing* and *drawing* (0.90, $p < 0.001$). The standardized factor loadings of the indicators of model 2 varied between 0.50 and 0.88 (all values $p < 0.001$). Following this change, the goodness-of-fit indicators of model 2 were considered excellent in compliance with the requirements for the study (Hu & Bentler, 1999; see lower row of Table 4).

The computed models were compared using a likelihood-ratio test. The test was statistically significant ($p < 0.001$), indicating that the second model produced a better solution than the first. The comparison of the models and their respective goodness-of-fit indicators are shown in Table 4. In addition, Cronbach's alpha coefficient was 0.92,

Table 3
Laterality quotients.

Variables	Mean ± SD	Range
Sex		
Female	75.1 ± 41.3	−100 to 100
Male	68.6 ± 43.5	−100 to 100
Area of residence		
Rural	76.2 ± 23.3	−17.7 to 100
Urban	72.6 ± 43.9	−100 to 100
Belonging to an indigenous people or community		
Yes	74.4 ± 40.8	−100 to 100
No	72.7 ± 42.4	−100 to 100

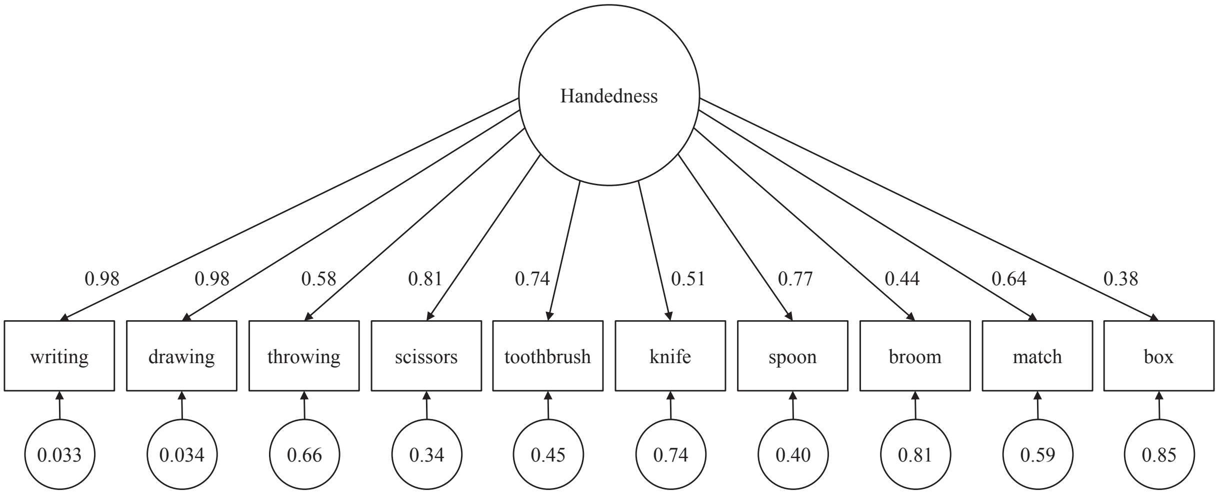

Fig. 1. Confirmatory factor analysis of model 1. The digits close to the arrows refer to the standardized factor loadings. Error variances are represented in the circles at the bottom.

demonstrating that the instrument has very high internal consistency. According to the criteria followed in this study (Fornell & Larcker, 1981), model two accounted for a suitable composite reliability (CR = 0.91) and convergent validity (AVE = 0.53).

4. Discussion

The aim of this study was to analyze the psychometric properties of a rigorously translated Spanish version of the EHI (Oldfield, 1971), confirming its unifactorial structure, in a sample of Chilean university students and to test the possible confounders included by different socio-demographic variables. In line with previous evidence, the vast majority of the sample was characterized as right-handed in a proportion similar to previously analyzed samples. Additionally, the percentage of left-handed people was inferior to that of the individuals categorized as ambiguous (both truly ambiguous and mixed-handed) in line with previous psychometric evaluations (Espírito-Santo et al., 2017; Fazio et al., 2012; Komarc et al., 2014; Milenkovic & Dragovic, 2012; Williams, 1991). In this regard, in contrast to the findings obtained with the Annett Questionnaire (Annett, 1970), Williams (1991) noted that individuals tend to respond *both equally* rather than choosing *left* as the alternative response (Papadatou-Pastou, Martin, & Munafò, 2013). In a similar vein, Espírito-Santo et al. (2017), who used different methods to calculate hand preference on the basis of the LQ, reported that the categorical classification of handedness largely depends on the cutoff scores used, which renders comparison between studies difficult (see also Edlin et al., 2015). For their part, Milenkovic and Dragovic (2012), by using a reduced and modified version of the EHI, were able to unfairly classify likely right-handed individuals as belonging to the mixed category, which is sometimes associated with pathologies.

