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Research report

The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference

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ARTICLE INFO

Article history:
Received 25 September 2012
Reviewed 8 November 2012
Revised 13 December 2012
Accepted 1 February 2013
Action editor Alan Beaton
Published online xxx

Keywords:
Dextral
Sinistral
Left
Right
Laterality
Asymmetry

ABSTRACT

Knowing whether an individual prefers the left or right hand for skilled activities is important to researchers in experimental psychology and neuroscience. The current study reports on a new measure of skilled hand preference derived from the Provins and Cunliffe (1972) handedness inventory. Undergraduates ($n = 3324$) indicated their lateral preference for their hands, feet, eyes and ears. A measure of hand performance and familial handedness was also obtained. Factor analysis identified ten items that loaded on skilled hand preference and these were included in the new FLANDERS questionnaire. Cluster analysis of the new questionnaire revealed three distinct groups (left-, mixed- & right-handed). The new test showed a strong association with other measures of lateral preference and hand performance. Scores on the test were also related to the sex of the respondent and the hand preference of their parents. The FLANDERS provides a measure of skilled hand preference that is easy to administer and understand and should be useful for experimenters wanting to screen for hand preference.

1. Introduction

An individual's hand preference is an important factor in experimental psychology and neuroscience. Handedness has been demonstrated to play a role in numerous individual differences, including intelligence (Johnston et al., 2009, in press; Nicholls et al., 2010, 2012), schizotypy (Bryson et al., 2009; Chapman et al., 2011; Nicholls et al., 2005) and sex roles (Nicholls and Forbes, 1996). Hand preference may also be an important marker of functional cerebral lateralisation. While the large majority of right-handers have language functions lateralised to the left hemisphere, this pattern has been found to be less distinct in left- and mixed-handers (Beaton, 2004; Knecht et al., 2000; Szaflarski et al., 2002). Handedness effects have also been observed in structural brain asymmetries related to the shape of the central sulcus (Sun et al., 2012) and the size of Broca's area (Foundas et al., 1998).

Given the importance of hand preference to psychological research, it is necessary to devise handedness tests that are valid and easy to administer. Although a number of handedness inventories have been devised, many of them suffer from one or more drawbacks related to their length, response format, instructions, factorial structure, or their age. The

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http://dx.doi.org/10.1016/j.cortex.2013.02.002

current study describes a new test of hand preference, which sought to overcome many of these shortcomings.

In relation to the length of the questionnaire, tests have varied over a wide range. Some researchers (e.g., Williams, 1986) have suggested that simply asking: 'Which hand do you use to write with?' provides a good index of handedness. While this may be the case for differentiating left and right, it has provided relatively little information about mixed-handers, who are thought to be an important group in their own right (Crow, 1997). On the other extreme, the questionnaires devised by Steenhuis and Bryden (1989) and Provins and Cunliffe (1972) contain 60 and 31 items, respectively. Like many others in the field, these questionnaires were designed to measure handedness as the principal variable of interest. While handedness is certainly a legitimate concern in and of itself, it also needs to be recognised that many researchers require a quick test of hand preference, which can be administered in the laboratory or clinic. In these cases, handedness has often been used as a proxy for cerebral dominance, allowing researchers to identify groups and assume a pattern of functional lateralisation. Good compromises in terms of length are the Edinburgh (Oldfield, 1971) and Annett (Annett, 1970) handedness inventories, which contain 10 and 12 items, respectively. These tests strike a balance between breadth and brevity and can be used to identify left-, mixed- and right-handers.

A diverse range of response formats has been used by the different handedness inventories. The Waterloo inventory (Steenhuis and Bryden, 1989) asked participants to respond along a five-point scale from: (1) always left to (5) always right, with a score of 3 indicating that either hand can be used. Similarly, the Edinburgh inventory (Oldfield, 1971) required respondents to indicate whether they have a strong or weak preference for the left or right hand by placing a '++' or '+' in the appropriate box. Fazio et al. (2012) demonstrated that these instructions were misunderstood by the majority of respondents. In particular, respondents failed to use the '++' response and this tendency was more marked amongst right-handers and those with fewer years of formal education. A simpler response format was used by Annett (1970) and Provins and Cunliffe (1972). In these tests, participants simply indicated whether they use the 'left', 'right' or 'either' hand for a particular task. Although the scales used by Steenhuis and Bryden (1989) and Oldfield (1971) most probably provided a finer-grained picture of hand preference, this level of detail may not be necessary when a simple indication of handedness is needed. In addition, it appears that response format produced noise, which may have obscured underlying differences in hand preference. With this in mind, a simple choice between 'left', 'right' or 'either' hand was used in the current study.

A related issue is how instructions are given to participants when filling out the questionnaire. McMeekan and Lishman (1975) examined the test–retest reliabilities of the Edinburgh and Annett inventories and found a significant, but somewhat disappointing, reliability score around .8. The relationship between the different handedness inventories was also less than perfect. Although a number of problems were discussed, one concern revolved around the issue of 'either' responses, which may have been affected by task instructions specific to each questionnaire (also see Williams, 1991). In addition to variance between tests, the proportion of 'either' response might have been affected by individual differences. Bryden (1977) administered the Crovitz and Zener (1962) test of hand preference, in addition to the Edinburgh inventory. In line with meta-analyses of the literature (Papadatou-Pastou et al., 2008), males had lower handedness scores than females. Bryden (1977) noted, however, that this effect of sex was primarily driven by a higher number of 'either' responses among males compared to females. Whether this ambidextrality in males is driven by a physiological mechanism related to cerebral dominance or simply reflected a personality trait whereby males had a proclivity for claiming that they 'could do it with both hands' is a matter for debate. It is also noteworthy that Annett (1970) observed differences in the frequency of 'either' responses, whereby undergraduates were more likely to respond 'either' compared to military recruits. In view of the problems associated with the interpretation of participants' 'either' responses, the current study attempted to reduce uncertainty by making a specific statement in relation to 'either' responses. Participants were asked to tick the 'either' box only when 'one hand is truly no better than the other'. While it was anticipated that this instruction would reduce the number of 'either' responses, it was also hoped that an 'either' response would become a more meaningful indication of the person's laterality.

