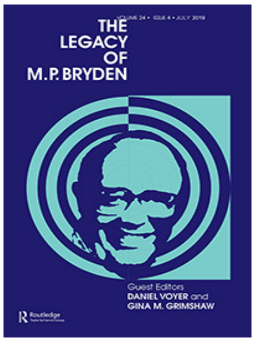

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The home handedness questionnaire: pilot data from preschoolers

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ABSTRACT
While handedness questionnaires are widely used in adults, there is no comparable measure designed specifically for children. The current study developed the Home Handedness Questionnaire (HHQ), a new measure for preschoolers administered by parents using common household items. The HHQ has two scales that distinguish action types typically combined on other measures: actions performed with only the right or left hand (i.e., *unimanual*, such as holding a toothbrush), and actions performed with one hand holding the object for the other hand's action (i.e., *role-differentiated bimanual manipulation or RDBM*, such as unscrewing a lid from a jar). The HHQ was able to detect right preference, left preference, and no preference for unimanual and RDBM actions in a proof of concept study in 3-year-olds ($N = 64$). The HHQ identified a majority of children as right-handed, but was also sensitive to variability in direction across skill types. Approximately one-quarter of children in the sample had mixed preferences for the two types of manual skills, suggesting that for a subgroup of children, hand use patterns may still be undergoing change. Suggestions for refining the HHQ are discussed. Overall, the HHQ is a promising multidimensional parent-led tool for assessing preschool handedness.

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KEYWORDS Handedness; hand preference; lateralization; preschoolers; questionnaire

Introduction

There is a marked bias in adult hand use, and at least 85% of the population is right-handed (Annett, 2002). Efforts to understand the phenomenon of handedness, or a bias in the way that the hands are used, have taken many approaches that span different disciplines such as psychology, kinesiology, anthropology, and biology, to name a few. In all of these fields, one of the

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most often debated questions is *how should handedness be measured?* In adults, self-report questionnaires are the norm, but multiple measures exist. The Edinburgh Handedness Inventory (EHI; Oldfield, 1971) is the most widely used based on citation rate (for a recent review on the use of the EHI, see Edlin et al., 2015). Additional examples of popular adult handedness questionnaires include the Annett Hand Preference Questionnaire (AHPQ; Annett, 1970), the Waterloo Handedness Questionnaire (WHQ-Revised; Elias, Bryden, & Bulman-Fleming, 1998), the Flinders Handedness survey (FLANDERS; Nicholls, Thomas, Loetscher, & Grimshaw, 2013), and a modified combined version of two of these measures called the Edinburgh-Waterloo Handedness Questionnaire (E-WHQ; Stone, Bryant, & Gonzalez, 2013).

An issue plaguing developmental scientists specifically is that these handedness measures were designed for adults; collectively, they contain items that are not suitable for young children. For example, the EHI asks about hand use for using a knife without a fork and for striking a match – actions that are not in preschoolers' repertoires. In addition, it is difficult for young children to report on their own actions. Cavill and Bryden (2003) chose to have an experimenter read aloud the 20 item version of the revised WHQ to children as young as 2–4 years of age, but no details were provided regarding whether young children actually understood the available responses of right or left always (95% or more of the time), right or left usually (75% or more of the time), or both hands equally. Bryden, Roy, and Spence (2007) later suggested that questionnaires that ask the child to imagine themselves performing the task and/or pantomime actions might not be appropriate for children under 5 years old. Alternatives to traditional questionnaires for assessing hand use preference include parent/teacher report of children's hand use and direct observations. A separate literature has examined differences between the hands on aspects of manual performance such as hand strength or speed, which is beyond the scope of this study (for a detailed review, see Scharoun & Bryden, 2014).

The majority of work on handedness over the preschool period (3–5 years of age) has examined hand use preference from the child's real-time (or video recorded) actions. For example, researchers have presented objects at the midline or in line with the left or right hand to assess hand use for reaching or bimanual manipulation in preschoolers, similar to how hand preferences are measured in infants (e.g., Cochet, Centelles, Jover, Plachta, & Vauclair, 2015; Fagard & Lockman, 2005; Fagard & Marks, 2000; Rönnqvist & Domellöf, 2006; Vauclair & Imbault, 2009). In other studies, test batteries utilize a combination of items that may include actions like asking the child to pick up and throw a ball, point, sweep the floor, pick up candy, remove a lid, unzip a zipper, cut paper, and use a comb and toothbrush, among other similar actions requiring fine motor control (Annett, 1967; Bruckner, Kastner-Koller, Deimann, & Voracek, 2011; Bryden & Roy, 2006; Coren, Porac, & Duncan, 1981; Curt, De Agostini, Maccario, & Dellatolas, 1995; Dellatolas et al., 2003; Kastner-Koller, Deimann, & Bruckner, 2007; Kaufman, Zalma, & Kaufman, 1978; Longoni & Orsini, 1988; McManus et al., 1988; Miller, 1982; Oztbrk et al., 1999). Writing/drawing hand is also a widely used measure of hand preference once children reach preschool age. Some test batteries use writing hand as an item among multiple fine motor skills (e.g., Longoni & Orsini, 1988; Marschik et al., 2008; McManus et al., 1988), but in other studies hand use for writing/drawing is the *only* measure of hand preference (e.g., Johnston, Nicholls, Shah, & Shields, 2009). Overall, the number of trials and types of actions varies widely across the literature in the preschool age range, with some studies using a small number of items (e.g., Annett, 1967, 5 actions) while others use a larger battery with multiple trials (e.g., Kastner-Koller et al., 2007, 16 items presented 3 times).