As expected, the results of this study corroborate the 10-item unifactorial structure of the EHI (Oldfield, 1971), providing evidence of excellent goodness-of-fit indicators, very high internal consistency, suitable composite reliability and suitable convergent validity for this Spanish version of the EHI. Although previous studies have criticized the unidimensionality of the EHI (Büsch et al., 2010; Christman et al., 2015), several psychometric analyses have corroborated this factor structure. Studies that have used CFA (Espírito-Santo et al., 2017; Fazio & Cantor, 2015) have reproduced the unifactorial structure of the instrument when some items were eliminated (Dragovic, 2004b; Milenkovic & Dragovic, 2012). For example, Milenkovic and Dragovic (2012) determined that the measurement properties of the EHI were poor, suggesting a brief version that eliminated problematic items, such as *broom* and *open a box*. It is worth noting that although the results of this study corroborated the validity and reliability of the EHI, these two items were the ones that presented the lowest, albeit fair, factor loadings (> 0.45 according to Tabachnick & Fidell, 2007). This is not uncommon when dealing with the adaptation of an instrument to a new context (Espírito-Santo et al., 2017). However, Milenkovic and Dragovic (2012) also labeled the items *writing* and *drawing* as problematic, eliminating the latter, given the presence of collinearity. This was also the case in this study, but when modeling a correlation between these two items, instead of eliminating one of them, factor loadings, goodness-of-fit indicators and AIC were optimized. It has been suggested that the differences in the factor solutions may be due to differences in the way in which handedness is assessed, a result of cultural differences and the difficulty in following the instructions (Espírito-Santo et al., 2017). The latter seems less likely with regard to the present study, since a rigorous translation process was followed (Sousa & Rojjanasrirat, 2011), and simplified instructions and a Likert-type response format were adopted (Christman et al., 2015; Fazio et al., 2012; Veale, 2014). However, the initial argument of Espírito-Santo et al. (2017) seems more appropriate if we consider that not all the studies mentioned followed the same exact instructions (Edlin et al., 2015).

Although carefully conducted, this study is not free of limitations. To the best of our knowledge, this is the first evaluation of the psychometric properties of a version of the EHI rigorously translated into Spanish. However, like many other studies, it is confined to a student sample for practical reasons (e.g., ease of access to the sample and cost reduction). Thus, generalization of the results of this study must await the application of this instrument to more heterogeneous samples;

Table 4
Comparison of models and goodness-of-fit indicators.

Model	χ^2(df)	$\Delta\chi^2$	CFI	TLI	RMSEA	SRMR	AIC
1	291.22(35)***		0.850	0.807	0.145	0.093	7681.224
2	74.03(34)***	217.19***	0.977	0.969	0.058	0.036	7370.286

Note: The goodness-of-fit indicators were adjusted using the Satorra-Bentler robust correction. ***$p < 0.001$.