Another issue is related to what factors are measured by the test. Factor analyses of longer handedness questionnaires have revealed solutions with multiple levels (Liederman and Healey, 1986). For example, Steenhuis and Bryden (1989) conducted a factor analysis on responses to 60- and 33-item handedness questionnaires. The first factor was associated with what Steenhuis and Bryden called 'skilled activities' and accounted for 41–50% of the variance. Steenhuis and Bryden (1989) defined skilled activities as those that involved the use of tools and manipulation of other objects. These skilled activities might have involved the "need to execute a relatively complex sequence of motor behaviours" (Steenhuis and Bryden, 1989, p. 299). The concept of skilled hand performance most likely overlapped with other concepts, such as 'dextrousness' (Jones, 1909) and praxis (Corballis, 2003). The second and third factors accounted for a much smaller amount of variance (<7%) and were associated with non-skilled activities. Finally, a fourth factor, which accounted for less than 4% of the variance, was associated with bimanual activities.

While Steenhuis and Bryden (1989) clearly showed that handedness was a multifactorial construct, it is possible that some factors may be of more interest to researchers in cognition and neuroscience. In particular, skilled hand performance may be the best indicator of cerebral dominance for language. The link between language and movement was investigated by Meador et al. (1999), who anaesthetised the left and right hemispheres using an intracarotid amobarbital procedure. For individuals with left hemisphere language lateralisation, more errors occurred for a pantomiming task when the left hemisphere was anaesthetised. Conversely, for individuals with atypical language lateralisation, more movement errors occurred when the right hemisphere was anaesthetised (also see Kimura, 1982). An impressive link between language lateralisation and praxis has been demonstrated by Vingerhoets et al. (2013). Using functional magnetic resonance imaging (fMRI), they showed that lateralisation for pantomimed tool use was very closely associated with lateralisation for language in a group of people with typical and atypical language lateralisation. Evolutionary theories examining the relation between handedness and language have also suggested that the development of fine motor skills in the left hemisphere was an important precursor to the evolution of left hemisphere language (Bradshaw and Nettleton, 1982; Corballis, 2003). Given the link between skilled hand preference and cerebral lateralisation, the present study used factor analysis to identify a cluster of items that specifically tap this skill.

A final problem with many tests of hand preference is that they are becoming old [see Dragovic and Hammond (2007) for a discussion of this issue]. A good example is the Provins and Cunliffe (1972) questionnaire which asked: "which hand do you use to wind a clock". While winding a clock may have been an everyday activity in the 1970s, the new generation would find this task anachronistic. The Waterloo inventory also asked about the hand used to wind a stopwatch. The shorter questionnaires, such as the Edinburgh and Annett tests, asked about more generic activities, which were less prone to becoming obsolete. Nevertheless, the Edinburgh inventory is 40 years old and has also been criticised for this reason (Fazio et al., 2012). The current study used factor analysis to identify items with high item/total correlations. If respondents found a particular item difficult to understand or anachronistic, this item would have had too much variability to remain in the final items identified by the factor analysis.

The present study reports on a revised version of the Provins and Cunliffe (1972) questionnaire, which made use of the advantages of the test, while also addressing the disadvantages. In the present study, the original questionnaire, with its easy-to-understand response format, was given to over 3300 respondents. Factor analysis was used to reduce the length of the questionnaire and to identify the ten items that loaded most heavily on skilled hand preference. These questions were then used to create the "Flinders Handedness Survey" (FLANDERS). Although the number of items used in the final questionnaire is relatively arbitrary, ten items were chosen because scores can easily be understood and converted into a quotient. The aim was to develop a test with good psychometric properties and high construct validity. To test the convergent validity of the new test, correlations were performed with other measures of laterality, including foot, eye and ear preference as well as a behavioural measure of hand performance. Construct validity was evaluated by assessing the effect of sex and paternal/maternal handedness on the FLANDERS. By evaluating the effect of these factors, we were able to gauge the validity of the test and also provide normative data.

2. Method

Participants. Complete data sets were collected from 3324 psychology students as part of their undergraduate teaching programme. There were 2570 females and 754 males born between 1946 and 1988. Testing was carried out over a period of 10 years between 1996 and 2006. The modal age of participants was 20 years and 75% of participants fell within an age range of 18–22 years of age. The students were drawn from a broad background, and while most were of European descent, there were also many people of an Asian descent. Participants gave informed consent and the study was approved by the Human Research Ethics Committee at the University of Melbourne.

Questionnaires and procedure. Participants completed the forms and other tests in a class-room setting. Year of birth and sex were assessed first. Hand preference was then assessed using the 31-item questionnaire devised by Provins and Cunliffe (1972); see Table 1 for the questions contained in this questionnaire. For each question, participants indicated whether they used their (a) left hand (b) either hand or (c) right hand.

Participants were told to tick the 'either' box only if one hand was truly no better than the other. They were also told that some of the items were a little obscure and that they should imagine doing the task before deciding which hand they preferred. Inspection of Table 1 reveals that seven items in the test asked for the non-dominant hand to be identified in a bimanual task (Qs 7, 10, 15, 19, 22, 26, 30). Foot, eye and ear preference were measured using the questions devised by Porac and Coren (1981); see Table 2. Like the hand preference questionnaire, participants indicated whether they preferred the (a) left-, (b) either- or (c) right-side.

Familial handedness was assessed by asking participants to indicate the hand that their biological father or mother used for writing. Response choices were: (a) left hand, (b) right hand, (c) either hand and (d) don't know. Hand performance was measured using a small hand-held digital/mechanical counter, which was mounted on a small block of wood. Pushing a button located on the top of the counter caused the digital display to increase by one value. Participants were asked to place the counter immediately in front of them on a table and tap as fast as they could, using their index finger. Half of the participants started with their left hand, while the other half started with their right hand. The number of taps produced by the hands within a 30 s period was counted.

3. Results and discussion

3.1. Item responses

Percentage responses of 'left', 'either' and 'right' to each of the 31 items contained in the Provins and Cunliffe (1972) questionnaire are shown in Table 1. To compare response rates with an existing questionnaire with a similar response format, the nine questions that overlapped with those used by Annett (1970) were selected. Although the wording was slightly different between questionnaires, the underlying motor activity was the same. Percentage response rates for the data collected by Annett (1970) are shown in Table 1. For the current study, the average percentage of 'left', 'either' and 'right' responses was 9.72%, 1.33% and 88.95%. For the Annett (1970) study, the proportion of 'left', 'either' and 'right' responses was 10.68%, 5.72% and 83.60%, respectively.

The data therefore indicate that, while the number of left responses was roughly equivalent, the number of mixed-responses was reduced in the current study. This low level of 'either' responses was most likely related to the test instructions. In the introduction, it was argued that participants have often misunderstood when to use an 'either' response and this could have led to variability between tests and

Please cite this article in press as: Nicholls MER, et al., The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference, Cortex (2013), http://dx.doi.org/10.1016/j.cortex.2013.02.002

Table 1 – Proportions within each of the response categories for the current study using the Provins and Cunliffe (1972) questionnaire. Note that questions 7, 10, 15, 19, 22, 26 and 30 ask for the non-dominant hand. For questions similar to those used in the Annett questionnaire, the response proportions collected by Annett (1970) are shown.