It is also worth noting that preschool measures do not typically separate manual action types. For example, throwing a ball is performed *unimanually* while unzipping a zipper is performed *bimanually* with one hand stabilizing the object and the other hand performing the manipulative action. The distinction is important because work from adults has argued for multidimensionality in handedness (e.g., Healey, Liederman, & Geschwind, 1986), but few studies with preschool aged children have explored how different dimensions of hand use preference, such as unimanual hand use and bimanual hand use, relate to each other. An exception among preschool measures is the WatHand Cabinet Test (WHCT; Bryden, Pryde, & Roy, 2000; Bryden et al., 2007), which is a custom-built lab apparatus that permits multiple unimanual and bimanual tasks. Four scores can be derived from the WHCT: a skilled score, a bimanual score, a consistency score, and a total score. The skilled score is calculated from six tasks: use a screwdriver, use a toy hammer, throw ball to target, push small buttons, place a ring on a hook, and open a lock with a key. The bimanual score reflects whether the participant used the same hand to open a door on the cabinet and to retrieve an item inside, or alternated the hands. The consistency score is computed from four trials of lifting a door with one hand. Finally, the total score is computed from the ten unimanual items (i.e., all items from the skilled score subset plus the four door lift trials). While a clear strength of the WHCT is that it distinguishes different types of hand use, there are a number of limitations. First, the WHCT determines bimanual preference from a sequential action that could be considered two unimanual steps, as compared to an action that requires coordination between both hands to perform it successfully (i.e., holding a bottle and twisting off the cap). Second, the WHCT uses a small number of trials. This weakness is most evident for the bimanual score, which in the past was computed from a single trial, although more recent work has used four trials (e.g., Scharoun & Bryden, 2015). Third, the WHCT uses an apparatus that is not commercially available and requires experimenter administration.

Thus, researchers interested in preschoolers' handedness are faced with selecting a measure from a variety of available tools, each with their strengths and weaknesses. While some measures are used more frequently by particular research teams, there is no definitive handedness measure that spans the preschool period and beyond. This gap in consistent methodology limits the questions that researchers can ask about how handedness develops. The *cascade theory of handedness* posits that handedness emerges from the complex interaction of motor asymmetries over time with hand preference for one skill affecting hand preference for subsequent manual skills (Michel, 2002, 2013). For example, a hand preference for reaching cascades into a preference for acquiring objects (Michel & Harkins, 1986), which leads to a preference for unimanual manipulation (Campbell, Marcinowski, Babik, & Michel, 2015; Hinojosa, Sheu, & Michel, 2003), and ultimately a preference for bimanual manipulation (Babik & Michel, 2016; Nelson, Campbell, & Michel, 2013). Other investigators have similarly argued for a cascade of events, or a snowball effect, in theories of the origin of handedness (e.g., Fagard, 2013; Güntürkün, 2005). The potential for differences in the timing of manual preferences that comprise the phenomenon of handedness necessitates that preferences for motor skills be examined separately.

Given the challenges associated with collecting data from child populations, ease of administration is an important quality for a preschool handedness assessment. Furthermore, a preschool handedness measure that does not require a special laboratory apparatus or researcher-led administration may be more widely accepted and used across different fields, particularly for investigators with limited resources. The aim of the current study was to develop a preschool performance-based hand use questionnaire that could be administered by parents using only common household items. In designing the questionnaire, we had two goals in mind. The first goal was to distinguish the common action types typically mixed together on other measures: actions that are performed with only the right or left hand (i.e., unimanual, such as holding a toothbrush), and actions that are performed with one hand holding the object for the other hand's action (i.e., RDBM, such as unscrewing a lid from a jar). The second goal was to sample each action type sufficiently in order to apply empirical cutoffs for calculating individual preferences (Hopkins, 2013a, 2013b; Tran & Voracek, 2018). To this end, we created 15 actions of each type and asked parents to administer items twice non-consecutively, yielding 30 data points for unimanual hand use and 30 data points for RDBM hand use (60 data points in total). Given the number of items in each subscale, binomial *z*-scores (+/−1.96) can be used to statistically determine hand preferences. The new measure adds to the field by providing a tool that can be used outside of the lab for measuring hand use preferences for two distinct manual skills.

While we hypothesized that hand preferences for unimanual and RDBM hand use would be related based on the cascade theory of hand preference (Michel, 2002, 2013), there is continued debate in the field regarding when handedness is established; reports vary from early infancy (e.g., Nelson et al., 2013) to school age (e.g., Gesell & Ames, 1947; McManus et al., 1988). Borrowing from the nonhuman primate literature, McGrew and Marchant (1997) define "handedness" as a pattern of hand use that is consistent across individuals, and across tasks. By systematically examining hand use for two different manual skills in 3-year-olds, we will be able to address whether an intermediate group of preschoolers exhibit handedness.

Method

Participants

Children were drawn from a database of 114 families who had previously participated in a prospective fetal ultrasound study at 11 to 14 weeks gestation to assess the size of areas in the developing brain (Abu-Rustum, Ziade, & Abu-Rustum, 2013). Of these families, 109 could be reached by phone for a preschool follow-up. Sixty-four families (males = 41) completed the Home Handedness Questionnaire (HHQ), a retention rate of 60.6%. Inclusion criteria for the original study were delivery without complications following full-term pregnancy of at least 37 weeks. At the time of HHQ testing, children ranged in age from 34 to 43 months of age (Mean = 40 months ± 56 days). One child was later diagnosed with leukemia, and another child was diagnosed with having an abnormal gait. These children were included in analyses, as these diagnoses did not involve any manual impairment. Mothers did not report any other medical or developmental diagnoses at the time of the HHQ administration. All families were from Tripoli, Lebanon. The local Institutional Review Board approved the following procedure, and mothers gave consent for their child to participate in the study. Families were not compensated for their participation in either portion of the research project.