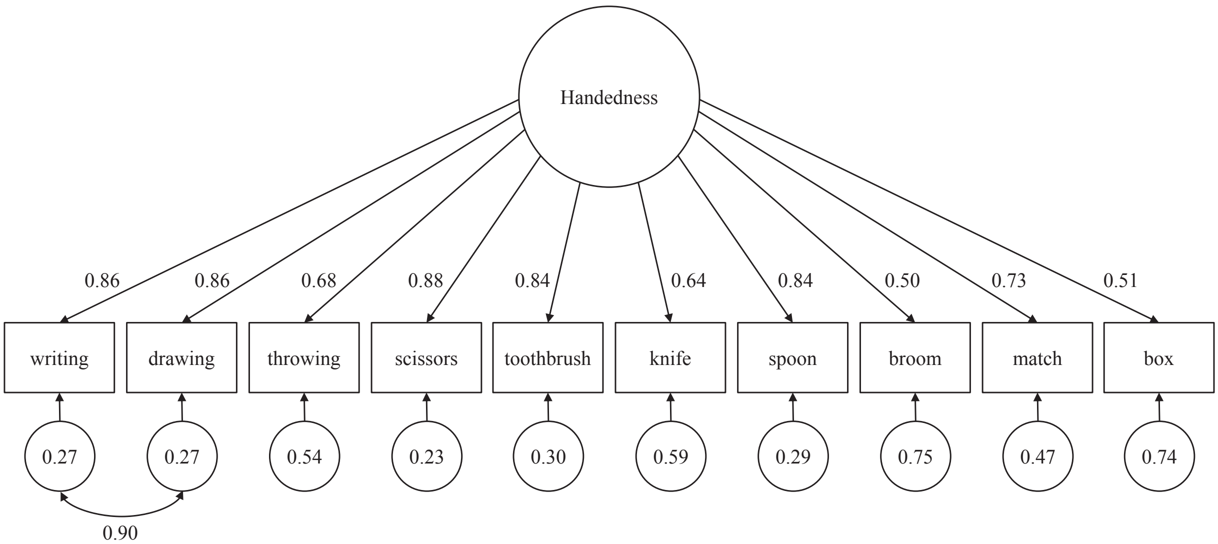

Fig. 2. Confirmatory factor analysis of model 2. The digits close to the arrows refer to the standardized factor loadings. Error variances are represented in the circles at the bottom.

nevertheless, it represents a useful resource for the vast corpus of studies that include university students as participants (Hanel & Vione, 2016). Importantly, the validation of this Spanish version of the EHI following rigorous statistical criteria is a tool that can benefit research in communities that speak Spanish, the second most spoken language worldwide by number of native speakers (Eberhard et al., 2019).

On the whole, the present study revealed that the Spanish version of the EHI is a valid tool for measuring handedness in Chilean individuals, with the potential for use in other Spanish-speaking countries. The Spanish EHI version is intended to be representative of typical individuals and it should very cautiously be generalized to pathological populations (as explored in Fazio, Lykins, & Cantor, 2014). Taking into account this consideration, researchers intending to work with Spanish speakers can make use of this tool, for instance, to study the effect/association of handedness on/with a phenomenon of interest (e.g., cognitive functioning). Many researchers might be interested also in selecting or excluding individuals on the basis of hand preferences to control a certain amount of variability (e.g., in order to compare groups matched regarding handedness; Edlin et al., 2015). However, although the practice of excluding left-handed individuals from studies is not uncommon, it is known that this represents a limitation in the generalization of results and, ultimately, in the understanding of brain functioning (Willems, Van der Haegen, Fisher, & Francks, 2014).

Finally, with the general aim of detailing the features of our convenience sample, we have paid great attention to including a series of socio-demographic variables. None of the controlled socio-demographic variables in this study significantly modulated handedness, and this could be dependent on the low heterogeneity of the sample. In line with previous studies (Oldfield, 1971; Yang et al., 2017), women tend to be categorized more often as right-handed than men as reflected in a higher LQ (however see Espírito-Santo et al., 2017; Williams, 1991 for lack of sex differences). Although the area of residence has scarcely been studied in terms of handedness, Espírito-Santo et al. (2017) showed that the EHI classified individuals as right-handed less frequently in suburban than in rural areas, suggesting that this phenomenon may reflect geographic and cultural pressure to be right-handed. It should be pointed out that our study included urban and rural areas, and like Espírito-Santo et al. (2017) found no differences. Finally, this study included the variable belonging to an indigenous people or community, given its high local relevance. Considering that all the cases of indigenous people or community identified as Mapuche, it should be emphasized that in this culture right is strongly associated with the concepts of good and life, whereas left is strongly associated with bad and evil (Faron, 1962). Despite the low sample size of this Mapuche subsample, the cultural pressure to be right-handed does not seem to be distinctive to this group. Instead, cultural right-handed bias may be shared by multiple groups (Espírito-Santo et al., 2017; Harris, 1990).

Overall, this adapted, Spanish version of the EHI has proven to be a valid and reliable instrument to measure hand preference in university students, being a rapid and cost-effective tool that is easy to administer. It contributes to the greater purpose of ultimately aiding the understanding of human cognitive and neural architecture, which is bounded to the availability of tools that measure accurately both direction and degree of handedness. By making the EHI available to the Spanish population at large, researcher and clinicians will produce a robust and large amount of data used to this end. Additionally to gain a better understanding of the anatomical bases of handedness, the application of valid and reliable versions of the EHI will contribute to broader related areas of research, such as the ontogenesis and clinical significance of hemispheric asymmetries (e.g., Francks et al., 2007; Arning et al., 2013; Ocklenburg, Beste, & Güntürkün, 2013) and their effects on cognition and behavior.

Author's contributions

JA, PV-G and CB-S collected and analyzed the data. JA, PV-G, CB-S, VP and GG-G wrote the manuscript. All of the authors read and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare no competing interests.

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