	Hand preference item	Current study			Annett		
		% Left	% Either	% Right	% Left	% Either	% Right
1	With which hand do you write?	10.0	.1	89.9	10.6	.3	89.1
2	In which hand do you prefer to use a spoon when eating?	10.1	1.8	88.1			
3	With which hand do you throw a ball?	7.5	2.0	90.5	9.4	1.3	89.3
4	In which hand do you prefer to hold a toothbrush when cleaning your teeth?	10.2	2.3	87.5	9.2	8.5	82.3
5	In which hand do you hold a tennis racquet?	7.7	1.6	90.8	8.1	2.6	89.3
6	If both hands were free, which hand would you use to put a key into a keyhole?	6.9	2.4	90.7			
7	In which hand do you hold the box when striking a match?	89.4	1.1	9.5	9.9	8.7	81.4
8	When cutting paper, in which hand do you hold the scissors?	6.6	.8	92.6	6.2	6.8	87.0
9	With which hand do you hold a penknife when sharpening a pencil?	14.6	1.1	84.3			
10	In which hand do you prefer to hold the pack when dealing cards?	86.2	1.3	12.5	17.0	3.3	79.7
11	In which hand do you prefer to hold the rubber when erasing a pencil mark?	10.0	1.3	88.7			
12	In which hand do you hold the needle when you are sewing?	9.3	.6	90.1			
13	When pinning a notice to a notice board, which hand presses in the drawing pin?	8.8	6.4	84.8			
14	With which hand do you prefer to turn a tap?	6.5	11.2	82.4			
15	When washing dishes, in which hand do you prefer to hold the dish?	88.0	2.3	9.7			
16	When pouring tea, in which hand do you prefer to hold the pot?	8.6	2.8	88.7			
17	With which hand do you use a comb?	7.7	6.1	86.2			
18	With which hand do you adjust a window blind?	7.1	12.4	80.6			
19	When buttering bread, which hand holds the bread?	89.9	.6	9.5			
20	Which hand do you use to wind a clock?	5.8	2.2	92.0			
21	In which hand do you prefer to carry a suitcase?	10.3	17.9	71.8			
22	In which hand do you prefer to hold the jar when unscrewing the lid?	82.7	2.2	15.1	16.5	17.5	66.0
23	With which hand do you put a plug into the power point?	7.2	10.4	82.4			
24	In which hand do you hold a hammer?	8.4	.6	91.0	9.2	2.5	88.3
25	In which hand do you carry or pass a glass full of water?	8.0	13.5	78.5			
26	In which hand do you hold an apple when you peel it?	90.4	.6	9.0			
27	Which hand do you prefer to use when removing an object from a high shelf?	7.9	8.2	83.9			
28	Which hand do you use to draw?	10.1	.5	89.4			
29	If catching a ball with one hand, which hand would you use?	9.1	9.0	81.9			
30	With which hand do you hold the implement steady when using a hand rotary beater or hand drill?	84.5	1.2	14.3			
31	When feeling material to determine its texture or thickness, which hand would you use?	8.5	15.9	75.6			

individuals. To reduce the noise associated with 'either' responses, the current study asked participants to respond 'either' only if 'one hand is truly no better than the other'. In contrast, the Annett (1970) inventory gave no specific instructions in relation to 'either' responses. It was therefore up to participants to interpret how to respond and this most probably resulted in a higher number of 'either' responses in the Annett (1970) data.

While the current study yielded a lower average proportion of 'either' responses compared to the Annett (1970) study, there were some items that were consistent across the studies. Inspection of Table 1 reveals that the proportions of left, either and right responses for writing hand was almost identical across the studies. Williams (1991) also demonstrated that the number of 'either' responses for writing hand in the Edinburgh and Annett inventories was only just above zero. Thus, when 'either' responses were minimised, the data collected in the current study resembled the data collected in other studies (e.g., Annett, 1970; Williams, 1991). It therefore appears that the university sample used in the current study was comparable to other studies in terms of the direction of hand preference. Differences seem to arise, however, when task instructions affect the proportion of 'either' responses.

Another interesting feature of the current data was the increased rate of 'right' responses compared to the Annett (1970) data. Given that the number of 'left' responses was roughly equivalent between the tests, there seems to have been a shift between 'either' and 'right' responses. While it should be acknowledged that comparisons were made between different questionnaires and test populations, it does appear that 'either' responses were more likely to be changed to 'right' responses. This may be relevant to how people with an intermediate hand preference were classified. For example, Peters and Murphy (1992) referred to individuals with an intermediate hand preference as 'inconsistent left'. The current data suggest that some of the people in this cluster were, in actual fact, inconsistent right responders.

Table 2 – Items used to assess foot, eye and ear preference. Adopted from Coren et al. (1979).

Foot preference
1) With which foot do you kick a football?
2) If you had to step up on a chair, which foot would you place on the chair first?
3) If you wanted to pick up a pebble with your toes, which foot would you use?

Eye preference
1) Which eye do you use to peep through a keyhole?
2) If you had to look into a dark bottle to see how full it was, which eye would you use?
3) Which eye would you use to sight down a rifle?

Ear preference
1) If you wanted to listen to a conversation behind a closed door, which ear would you place against the door?
2) If you wanted to hear someone's heart-beat, which ear would you place against the person's chest?
3) Into which ear would you place the earphone of a transistor radio?

3.2. *Factor analysis*

The hand preference data were subjected to a principal components factor analysis. A varimax rotation procedure was used with the critical Eigenvalue for inclusion set at 1.0. The analysis produced two significant factors (see Table 3).

The first had an Eigenvalue of 19.95, which accounted for 64.36% of the variance in the total test. Questions that loaded particularly heavily on this factor included items relating to the hand used to write, draw and sew. This factor was similar to the one identified by Steenhuis and Bryden (1989), who performed a factor analysis. Their first factor, which accounted for over 40% of the variance, included items related to writing, drawing and using a hammer.

The second factor had a much smaller Eigenvalue of 1.23 and only accounted for 3.97% of the variance. Questions that loaded heavily on this factor included items relating to the hand used to turn a tap or push a plug into a power point. Tasks of this kind are similar to those identified by Steenhuis and Bryden (1989) in their second and third factors. These factors, which accounted for 4–7% of the variance in their study, included items relating to lifting a variety of objects. It appears that these questions related to less-skilled activities, which are also less lateralised.