Procedure

Mothers were contacted by phone for the HHQ assessment. After giving verbal consent to participate, mothers were sent a detailed explanation of the study and its purpose via the wifi-based WhatsApp messenger. WhatsApp allows sending text, images, videos, and voice recordings. Mothers received a text copy and voice memo recording explaining each action in the HHQ. In addition, a list of household items to be used in conjunction with the questionnaire was provided so that all objects were ready and close at hand. Objects included a cloth, pen or pencil, paper, toothbrush, toothpaste, hairbrush/comb, ball, water bottle with cap, ring, bracelet, bag, book, rubber band, food item, broom, plate, sponge, spoon, cup, sugar, shoe, wallet, stuffed animal, small toy, jar, and purse. The mother recorded the answers to the HHQ prompts on a template, and all responses were returned electronically. No instructions were given as to the size of the objects to be used, and no mother asked for clarification on object selection. Families participated in one session in their homes with their child to complete the HHQ.

Home Handedness Questionnaire (HHQ). The HHQ was designed to assess preschool hand use on two domains of manual skill commonly evaluated for handedness (see Table 1). Actions were designed with the following criteria in mind: (1) familiarity to parents for ease of understanding directions/ administration; (2) did not require special objects or apparatus to administer; and (3) prompts clearly elicited the target manual action. The HHQ includes 2 sub-scales: fifteen items that assess unimanual manipulation, and fifteen items that assess role-differentiated bimanual manipulation (RDBM) where

Table 1. Items on the home handedness questionnaire (HHQ) for preschoolers.

Unimanual actions (Performed twice)
1. Pick up a bottle cap
2. Bang or slap on a surface
3. Brush/comb hair
4. Tap a cup with a spoon
5. Pick up a bottle
6. Hand caregiver a bottle
7. Hold a toothbrush when brushing teeth
8. Throw a ball
9. Open a drawer/closet
10. Pick up a sheet of paper off a table
11. Pick up a cloth off a table
12. Pat/pet a stuffed animal
13. Put a bracelet on own arm
14. Hand caregiver a bracelet
15. Put a ring on own finger
RDBM actions (Performed twice)
16. Hold bag and retrieve a toy from inside (record hand that takes toy)
17. Hold caregiver hand and put a ring on it (record hand that places ring)
18. Hold caregiver hand and put a bracelet on it (record hand that places bracelet)
19. Hold toothpaste and open top (record hand that opens top)
20. Hold brush/comb and remove hair (record hand that picks hair)
21. Hold jar/bottle and unscrew lid (record hand that unscrews lid)
22. Hold paper and write/draw (record the hand that writes/draws)
23. Hold book and turn a page (record hand that turns the page)
24. Hold bottle and place a rubber band on it (record hand that places rubber band)
25. Hold a cup and retrieve a snack inside (record hand that takes food)
26. Hold hair and pretend to cut (record hand that "cuts")
27. Hold plate and wash with a sponge (record hand that uses sponge)
28. Hold cup and pour or stir sugar inside (record hand that pours/stirs)
29. Hold caregiver foot and put a shoe on it (record hand that places shoe)
30. Hold purse/bag and retrieve a wallet from inside (record hand that retrieves wallet)

Preferences were computed separately for unimanual and RDBM actions. See text for details.

one hand stabilized an object for the other hand's manipulation. Items were generated with input from multiple experts in the field.

For the unimanual subscale, general instructions to mothers were to place the target object within reach of the child on a table or countertop, and ask the child to perform the target action with the object (e.g., hand them a bottle, throw the ball). Mothers then recorded the hand their child used to fully-execute the action with the object (scored as the preferred hand). For the RDBM subscale, general instructions to mothers were to place the target object within reach of the child at a table or countertop, and ask the child to perform the target action with the object (e.g., hold bag and retrieve toy from inside). Mothers then recorded the hand that actively performed the manipulation, which was scored as the preferred hand (i.e., the hand that stabilized the object was considered the non-preferred hand). Parents were instructed to complete each action twice non-consecutively with their pre-schooler, yielding 30 data points on unimanual hand preference and 30 data points on bimanual hand preference (60 data points overall). A staff member called mothers to check if they had any questions or encountered any problems when administering the tasks, ensuring that mothers understood the tasks and how to record their child's responses.

Analyses

A Handedness Index was computed for each child separately for unimanual hand use ($HI_{UNIMANUAL}$) and RDBM hand use (HI_{RDBM}) using the formula $HI = (R–L)/(R + L)$, where R is the number of right hand actions and L is the number of left hand actions. HI scores vary on a continuum from −1.00 (exclusive left hand use) to 1.00 (exclusive right hand use). One-sample *t*-tests were performed on HI scores against a test value of 0 to evaluate population-level biases. The absolute value of each HI score was computed to determine the strength of hand use biases ($ABSHI_{UNIMANUAL}$, $ABSHI_{RDBM}$). ABSHI scores range from 0 (not lateralized) to 1.00 (completely lateralized). Independent samples *t*-tests were used to examine the effect of sex on HI and ABSHI scores. Individual preferences were determined by binomial *z*-scores where $z < −1.96$ = left preference, $z > 1.96$ = right preference, and all other *z*-scores = no preference. These cutoffs correspond to $p < 0.05$ for two-tailed tests. Paired samples *t*-tests were used to compare direction (HI scores) and strength of preferences (ABSHI scores) across the two motor skills. The relations between age, unimanual hand preference, and RDBM hand preference were examined using Pearson correlations. Finally, hand use for writing/drawing was compared to hand preference classifications from the HHQ since a number of studies have previously calculated hand preference exclusively from writing/drawing hand. Statistical analyses were conducted in IBM® SPSS® Statistics 20 with an alpha level of 0.05.

Results

Unimanual hand use preference

Individual unimanual hand use data are given in Table 2. Children performed between 23 and 30 successful unimanual actions ($M \pm SD = 29.71 \pm 1.02$). No child refused to attempt a unimanual item (Table 3). Eight children performed a unimanual item bimanually (i.e., with both hands). Frequencies for items attempted bimanually are given in Table 4. Hand preference scores were calculated based on the number of unimanual actions performed with the left or right hand only. $HI_{UNIMANUAL}$ scores ranged from −0.80 to 1.00 ($M \pm SD = 0.61 \pm 0.43$). A population-level *t*-test on $HI_{UNIMANUAL}$ scores found a significant right hand use bias, $t(63) = 11.322$, $p < 0.001$. Individually, 52 children were classified as having a right hand use preference (81.25%), 3 children were classified as having a left hand use preference (4.69%), and 9 children were classified as having no hand use preference (14.06%) for unimanual manipulation according to binomial *z*-scores using +/−1.96 cutoffs. An independent samples *t*-test found no effect of sex on $HI_{UNIMANUAL}$ scores, $t(61) = -1.253$, $p = 0.215$ ($M_{MALES} = 0.57 \pm 0.45$; $M_{FEMALES} = 0.71 \pm 0.33$). Age did not correlate with $HI_{UNIMANUAL}$ scores, $r = 0.044$, $p = 0.732$. $ABSHI_{UNIMANUAL}$ scores ranged from 0.10 to 1.00 ($M \pm SD = 0.69 \pm 0.26$). There was no relation between $ABSHI_{UNIMANUAL}$ scores and sex, $t(61) = -0.906$, $p = 0.369$ ($M_{MALES} = 0.68 \pm 0.26$; $M_{FEMALES} = 0.74 \pm 0.25$). Age did not correlate with $ABSHI_{UNIMANUAL}$ scores ($r = -0.176$, $p = 0.165$).

RDBM hand use preference

Individual RDBM hand use data are given in Table 2. Children performed between 20 and 30 RDBM actions ($M \pm SD = 29.38 \pm 1.70$). Parents reported infrequently that an item was either refused (2 children) or performed with both hands symmetrically (i.e., not with one hand stabilizing and the other hand manipulating; 11 children). Specific items and the frequencies of refusals are given in Table 3 and details regarding symmetrical bimanual attempts are given in Table 4. Hand preference scores were calculated based on the number of RDBM actions performed with the left or right hand only. HI_{RDBM} scores ranged from −1.00 to 1.00 ($M = 0.57 \pm 0.48$). A population-level *t*-test on HI_{RDBM} scores found a significant right hand use bias, $t(65) = 9.629$, $p < 0.001$. Individually, 49 children were classified as having a right hand use preference (76.56%), 5 children were classified as having a left hand use preference (7.81%), and 10 (15.63%) children were classified has having no hand use preference for RDBM according to binomial *z*-scores using +/−1.96 cutoffs. An independent samples *t*-test found no effect of sex on HI_{RDBM} scores, $t(61) = -0.380$, $p = 0.705$ ($M_{MALES} = 0.58 \pm 0.47$; $M_{FEMALES} = 0.62 \pm 0.38$). Age did not correlate with HI_{RDBM} scores, $r = 0.055$, $p = 0.666$. $ABSHI_{RDBM}$

Table 2. Individual hand use data on the unimanual and RDBM tasks.