After examining the loadings of the different items and the contributions made by the factors, we decided to use the items with the best loadings on the first factor in the FLANDERS. These items, which are highlighted in Table 3, had loadings on the first factor ranging from .878 (Q 1. Writing hand) to .778 (Q 26. Peeling an apple). All of the items appeared to tap functions related to skilled hand performance. As such, the items should effectively discriminate between left- and right-handers (Steenhuis and Bryden, 1989). In addition, the skilled activities appeared to involve sequential, praxic activities, which are associated with a left hemisphere control system (Kimura, 1982) and may be associated with the lateralisation of other functions, like language (Bradshaw and Nettleton, 1982; Corballis, 2003; Meador et al., 1999).

3.3. *The FLANDERS hand preference scale*

The item/total correlations for the 10 items selected for the new questionnaire are shown in Table 3. As can be seen, there was a very high level of correlation between the items, suggesting they were measuring the same construct. A split-half reliability analysis revealed a very high level of reliability (Cronbach's alpha = .96). The fact that all items loaded heavily on the one construct and were reliable suggests that the items asked questions that participants readily understand. As such, items that participants found anachronistic or difficult to understand in the original questionnaire would have been removed.

Like the Provins and Cunliffe (1972) questionnaire, a measure of hand preference was calculated by assigning values of −1, 0 and +1 to responses of left, either and right (respectively) and then summing the scores. Scores therefore ranged from −10 to +10 in steps of one unit. The scores obtained for the 3324 respondents for the revised 10-item scale are shown in Fig. 1. As has been found previously for short handedness questionnaires (Peters, 1992), the data could be described with a bimodal distribution with peaks for extreme left- and right-handedness ('J' shaped curve). The graph also shows a clear majority of right-handers.

3.4. *Handedness categories*

Despite the research showing hand preference has been best construed as a continuous variable (Annett, 1970; Beaton, 2003), the issue of categorising an individual's hand preference has inevitably emerged. A number of issues have arisen when categorising hand preference. The first related to the categories that were used. Individuals could simply be described along a dichotomous dimension as either 'left-handed' or 'right-handed'. Alternatively, a third dimension could be introduced of 'mixed-handed' and this classification was sometimes combined with left-handedness to form a grouping of 'non-right-handed'.

Research has indicated that people without a strong preference for either the left or right hand (i.e., mixed-handed) have a number of special characteristics in their own right. For example, Crow (1997) suggested that strong cerebral dominance was needed to establish normal language function and avoid a propensity for schizophrenia. Similarly, Nicholls et al. (2005) have demonstrated higher levels of schizotypical behaviour in mixed-handers (also see Bryson et al., 2009; Chapman et al., 2011). A three-level categorisation of handedness (left, mixed and right) has also been used in recent evaluations of the Edinburgh inventory (Dragovic, 2004). With this in mind, a three-level categorisation of left-, mixed- and right-handed was used in the current study.

The issue of where to place the boundary between the handedness categories is also complex and could significantly influence the relative proportions of left-, mixed- and right-handers (Peters, 1992). Using a liberal criterion, left- or right-handers would be defined as anyone with a positive or negative handedness score (50% criterion). At the other extreme, someone would be deemed to be left- or right-handed only when they do everything with their left or right hand. Using this sort of classification, Annett (1970) found the proportions of left-, mixed- and right-handers were 4.2%, 28.6% and 67.2%,

Table 3 – Results of item analyses for the original Provins and Cunliffe (1972) and the revised (FLANDERS) hand preference questionnaires. The items with the 10 highest loadings on the first factor are highlighted. Item/total correlations for these ten items are shown.

	Hand preference item	1st Factor	2nd Factor	Item/total correlation
1	With which hand do you write?	.878	.352	.945
2	In which hand do you prefer to use a spoon when eating?	.829	.378	.903
3	With which hand do you throw a ball?	.663	.553	
4	In which hand do you prefer to hold a toothbrush when cleaning your teeth?	.799	.389	.873
5	In which hand do you hold a tennis racquet?	.713	.513	
6	If both hands were free, which hand would you use to put a key into a keyhole?	.588	.555	
7	In which hand do you hold the box when striking a match?	.779	.416	.855
8	When cutting paper, in which hand do you hold the scissors?	.719	.433	
9	With which hand do you hold a penknife when sharpening a pencil?	.602	.303	
10	In which hand do you prefer to hold the pack when dealing cards?	.533	.449	
11	In which hand do you prefer to hold the rubber when erasing a pencil mark?	.836	.408	.926
12	In which hand do you hold the needle when you are sewing?	.854	.416	.939
13	When pinning a notice to a notice board, which hand presses in the drawing pin?	.517	.639	
14	With which hand do you prefer to turn a tap?	.294	.718	
15	When washing dishes, in which hand do you prefer to hold the dish?	.704	.460	
16	When pouring tea, in which hand do you prefer to hold the pot?	.625	.520	
17	With which hand do you use a comb?	.719	.522	
18	With which hand do you adjust a window blind?	.406	.668	
19	When buttering bread, which hand holds the bread?	.824	.418	.911
20	Which hand do you use to wind a clock?	.491	.611	
21	In which hand do you prefer to carry a suitcase?	.155	.672	
22	In which hand do you prefer to hold the jar when unscrewing the lid?	.236	.460	
23	With which hand do you put a plug into the power point?	.464	.673	
24	In which hand do you hold a hammer?	.806	.482	.915
25	In which hand do you carry or pass a glass full of water?	.450	.655	
26	In which hand do you hold an apple when you peel it?	.778	.445	.872
27	Which hand do you prefer to use when removing an object from a high shelf?	.496	.668	
28	Which hand do you use to draw?	.872	.358	.942
29	If catching a ball with one hand, which hand would you use?	.435	.623	
30	With which hand do you hold the implement steady when using a hand rotary beater or hand drill?	.444	.384	
31	When feeling material to determine its texture or thickness, which hand would you use?	.385	.638	

respectively. If a similar extreme classification were applied to the current sample, the proportions of left-, mixed- and right-handers were 6%, 13.9% and 80.1%, respectively. Thus, as with responses to individual items, the FLANDERS appears to be producing fewer mixed-handers than previous questionnaires. Also, as with the item response data, this shift appears to be happening mostly at the expense of right-handers. The most likely explanation for the low rate of mixed-handers identified by the current study was the task instructions, which encouraged participants to respond 'either' only when there was truly no difference between the hands.