ID	Sex	L_{UNI}	R_{UNI}	HI_{UNI}	Z_{UNI}	L_{RDBM}	R_{RDBM}	HI_{RDBM}	Z_{RDBM}
Right preference for both skills ($N = 45$)									
55755	M	4	26	0.73	**3.83**	4	26	0.73	3.83
43710	M	0	28	1.00	**5.10**	0	30	1.00	**5.29**
55784	M	5	25	0.67	**3.47**	3	27	0.80	**4.20**
53951	M	9	21	0.40	**2.01**	4	26	0.73	**3.83**
51072	M	9	21	0.40	**2.01**	6	24	0.60	**3.10**
55745	M	7	23	0.53	**2.74**	4	26	0.73	**3.83**
A5101	M	6	22	0.57	**2.83**	2	24	0.85	**4.12**
A5103	M	5	25	0.67	**3.47**	2	28	0.87	**4.56**
55821	M	4	26	0.73	**3.83**	1	29	0.93	**4.93**
55813	M	1	29	0.93	**4.93**	3	27	0.80	**4.20**
50986	M	4	26	0.73	**3.83**	3	27	0.80	**4.20**
55847	M	2	26	0.86	**4.35**	0	28	1.00	**5.10**
54027	M	1	29	0.93	**4.93**	0	30	1.00	**5.29**
50456	M	8	22	0.47	**2.37**	0	30	1.00	**5.29**
55183	M	0	30	1.00	**5.29**	0	30	1.00	**5.29**
55845	M	0	30	1.00	**5.29**	0	30	1.00	**5.29**
55899	M	1	29	0.93	**4.93**	3	27	0.80	**4.20**
55063	M	4	26	0.73	**3.83**	4	26	0.73	**3.83**
49739	M	0	28	1.00	**5.10**	0	26	1.00	**4.90**
50623	M	1	27	0.93	**4.72**	0	30	1.00	**5.29**
51473	M	1	29	0.93	**4.93**	5	25	0.67	**3.47**
55935	M	2	28	0.87	**4.56**	2	28	0.87	**4.56**
50534	M	0	30	1.00	**5.29**	0	30	1.00	**5.29**
54032	M	7	23	0.53	**2.74**	7	19	0.46	**2.16**
56170	M	3	27	0.80	**4.20**	0	30	1.00	**5.29**
49506	M	7	23	0.53	**2.74**	8	22	0.47	**2.37**
55769	F	4	26	0.73	**3.83**	6	24	0.60	**3.10**
55160	F	6	24	0.60	**3.10**	6	24	0.60	**3.10**
55641	F	4	26	0.73	**3.83**	5	25	0.67	**3.47**
54070	F	8	22	0.47	**2.37**	8	22	0.47	**2.37**
47317	F	4	25	0.72	**3.71**	4	24	0.71	**3.59**
50635	F	6	24	0.60	**3.10**	5	25	0.67	**3.47**
55806	F	4	26	0.73	**3.83**	0	30	1.00	**5.29**
48437	F	2	28	0.87	**4.56**	6	24	0.60	**3.10**
48447	F	1	29	0.93	**4.93**	1	29	0.93	**4.93**
46480	F	1	22	0.91	**4.17**	5	23	0.64	**3.21**
55913	F	0	30	1.00	**5.29**	0	30	1.00	**5.29**
50438	F	3	27	0.80	**4.20**	5	19	0.58	**2.65**
55968	F	1	29	0.93	**4.93**	2	28	0.87	**4.56**
55961	F	0	30	1.00	**5.29**	0	30	1.00	**5.29**
54052	F	0	30	1.00	**5.29**	0	30	1.00	**5.29**
46453	F	0	30	1.00	**5.29**	0	30	1.00	**5.29**
55994	F	1	29	0.93	**4.93**	5	25	0.67	**3.47**
A5340	F	0	30	1.00	**5.29**	0	30	1.00	**5.29**
45388	F	5	25	0.67	**3.47**	7	23	0.53	**2.74**
Left preference for both skills ($N = 1$)									
49783	M	27	3	−0.80	**−4.20**	30	0	−1.00	**−5.29**
Right unimanual/No preference RDBM ($N = 7$)									
48781	M	1	29	0.93	**4.93**	10	10	0.00	0.00
53275	M	6	24	0.60	**3.10**	14	16	0.07	0.18
52102	M	4	26	0.73	**3.83**	10	20	0.33	1.64
47865	M	3	27	0.80	**4.20**	9	19	0.36	1.70
53834	M	2	28	0.87	**4.56**	12	18	0.20	0.91
46592	F	9	21	0.40	**2.01**	9	19	0.36	1.70
46707	F	6	24	0.60	**3.10**	14	16	0.07	0.18

(*Continued*)

Table 2. Continued.

ID	Sex	L_{UNI}	R_{UNI}	HI_{UNI}	Z_{UNI}	L_{RDBM}	R_{RDBM}	HI_{RDBM}	Z_{RDBM}
Left unimanual/No preference RDBM (N = 1)									
53179	M	21	9	−0.40	**−2.01**	17	13	−0.13	−0.55
No preference unimanual/Right RDBM (N = 3)									
50841	M	13	17	0.13	0.55	1	29	0.93	**4.93**
55150	M	10	20	0.33	1.64	9	21	0.40	**2.01**
50417	M	12	18	0.20	0.91	7	23	0.53	**2.74**
No preference unimanual/Left RDBM (N = 4)									
A5048	M	12	18	0.20	0.91	21	9	−0.40	**−2.01**
48326	M	19	11	−0.27	−1.28	21	7	−0.50	**−2.46**
55895	M	20	10	−0.33	−1.64	29	1	−0.93	**−4.93**
55923	F	16	13	−0.10	−0.37	22	8	−0.47	**−2.37**
Left unimanual/Right RDBM (N = 1)									
55807	M	25	5	−0.67	**−3.47**	9	21	0.40	**2.01**
No preference for either skill (N = 2)									
A5085	M	10	20	0.33	1.64	12	18	0.20	0.91
55867	F	19	11	−0.27	−1.28	17	13	−0.13	−0.55

M = Male, F = Female. L = Number of left hand actions, R = Number of right hand actions. HI = Handedness Index (see text for calculation). UNI = Unimanual. RDBM = Role-differentiated bimanual manipulation. Z = Binomial z-score. $Z > 1.96$ = Right hand preference, $Z < -1.96$ = Left hand preference. All other z-scores denote no hand preference. Bolding indicates a significant hand preference.

Table 3. Frequency of refusals for HHQ items.

Item	Frequency	ID (Number)
Refusals of unimanual items		
—	—	—
Total	0	
Refusals of RDBM items		
16	4	48781 (2); 54032 (2)
17	2	48781
18	2	48781
20	2	48781
26	2	48781
Total	12 (0.63% of responses)	

See Table 1 for description of HHQ items.

scores ranged from 0 to 1.00 ($M \pm SD = 0.68 \pm 0.29$). There was no relation between $ABSHI_{RDBM}$ scores and sex, $t(61) = 0.069$, $p = 0.945$ ($M_{MALES} = 0.68 \pm 0.31$; $M_{FEMALES} = 0.68 \pm 0.27$). Age was not correlated with $ABSHI_{RDBM}$ scores ($r = -0.205$, $p = 0.104$).

The relationship between unimanual and RDBM hand use preferences

Hand preference direction (left or right) was strongly correlated between unimanual manipulation and RDBM, $r = 0.759$, $p < 0.001$. A paired samples t-test found no difference between $HI_{UNIMANUAL}$ and HI_{RDBM} scores, $t(63) = 0.824$, $p = 0.411$. Similarly, hand preference strength was moderately

Table 4. Frequency of bimanual attempts for HHQ items.