While handedness could be categorised using predefined boundaries or by 'eye-balling' the data, the current study used a more parsimonious approach generated by the data itself. To this end, a K-means cluster analysis was used to identify groups of left-, mixed- and right-handers within the FLANDERS. The first cluster (left-handers) included 280 individuals (8.3% of the total), with scores ranging from −10 to −5. The second cluster (mixed-handers) included 70 individuals (2.2% of the total), with scores ranging from −4 to +4. Compared to other handedness inventories (Annett, 1970; Oldfield, 1971; Steenhuis and Bryden, 1989), the proportion of mixed-handers was low. By tightening the criteria for 'either' responses, however, we hoped that the mixed-handers identified by the FLANDERS would be a more meaningful category of respondents. Finally, the third cluster (right-handers) comprised 2974 individuals (89.5% of the total) with scores ranging from +5 to +10. The finding that 89.5% of the sample was right-handed ties in well with the general consensus that 90% of the current-day population is right-handed (McManus and Hartigan, 2007). The boundaries between the categories can be seen in Fig. 1.

3.5. *Foot, eye and ear preference*

Responses were scored as −1, 0 and +1 for left, either and right responses, respectively. Individual items were summed to produce a score that ranged from −3 to +3. Negative scores

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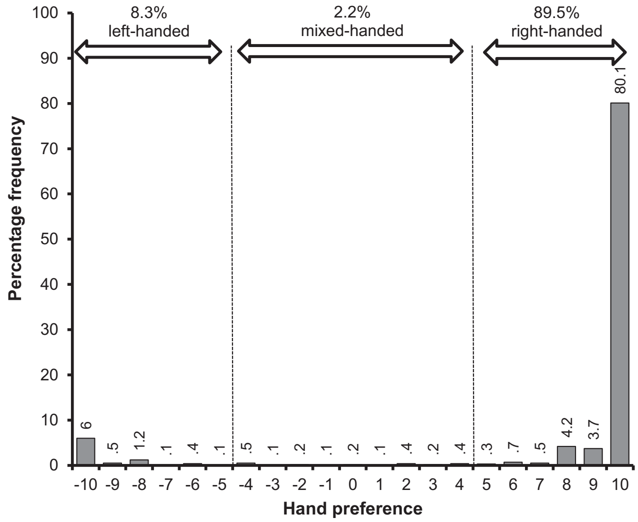

Fig. 1 – Graph showing percentage frequency of scores for the FLANDERS handedness questionnaire for all participants (n = 3324). Values corresponding to each of the possible scores are shown above each column. The data were categorised as left-, mixed- or right-handed according to the cluster analysis (see text).

indicated a left preference whereas positive scores indicated a right preference. The data are shown in Fig. 2.

Like the hand preference data, there was a clear bimodal pattern to the data, where responses were clustered towards extreme left or right preferences. Using the classification system employed by Porac and Coren (1981), individuals were deemed to have a rightward preference if their score was above zero (see Fig. 2). Porac and Coren reported a rightward preference of 81.0% for the feet, 71.1% for the eyes and 59.4%

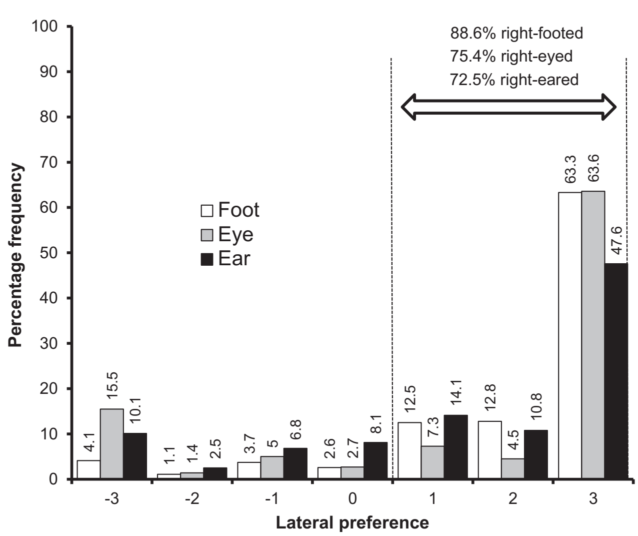

Fig. 2 – Graph showing percentage frequency of scores for the foot, eye and ear preference scores for all participants (n = 3324). Values corresponding to each of the possible scores are shown above each column. Individuals were classified as right-footed, -eyed or -eared using the criterion used by Porac and Coren (1981).

for the ears. As can be seen in Fig. 2, the general pattern across modalities was similar in the present study, with the strongest right preference for the feet and the weakest for the ears. The rightward preference observed appeared to be generally stronger in the current study compared to Porac and Coren (1981). Given that participants completed the handedness questionnaire first, it is possible that the instructions from the handedness questionnaire generalised to the other measure of lateral preference. Thus, like the hand preference data, restrictions related to ‘either’ responses may have inflated the number of individuals with a very strong right preference.

3.6. *Hand performance*

Raw tapping scores were analysed with a mixed model analysis of variance (ANOVA) with hand (left, right) as a within participants factor and sex (male, female) as a between-subjects factor. More taps were produced by the right hand ($\bar{x} = 181.3$) than the left hand ($\bar{x} = 155.7$) [F (1,3322) = 2141.6, $p < .001$] and by males ($\bar{x} = 177.5$) compared to females ($\bar{x} = 159.5$) [F (1,3322) = 382.4, $p < .001$]. The right hand advantage was consistent across the sexes [F (1,3322) < 1].

A measure of relative ability to tap was calculated by subtracting the number of taps produced by the left hand from the number produced by the right hand. This difference score was then divided by the total number of taps produced by both hands and converted to a percentage. Possible scores therefore ranged from −100 to +100, with negative and positive scores indicating a left- and right-hand advantage, respectively.

To examine the association of hand performance with each of the questions from the original 31-item inventory (Provins and Cunliffe, 1972), a series of 31 correlations were calculated between an individual’s response on the item (−1, 0 or +1) and their hand performance (ranging between −100 and +100). Pearson correlation values ranged between .456 (writing hand) and .235 (carrying a suitcase). What was most remarkable, however, was that the 10 items that had the highest correlation with hand performance were also the ten items identified using factor analysis for inclusion in the FLANDERS. Correlations for items included in the FLANDERS ranged from .456 to .409 with a mean of .431. In contrast, correlations for items excluded from the FLANDERS ranged from .406 to .235 with a mean of .340. It was therefore evident that, even though hand performance played no part in the factor analysis and the selection of the ten items in the FLANDERS, it was nevertheless strongly associated with these hand preference items. These results confirmed the idea that the FLANDERS taps skilled hand performance, which is related to the execution of movement sequences.