Item	Frequency	IDs (Number)
Bimanual attempts on unimanual items		
1	1	46480 (1)
8	2	49739 (2)
9	3	43710 (2); 47317 (1)
10	5	46480 (2); 55847 (2); 50623 (1)
11	5	46480 (2); 50623 (1); A5101 (2)
12	1	55923 (1)
15	2	46480 (2)
Total	19 (0.99% of responses)	
Bimanual attempts on RDBM items		
18	4	A5101 (2); 50438 (2)
20	2	49739 (2)
23	4	A5101 (2); 55847 (2)
24	12	50438 (2); 48781 (2); 46592 (2); 47865 (2); 46480 (2); 54032 (2)
25	2	50438 (2)
27	2	48326 (2)
29	2	47317 (2)
30	2	49739 (2)
Total	30 (1.56% of responses)	

See Table 1 for description of HHQ items. Note: For RDBM items, bimanual indicates that the hands were used symmetrically (i.e., not in a role-differentiated manner).

correlated across the two motor skills, $r = 0.476$, $p < 0.001$. There was no difference between $ABSHI_{UNIMANUAL}$ and $ABSHI_{RDBM}$ scores, $t(63) = 0.293$, $p = 0.771$.

At the individual level, the most common pattern in children was a right preference for both unimanual and RDBM actions (70%). The patterning in the remainder of the sample was distributed as follows: 1.5% preferred the left hand for both action types; 13% had an identifiable preference for unimanual actions, but no preference for RDBM actions, 11% had an identifiable preference for RDBM actions, but no preference for unimanual actions; 1.5% had opposite preferences for the two action types; and 3% had no identifiable preference for either action type (Table 2).

Can writing/drawing hand be used to determine handedness instead of the HHQ?

Children were asked to hold a paper and write/draw on two separate nonconsecutive trials for Item 22 on the HHQ. Responses were examined for each child to determine whether writing/drawing hand correctly identified hand preferences for unimanual and RDBM skills as determined by the more detailed full HHQ assessment. All but one child (1.6%) used the same hand on both writing/drawing trials. The child who alternated hands across writing/drawing trials (i.e., one trial used left hand, one trial used right hand) was similarly identified by the HHQ as having no preference for unimanual or RDBM actions. Fifty-seven children (89.0%) used the right hand for writing/drawing, while 6 children (9.4%) used the left hand. Concordance

Table 5. Concordance between the HHQ and hand preference for writing/drawing.

	Writing/Drawing hand		
HHQ	Right preference	Left preference	No Preference
Right preference for both skills	45	0	0
Right preference unimanual only	7	0	0
Right preference RDBM only	3	0	0
Left preference for both skills	0	1	0
Left preference unimanual only	0	1	0
Left preference RDBM only	1	3	0
Left unimanual but right RDBM	0	1	0
Right unimanual but left RDBM	0	0	0
No preference for either skill	1	0	1
Total	57	6	1

between the HHQ and writing/drawing hand preference is given in Table 5. Writing/drawing hand correctly identified 79.0% of right-handed children (i.e., right hand preference for both motor skills on the HHQ). Twenty-one percent of children with a right preference for writing/drawing were misidentified as right-handed according to the McGrew and Marchant (1997) criteria that requires consistency across tasks. The majority of these children did show a right preference for one skill, but no preference for the other skill. Among children with a right preference for writing/drawing, one child exhibited a *left* preference for one manual skill and no preference for the other skill, and one child had *no preference* for either skill. Writing/drawing hand only correctly identified 16.7% of left-handed children (i.e., left hand preference for both motor skills). Of the 83.3% misidentified as left-handed, the majority had a left preference for one skill but no identifiable preference for the other skill. One child had opposing preferences with a left preference for one skill but a *right* preference for the other skill. Overall, the HHQ is a more precise measure compared to examining strictly writing/drawing hand. Although writing/drawing hand may largely indicate the direction of preference, it cannot be used to determine strength, and may underrepresent the true variability in hand use.

Discussion

The current study piloted the HHQ, a newly developed handedness measure, in 3-year-old children. Our main goals were to (1) differentiate between unimanual and RDBM actions, which have been mixed together in previous measures of hand preference in child populations, and (2) sample manual actions sufficiently (30 per subscale) to calculate individual preferences with statistical cutoffs. The HHQ was able to detect right preference, left preference, and no preference for unimanual actions and RDBM actions in 3-year-olds. For unimanual actions, 81.25% of children were classified as having a right hand preference, 4.69% were classified as having a left hand preference, and 14.06% had no identifiable preference. For RDBM, 76.56% of children had a right preference, 7.81% had a left preference, and 15.63% had no identifiable preference. Hand preferences for unimanual and RDBM skills were strongly correlated. Seventy percent of children exhibited a right hand preference for both skills, and were classified as right-handed. Likewise, 1.5% of children exhibited a left hand preference for both skills, and were classified as left-handed. However, a large subset of children (25.5%) exhibited hand preference patterns that were inconsistent across unimanual and RDBM skills. Only 3% of children had no identifiable preferences for either skill. These data suggest that handedness, defined as consistency within an individual across tasks (cf., McGrew & Marchant, 1997), was not evident in one-third of our sample.

The overall patterns of hand preference identified by the HHQ with a majority right and minority left are similar to results from previous studies focusing on early childhood (Carlier, Doyen, & Lamard, 2006; Cochet et al., 2015; Coren et al., 1981; Johnston et al., 2009; Kastner-Koller et al., 2007; Kilshaw & Annett, 1983; Marschik et al., 2008; Tan, 1985). The principle strength of the HHQ is not its ability to detect right-handers, but rather that it is able to detect a large amount of variability in hand use patterns within and between unimanual and RDBM skills that previous measures may not have adequately described. Approximately one-quarter of children in the sample had mixed preferences across unimanual and RDBM actions: some had a unimanual hand preference only and no RDBM preference, or vice versa. Research in the preschool age range that directly compares unimanual and RDBM hand preference is limited, so estimating how many children have a mixed preference across these two skill types from previous literature is difficult. Fagard and Marks (2000) reported that 35% of their sample demonstrated mixed preference between 10 unimanual trials and two bimanual trials, but this study only spanned 18 to 36 months of age. Work by Bryden et al. (2007) did not find a significant correlation between the WHCT bimanual score and the WHCT total score (which includes only unimanual actions) in children 3 to 5 years old. Findings with the HHQ support one of the earliest accounts of handedness in children that raised concerns in measuring unimanual versus bimanual actions, and suggested measuring these skills separately (Updegraff, 1932).