The relationship between mean hand performance and scores on the FLANDERS was explored in two ways. First the association between hand performance and each of the possible 21 scores (from −10 through 0 to +10) for the FLANDERS was investigated. Scores ranging between −10 and +10 were plotted against mean hand performance (see Fig. 3).

As can be seen, there was a shift from negative hand performance scores (i.e., the left hand taps more) at hand preference values of −10 to positive hand performance scores (i.e., the right hand taps more) at hand preference values of +10. The linear regression reveals a cross-over between negative

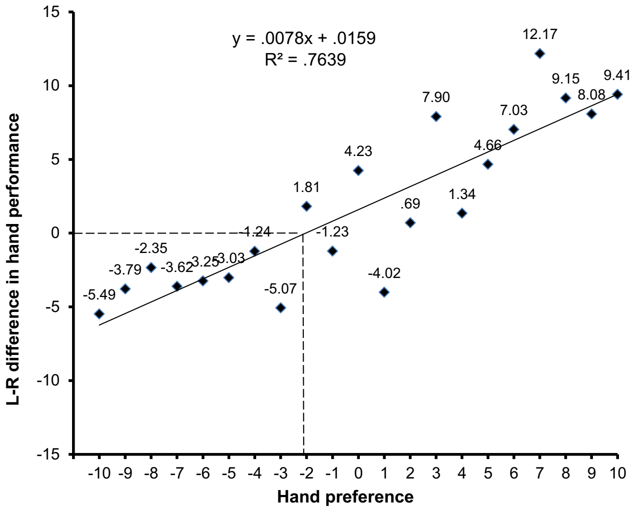

Fig. 3 – Graph showing mean hand performance scores within each of the hand preference scores (ranging between −10 and +10). Mean hand performance scores are displayed on the graph with negative and positive scores indicating more taps with the left and right hands, respectively. The best fitting linear regression line is shown together with the formula and R^2 value. The dotted line indicates the hand preference score corresponding to a hand performance score of zero.

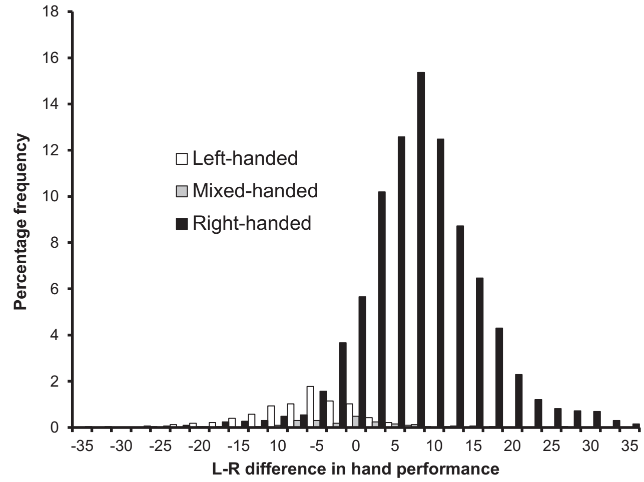

Fig. 4 – Graph showing percentage frequency of hand performance scores for individuals categorised as left-, mixed- or right-handed using the FLANDERS.

and positive hand performance scores occurred around hand preference scores of −2 (see Fig. 3). This asymmetry was most probably driven by a stronger right-hand advantage in dextrals compared with the left-hand advantage in sinistrals. There was some noise along intermediate values of hand preference, which was most likely caused by the small number of individuals within some of the mixed hand preference scores. Peters and Durding (1978) examined the relationship between finger tapping and a seven-item test of hand preference. Their results were very similar to those reported in the current study and showed a linear relation between preference and performance together with a smaller performance asymmetry for left- compared to right-handers (see also: Triggs et al., 2000).

The relationship between mean hand performance and preference was also explored by examining hand performance within each of the hand preference categories (left-, mixed- and right-handed). A histogram showing the spread of scores for left-, mixed- and right-handers is shown in Fig. 4.

Overall, the data showed a unimodal distribution, which would be expected for a measure of tapping asymmetry between the hands (Corey et al., 2001). Examination of the different hand preference groups within the distribution revealed a series of unimodal, overlapping distributions. Performance for left-handers was shifted to the left of zero (mean = −4.77), whereas right-handers were shifted to the right of zero (mean = 9.31). Mixed-handers had scores that were intermediate between left- and right-handers (mean = .02).

Discriminant function analyses tested how well hand performance predicted membership within the FLANDERS hand preference categories (left, mixed, right). There was a significant relationship between hand performance and hand preference category [Wilks' Lambda = .78, χ^2 (2) = 803.92, $p < .001$]. Individuals were assigned to the correct category 72.4% of the time. Correct classification rates for left-, mixed- and right-handers were 68.2%, 45.7% and 73.4%, respectively. Given the relatively low number of correct classifications for mixed-handers, the discriminant function analysis was repeated with mixed-handers removed. The hand performance data showed a strong ability to predict whether the individual was classified as left- or right-handed [Wilks' Lambda = .79, χ^2 (2) = 752.05, $p < .001$]. Individuals were assigned to the correct category 86.5% of the time. Correct classification rates for left- and right-handers were 88.6% and 86.3%, respectively. The association between performance asymmetry and membership within hand preference categories resembled the data collected by Corey et al. (2001). They found that a composite measure of hand performance (tapping and peg moving) correctly classified individuals into left- and right-handed categories on 90% of occasions. It therefore appears that both the new FLANDERS test and the measure of tapping asymmetry provided a good indication of the underlying construct related to skilled hand activities.

3.7. *Sex differences*

Table 4 shows the proportion of individuals classified as left-, mixed- or right-handed as a function of sex.

The data showed that females were more likely to be classified as right-handed than males, but were less likely to be classified as left- or mixed-handed. A chi-squared test

Table 4 – Percentage proportion of left-, mixed- and right-handers within each of the sexes.

	Left-handers	Mixed-handers	Right-handers
Male	9.4%	3.3%	87.3%
Female	8.1%	1.8%	90.1%

Please cite this article in press as: Nicholls MER, et al., The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference, Cortex (2013), http://dx.doi.org/10.1016/j.cortex.2013.02.002

Table 5 – Sex differences for all measures of laterality and the results of independent samples *t*-tests. For all *t*-tests, the df was 3322.