Despite the recommendation from Updegraff (1932), contemporary studies have utilized measures that mixed unimanual and bimanual skills. This mixing of unimanual and RDBM skills in previous assessments could have also contributed to the argument that handedness does not consolidate until later childhood (e.g., De Agostini, Paré, Goudot, & Dellatolas, 1992). Findings from the HHQ suggest that most children exhibited handedness at 3 years of age, but for a subgroup of children, hand use patterns may still be undergoing change. Due to its easy use in the home with minimal effort on the part of the parent, research using the HHQ can broaden our understanding of individual differences in how hand preference for different skills develops over time. The ability to detect individual differences in children's hand use over time is important, as recent research found that differences in hand preference trajectories for specific manual skills (i.e., reaching, RDBM) early in development predicted later language skills at 2 and 3 years of age (Nelson, Campbell, & Michel, 2014; Nelson et al., 2017).

The HHQ's use of standardized statistical cutoffs to determine hand preference makes it robust against erroneous categorization that may result from fewer trials and arbitrary cutoffs. The HHQ targets 30 actions per trial type so that even with some data loss, binomial *z*-scores can be used to determine hand preference based on statistical probability (Gonzalez & Nelson, 2015; Hopkins, 2013a, 2013b). This approach contrasts with prior work in determining individual child hand use preferences, which makes comparisons across studies difficult (e.g., Coren et al., 1981; Fagard & Lockman, 2005; Kaufman et al., 1978; Kilshaw & Annett, 1983). Additionally, because the HHQ allows for separate calculation of $\mathrm{ABSHI}_{\mathrm{UNIMANUAL}}$ and $\mathrm{ABSHI}_{\mathrm{RDBM}}$ scores, the HHQ can be utilized for research questions focused on the degree of handedness (i.e., examining preferences on a continuous scale) rather than only direction (i.e., categorical). The pilot data presented here indicate the HHQ's potential for obtaining reliable, empirically determined hand use preferences that will facilitate cross-study comparisons.

For comparison to previous studies (e.g., Cermak, Quintero, & Cohen, 1980; Hill & Khanem, 2009; Johnston et al., 2009), we also calculated hand preference from writing/drawing hand alone taken from two trials on the HHQ. Results indicate that the HHQ is a more sensitive measure of handedness than hand preference for writing/drawing, with the HHQ detecting a greater number of children without a hand preference. Compared to hand preference based on the unimanual scale of the HHQ, using writing/drawing hand alone resulted in an 8% increase in how many children were classified as having a right hand preference, a 5% increase in how many children were classified as having a left hand preference, and a 13% decrease in how many children were classified as having no hand preference. Compared to RDBM hand preference, hand preference based on writing/drawing hand resulted in a 13% increase in how many children were classified as right handed, a 2% increase in how many children were classified as left handed, and 14% decrease in how many children were classified as having no preference for RDBM. Thus, writing hand may inflate the percentage of children with a hand preference compared to the HHQ, resulting in an overestimation of the laterality of the sample. In particular, writing hand identified far fewer children with no preference compared to both scales of the HHQ, and did not map directly onto hand preferences for unimanual and RDBM actions in all children. Therefore, we caution that using writing/drawing hand use as a proxy for the construct handedness may lead researchers to erroneous conclusions.

No significant sex differences were found for unimanual or RDBM hand preference using the HHQ. The literature on sex differences in handedness is mixed. While some studies in early childhood have reported sex differences (Brito, Lins, Paumgartten, & Brito, 1992; Bryden, MacRae, & Steenhuis, 1991; De Agostini et al., 1992), multiple studies do not find significant differences in hand preference between girls and boys (Archer, Campbell, & Segalowitz, 1988; Coren et al., 1981; Kaufman et al., 1978; Longoni & Orsini, 1988; Vauclair & Imbault, 2009). Mostly, studies with reported sex differences find a significantly higher rate of males with left hand preference or mixed preference (e.g., Brito et al., 1992). A meta-analysis by Papadatou-Pastou, Martin, Munafo, and Jones (2008) reported a robust sex effect in adult handedness with greater left-handedness in males, indicating that further research is needed to elucidate potential sex differences in handedness over development.

To our knowledge, research on hand use in Lebanese children in early childhood is lacking, making this study the first to report on handedness in this population. Inclusion of non-Western samples is critically needed in research, particularly for studies reporting on motor functions in young children (Karasik, Adolph, Tamis-LeMonda, & Bornstein, 2010). Although some literature has reported on potential cultural difference in adult hand preference (Mandal, 1999; Singh & Bryden, 1994), the majority of children in our sample demonstrated a right hand preference for unimanual and RDBM actions, which is comparable to samples of children from other countries around the same age (Austria: Kastner-Koller et al., 2007; Australia: Johnston et al., 2009; Brazil: Brito et al., 1992; Canada: Bryden et al., 2007; Great Britain: Kilshaw & Annett, 1983; Italy: Longoni & Orsini, 1988). The items used to perform the actions on the HHQ were selected purposefully to be easily available across many cultures and countries. However, additional studies are needed to ensure the HHQ is appropriate for use in diverse settings.

Data collected on the pilot use of the HHQ suggest that the measure was suitable for its target population of preschoolers based on parent reported completion rates. Since parents are the best judges of their child's limits, we are confident that the length of the assessment was appropriate. No child refused to complete a unimanual item, and less than 1% refused to complete an RDBM item. Moreover, the majority of children completed the full assessment of 60 trials, indicating that hand preference can be successfully measured using a large number of trials (e.g., Campbell, Marcinowski, Latta, & Michel, 2015). Bimanual attempts (i.e., using the hands together for the same action) for unimanual and RDBM items were also low (about 1% and 1.5% respectively), indicating that the items for each skill type adequately afford and elicit the target action needed to measure hand preference for different skills (Fagard & Marks, 2000). It is important to note that object size can affect reaching strategy, with larger objects eliciting more symmetrical bimanual grasps (Fagard & Jacquet, 1996; Fagard & Pezé, 1997; Newell, Scully, McDonald, & Baillargeon, 1989). Moreover, task demands can play an important role in the expression hand preference (e.g., Potier, Meguerditchian, & Fagard, 2013). The HHQ relies on objects available in the home, thus object size was not standard across participants. Thus, it is unclear whether object size could have had an effect on the few items that elicited bimanual attempts. Individual items that elicited greater frequencies of bimanual attempts such as pick up a sheet of paper and pick up a cloth (from the unimanual scale) and put bracelet on caregiver's arm, turn a page of a book, and place a rubber band on a bottle (from the RDBM scale) should be examined in additional data sets to determine whether the prompts for these items should be adjusted to ensure actions are performed as intended.

Overall, parent success in administering the HHQ at home highlights the potential of using the measure outside of traditional laboratory settings. Using the HHQ at home eliminates the need for parents to travel to a lab, alleviating a possible barrier for participation. Asking parents to complete the HHQ prior to or after an in-person visit could also reduce the length of lab visits or free up time to administer other in-lab measures. The use of technology and telecommunications is expanding in psychology (e.g., Libertus & Violi, 2016), and the HHQ is poised to match this new direction in research. Future studies interested in measuring child handedness could use the HHQ with Whatsapp or other messaging platforms, over the phone, via video chat, or have parents log their child's hand use for the items through an online format such as Qualtrics.

Limitations

The current study was the pilot testing of the HHQ. Data reported here do not address the suitability of the HHQ for other ages, or can they address longitudinal changes in hand use preferences. Longitudinal data would speak to differences or changes in trajectories in hand preference across unimanual and RDBM skills over time. A potential limitation of the HHQ as used here is its reliance on parent report rather than direct researcher observation. However, as noted above, the HHQ could be used flexibly in a variety of settings, including over video chat, thus it is possible to have an experimenter verify hand use with the HHQ to address compliance. The main contribution of the HHQ is to serve as a home measure of hand preference that can be administered easily by parents with common household objects. A methodological tradeoff is lack of control over the size of the objects used or child familiarity with objects compared to traditional lab assessments. Prior to participation using the HHQ, researchers should notify parents of the objects they may need to locate at home to complete the HHQ, and if the exact items are not available, similar items can be used. To ameliorate the potential effect of object size, future instructions for the HHQ should ask parents to utilize objects that are small enough for their child to hold with one hand. If a child initially performs an action incorrectly (i.e., bimanual reaching instead of unimanual) parents could also be instructed to encourage their child to perform the action again using the correct number of hands for the target action (i.e., "use one hand to pick up the paper" or "use one hand to hold the bottle and another hand to place the rubber band"). It is also important to note that the HHQ as it was used here focused on the multidimensionality of hand preference across two manual skills (unimanual and RDBM). We acknowledge that there are other dimensions related to handedness that were not measured here such as performance-based metrics (e.g., speed), action sequence, or grip morphology. However, researchers interested in questions relating to other aspects of hand use could collect additional variables from the HHQ. Current efforts are underway to validate the HHQ in children at other ages, as well as in adults.

Conclusion

Findings demonstrate that the HHQ is able to identify a majority of right handed children as expected based on previous literature, but is also able to detect variability in the direction of hand use across skill types, which has been lacking in previous measures of hand preference. A major takeaway point from these pilot data is the inconsistency in hand preference found for some children across unimanual and RDBM skills. Recent work has demonstrated that hand use patterns matter for cognitive development (Gottfried & Bathurst, 1983; Kee, Gottfried, & Bathurst, 1991; Kee, Gottfried, Bathurst, & Brown, 1987; Nelson et al., 2014, 2017; Wilbourn, Gottfried, & Kee, 2011). Further research is needed on the links between motor skills, such as how the hands are used, and cognition. The HHQ can provide researchers interested in this area with a measure that is convenient to administer.

Overall, the HHQ is the first handedness measure of its kind. The HHQ allows for nuanced multidimensional measurement of hand preference across multiple trials of unimanual and RDBM skills in preschool aged children, using common household items and without the need of an experimenter present. Using the HHQ, researchers can generate separate unimanual and RDBM hand preference scores, and use statistical cutoffs to calculate individual preferences. The HHQ is easily administrated in a home setting by parents as "citizen scientists", does not require special equipment, and is easily translatable across administration platforms (i.e., in the home independently, over the phone or video chat, or through messaging or online surveys). Researchers interested in measuring handedness in conjunction with other cognitive and/or neural measures would greatly benefit from using the HHQ because it provides a robust measure of hand preferences. Ultimately, the multidimensional approach used by the HHQ to measure hand preferences in children provides a new take on measuring distinct trajectories for hand use across skills, allowing for research on handedness in children to shift from questions of what does handedness look like, to questions regarding how individual differences and trajectories in hand use interplay with other facets of development.

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