		Sex	*n*	Mean	SD	*t*	*p*
Relative	Hand preference	F	2570	8.118	5.306	1.87	.061
		M	754	7.715	5.698		
	Foot preference	F	2570	2.173	1.518	5.31	.001
		M	754	1.834	1.606		
	Eye preference	F	2570	1.559	2.280	1.50	.133
		M	754	1.417	2.231		
	Ear preference	F	2570	1.475	1.926	5.87	.001
		M	754	.986	2.156		
	Hand performance	F	2570	.081	.087	2.49	.013
		M	754	.072	.086		
Absolute	Hand preference	F	2570	9.619	1.227	2.57	.010
		M	754	9.468	1.519		
	Foot preference	F	2570	2.525	.806	8.15	.001
		M	754	2.240	.962		
	Eye preference	F	2570	2.652	.770	4.93	.001
		M	754	2.489	.886		
	Ear preference	F	2570	2.236	1.012	3.16	.002
		M	754	2.100	1.098		
	Hand performance	F	2570	.098	.067	2.07	.039
		M	754	.092	.064		

confirmed sex differences in membership within the different hand preference categories [χ^2 (2) = 8.44, $p < .05$]. The finding that roughly 90% of female respondents were right-handed and that this proportion dropped to 87% for males was consistent with other reports on sex differences in handedness (Papadatou-Pastou et al., 2008).

Mean differences between men and women for all measures of relative and absolute laterality are shown in Table 5.

For relative laterality, there was a tendency for females to have scores shifted towards higher (more rightward) scores compared to males. This difference was significant for foot preference, ear preference and hand performance, but failed to reach statistical significance for hand preference. The lack of effect for hand preference was surprising given the reports of other studies (Beaton, 2003) and that the categorical analysis showed females were more likely to be classified as right-handed. However, sex differences in hand preference were not always found (Williams, 1991) and were often not statistically significant (Bryden, 1977). A number of factors may have contributed to the discrepancy. First, as noted by Bryden (1977), sex differences in hand preference could be driven by more 'either' responses from males compared to females. Given that the FLANDERS discourages erroneous 'either' responses, it may also have reduced sex differences in the degree of hand preference. Second, a sex difference in hand skill (irrespective of hand) has appeared to depend upon the object being manipulated and the type of movement (Peters and Campagnaro, 1996). The discrepancy may therefore also depend on the range of tasks indexed by the handedness questionnaire.

No sex difference was observed for relative eye preference. It seems that eye preference may not show the typical pattern whereby females have a stronger rightward preference. Indeed, data collected by Porac and Coren (1981) showed that males had a stronger preference for their right eye compared to females – the opposite of what might have been predicted.

The strength of lateral preference, as opposed to the direction, is a potentially significant factor in laterality research (Crow, 1997). To investigate whether the sexes differed in relation to the degree of lateral preference, the sign was removed from the scores to produce an absolute measure (see Table 5). Consistent with other reports (Porac and Coren, 1981), females had stronger asymmetries for all measures of laterality.

The FLANDERS therefore appears to behave like many other tests of lateral preference. It shows a higher prevalence of non-right-handedness in males, though this was not reflected in mean hand preference scores. Males, however, did show a weaker hand preference irrespective of side compared to females. The fact that the FLANDERS was affected by sex, which is known to affect handedness (Papadatou-Pastou et al., 2008) and functional lateralisation in the brain (Kansaku et al., 2000), suggested that the test provides a good measure of a construct related to skilled hand performance. The data are also consistent with Annett's (1985, 2002) proposal that handedness is related to a 'right shift' gene, which is expressed more strongly in women.

3.8. *Correlations*

The association between all measures of lateral preference and performance was examined using Pearson product-moment correlations. The correlation matrix, together with the *r* and *p* values, is shown in Table 6.

Consistent with previous reports (Porac and Coren, 1981), there was a strong correlation between the different measures of lateral preference. Like Porac and Coren (1981), the strongest correlation was between hand and foot preference and one of the weakest was between hand and ear preference. The correlation between the FLANDERS and other measures of laterality suggests a common mechanism plays a role in

Table 6 – Correlation matrix showing Pearson *r* scores and *p* values between measures of laterality. For all cases df = 3323.

	Hand preference	Foot preference	Ear preference	Eye preference
Foot preference	$r = .659$ $p < .001$			
Ear preference	$r = .385$ $p < .001$	$r = .457$ $p < .001$		
Eye preference	$r = .377$ $p < .001$	$r = .346$ $p < .001$	$r = .322$ $p < .001$	
Hand performance	$r = .465$ $p < .001$	$r = .343$ $p < .001$	$r = .206$ $p < .001$	$r = .190$ $p < .001$

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Table 7 – Mean hand preference and handedness classification for children born to left- or right-handed mothers and fathers.

			Father's handedness	
			Left	Right
Mother's handedness	Left	Mean hand preference (*n*)	2.38 (26)	6.18 (203)
		% Left-handed	34.6	15.8
		% Mixed-handed	7.7	4.4
		% Right-handed	57.7	79.8
	Right	Mean hand preference (*n*)	7.60 (241)	8.21 (2609)
		% Left-handed	10.4	7.8
		% Mixed-handed	2.1	1.8
		% Right-handed	87.5	90.4

lateral preference – possibly related to the right shift mechanism proposed by Annett (1985, 2002). That said, variations in the level of correlation also suggest that factors specifically related to each of the modalities play a role.

3.9. Parental handedness

Individuals who indicated that they did not know the hand preference of one or either parent were removed from the analysis. Relatively few participants indicated that their father or mother could use either hand to write ($n = 69$ and 44, respectively). Because of the small numbers in these 'either' categories, these individuals were also removed. After these exclusions, 3079 respondents remained in the sample ($m = 692$, $f = 2387$).

An ANOVA was conducted on responses to the FLANDERS questionnaire with paternal (left, right) and maternal (left, right) handedness as between-subjects factors. There were strong effects of paternal [F (1,3074) = 13.47, $p = .001$] and maternal [F (1,3074) = 36.52, $p < .001$] handedness whereby the mean FLANDERS score was lower for children born to left-handed parents (see Table 7).

In addition, there was an interaction between paternal and maternal handedness [F (1,3074) = 7.06, $p = .008$], indicating that paternal handedness had a weaker effect on the child's hand preference than maternal handedness. Analysis of mean FLANDERS scores was borne out by an examination of the distribution across hand preference categories (see Table 7). The chance of an offspring being left-handed was 34.6% if both parents were left-handed. The chance of an offspring being left-handed fell to 7.8% if both parents were right-handed. These proportions resemble those reported for two left-handed (26.1%) and two right-handed (9.5%) parents by McManus and Bryden (1992).

The strong effect of parental handedness on an offspring's hand preference most likely reflects the genetic inheritance of handedness (Beaton, 2003; Corballis, 1997; Medland et al., 2009). The genetic transfer of handedness may have involved the action of dominant and recessive genes/alleles, which code for dextrality and chance hand preference (Annett, 1985, 2002; McManus, 1985). Although handedness is undoubtedly the product of an interaction between many genes, recent work has focused on whether the gene *LRRTM1* on chromosome 2p12 plays a particularly important role in determining handedness (see Francks et al., 2007). The importance of this gene, however, is strongly contested (see Crow et al., 2009; Francks, 2009).

Examination of the mean handedness scores and the categorical data both showed that maternal handedness had a stronger influence on the child's handedness than paternal handedness. A stronger effect of maternal handedness has been reported before (McManus and Bryden, 1992) and may reflect a sex-linked genetic effect (Corballis, 1997; Francks et al., 2007) possibly to the X chromosome (Jones and Martin, 2001; McManus and Bryden, 1992). As an alternative, Annett (2008) has suggested that the maternal/paternal difference may be related to a Carter (1961) effect whereby characteristics which were expressed less frequently in females (left-handedness) were expressed more frequently in their offspring. While it is highly likely that genes played a role in the maternal/paternal effect, environmental and social factors may have also played a role (Provins, 1997). Closer contact between the mother and the offspring compared to the father and offspring could therefore not be discounted. Finally, there was also the issue of parental certainty. The mother is almost always known whereas the 'father' may not be the biological father. This uncertainly would add noise to the relationship between fathers' handedness and their offspring.

4. Conclusion

This study developed a new, shortened test of skilled hand performance based on data collected from the original Provins and Cunliffe (1972) handedness inventory. Factor analysis of the original handedness inventory revealed a strong component related to skilled hand use. The ten items that loaded most heavily on this factor were then used in the FLANDERS. Serendipitously, these ten items were also the same items that had the best correlation with hand performance, as measured by tapping speed. The FLANDERS also showed a good association with other tests of lateral preference and scores were related to sex and familial handedness.

Analysis of the new test revealed that it performed very well. The test showed a typical bimodal distribution of scores and cluster analysis revealed three distinct groups: left-, mixed- and right-handers. The proportions of individuals who were classified as left- or right-handed matched established norms for left- and right-handers. Compared to other similar tests of hand preference, such as the Annett (1970) inventory, fewer individuals were classified as mixed-handed. In the introduction it was argued that 'either hand' responses were problematic for tests of hand preference and subject to idiosyncratic interpretations and biases. To overcome these biases, the FLANDERS asked participants to respond 'either' only when one hand is truly no better than the other. While it is likely that this response requirement reduced the number of mixed-handers, individuals identified within this category should be more likely to be truly mixed-handed.

The current study used a university student population to collect data and establish normative statistics. While there was a spread of ages, and students came from a number of socio-economic and ethnic backgrounds, the sample was inevitably biased towards Caucasian, middle-class, young adults. Although it is likely that hand preference is affected by culture (Fagard and Dahmen, 2004), the extent to which hand preference scores were affected is a matter of debate. For example, Medland et al. (2004) investigated responses to three measures of handedness in formal and non-formal cultures. Writing with the left hand, which is sensitive to cultural pressure, was clearly lower in the formal cultures. Responses to other items in the Annett inventory, which are less subject to cultural pressure, showed reduced cultural effects. It therefore appears that overall scores on a handedness inventory should only show a modest effect of culture. That said, the next step in the development of the FLANDERS will be to test a more representative sample to establish general norms.

There has been much discussion about the length of handedness inventories, the type of response format and their factorial structure (Healey et al., 1986; Peters, 1992; Steenhuis and Bryden, 1989). If the primary aim of a study is to investigate handedness as the chief phenomenon of interest, it is likely that a longer questionnaire with a wider response format is required. If the aim of the study, however, is to categorise left-, mixed- and right-handers for the purpose of identification or screening, then the FLANDERS will be ideal. It is easy for participants to understand, taps skilled hand performance and shows a good association with variables of interest. A copy of the FLANDERS is contained in the Appendix 1, together with a short set of instructions.

Acknowledgements

Thanks are extended to Alan Beaton for his helpful suggestions on an earlier version of this manuscript. Credit also goes to the left-handed cartoon character, who was the inspiration for the title of this new test.

Note for Appendix 1

Appendix 1 contains the questions used for the FLANDERS test. Note that items 4, 7 and 9 have been altered from the original questions used by Provins and Cunliffe (1972). In their original format, these questions asked for the less-skilled hand to be nominated in a bilateral task. Although reversing questions within a questionnaire can discourage repetitive and/or acquiescent responses (Ray, 1979), there are also disadvantages. For one, the test is slightly more complicated to score. Additionally, the questions themselves can be harder for the participant to understand (Swain et al., 2008). Bearing these considerations in mind, all of the questions asked for the skilled hand. Instructions to the participants are given at the top of the questionnaire together with some questions relating to basic demographic data. Responses of 'left', 'either' and 'right' are assigned scores of −1, 0 and +1, respectively. These scores are then summed to give a test score that ranges from −10 to +10. Individuals with scores ranging between −10 and −5 are deemed to be left-handed whereas individuals with scores ranging between +5 and +10 are right-handed. Individuals with scores between these ranges are mixed-handed. Printable versions of the FLANDERS in English and other languages (Japanese, Chinese (Mandarin), French, German, Italian and more). can be found at: http://www.flinders.edu.au/sabs/psychology/research/labs/brain-and-cognition-laboratory/flanders-handedness-questionnaire.cfm.

Appendix 1

Flinders Handedness Survey (FLANDERS)

Surname:..First name:...

Date of birth:.......................................Sex (m/f)..

The ten questions below ask which hand you prefer to use in a number of different situations. Please tick one box for each question, indicating whether you prefer to use the left-hand, either-hand, or the right-hand for that task. Only tick the 'either' box if one hand is truly no better than the other. Please answer all questions, and even if you have had little experience in a particular task, try imagining doing that task and select a response.

		Left	Either	Right
1	With which hand do you write?			
2	In which hand do you prefer to use a spoon when eating?			
3	In which hand do you prefer to hold a toothbrush when cleaning your teeth?			
4	In which hand do you hold a match when you strike it?			
5	In which hand do you prefer to hold the rubber when erasing a pencil mark?			
6	In which hand do you hold the needle when you are sewing?			
7	When buttering bread, which hand holds the knife?			
8	In which hand do you hold a hammer?			
9	In which hand do you hold the peeler when peeling an apple?			
10	Which hand do you use to draw?			

Handedness score (please don't fill this out)	

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Please cite this article in press as: Nicholls MER, et al., The Flinders Handedness survey (FLANDERS): A brief measure of skilled hand preference, Cortex (2013), http://dx.doi.org/10.1016/j.cortex.2013.02.002