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BRIEF COMMUNICATION

Establishing hand preference: why does it matter?

Diane E. Adamo · Anam Taufiq

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Abstract Hand preference has been associated with psychological and physical well-being, risk of injury, pathological irregularities, longevity, and cognitive function. To determine hand preference, individuals are often asked what hand they use to write with, or what hand is used more frequently in activities of daily living. However, relying only on one source of information may be misleading, given the strong evidence to support a disassociation between self-reported hand preference and outcomes of hand performance assessments. This brief communication is intended to highlight the various methods used to determine hand preference, to discuss the relationship between hand preference inventories and performance measures and to present some recent findings associated with hand preference and musculoskeletal disorders.

Keywords Hand assessments · Hand preference · Performance measures

Introduction

Based on self-reports, approximately 90% of the population is right-handed [10, 50, 68]. According to Corey et al. [38], *hand preference is the most blatant behavioral asymmetry observed in humans and is manifested by the preferential use of one hand over the other for a specific task*. The notion that hand preference may be localized to a specific cerebral hemisphere was first suggested by Liepmann [60] following on earlier discoveries by Broca [23] and Wernicke [103] regarding the specific localization of language in the left hemisphere [23, 60, 103]. Recent findings have supported the hypothesis of an association between hemispheric lateralization of hand dominance and language centers. Ninety-eight percent of right-handers have language lateralized to the contralateral hemisphere, and about 70% of left-handers have language lateralized to the ipsilateral hemisphere [38] with about 14% showing bilateral involvement and 10% having right hemisphere lateralization [81]. It has been postulated that cerebral unilateral control of speech and handedness appear to reflect a constraint on the brain's bilateral motor control [32, 56].

Although the majority of studies report more left-handers in males than females [9, 25, 68] not all studies agree [7, 91]. Nonetheless, it has been suggested that hemispheric lateralization associated with handedness is greater in males than females [6]. In addition, a relatively larger parietal association cortex found in men [39] and stronger interhemispheric interactions associated with greater bilateral activation [105] mediated by a corpus callosum larger in size and in number of neurons in females [13] supports less lateralization in females. Furthermore, it is well established that the manifestation of dominant hand activity is localized in the contralateral hemisphere [11] and considered a strong indicator associated with the asymmetrical functional and structural organization of the brain. Differences in self-reports of one's handedness and better performing hand have prompted the use of brain-mapping techniques to identify a possible neuronal substrate for unimanual and bimanual limb movements performed in right and left-handers [53, 55, 61]. Handedness has been associated with the lateralization of specific cortical activations in the primary motor cortex [12], cingulate

D. E. Adamo (✉) · A. Taufiq
Eugene Applebaum College of Pharmacy and Health Sciences,
Physical Therapy Department, Wayne State University,
259 Mack Ave.,
Detroit, MI, USA
e-mail: dadamo@wayne.edu

motor area, supplemental motor areas, and cerebellar regions [61] during the performance of sensorimotor tasks [53, 61, 101]. For right-handers, left-hand movements are under more direct neural control of the right than left hemisphere [57] and may benefit from this hemisphere's better representation of the coordinates of spatial locations [56]. This, in turn, may explain the left-hand's ability to precisely position the fingers and adapt to subtle differences in processing spatial information related to proprioceptive information. Such limb differences have contributed to further investigations into asymmetries in processing sensory-based information.

To investigate this from a behavioral perspective, contralateral upper limb-matching paradigms are one such methodology that has been employed. Asymmetries in upper limb position were found to be dependent upon whether the right dominant or left non-dominant limb produced the reference or performed the match [1, 2, 44, 45, 83, 98]. In some studies, for right-handed individuals, absolute matching errors were less for the left than right limb when matching passively imposed contralateral limb movements. It may be presumed that passive right limb movements were better represented in larger left than right somatosensory regions that, in turn, resulted in smaller errors when matching movements in the contralateral limb. Larger left than right somatosensory regions found in right-handed individuals using magnetic imaging techniques aligns with these findings [95]. It was further suggested that interhemispheric transfer of information was more efficient from left to right than in the opposite direction [46, 109] and, as such, contributed to less left than right limb matching errors. However, other studies showed no significant differences in matching performance between the limbs [27, 28, 48, 107]. These contrasting results may stem from task-specific differences associated with the context in which kinesthetic perception is tested.

The dynamic dominance theory proposed by Sainburg [84] offers additional insight into the specialization of limb control for each limb/hemisphere system in right-handed individuals. According to this theory, the dominant right limb/left hemisphere system is specialized for controlling limb dynamics whereas the non-dominant left limb/right hemisphere is specialized for controlling static limb position [14, 85, 102]. Findings from these studies highlight the importance of considering each hand/limb system as a separate entity and contribute to bilateral upper limb movements.

Preferred hand use may have also been influenced by cultural and biological factors. In the early twentieth century, there were significant pressures to switch the writing hand from left to right in order to avoid religious and social stigmas associated with being left-handed [43, 77, 79, 90]. It was believed that left-handed individuals were at a physical [15, 36, 37, 79] and psychological [64] disadvantage compared to right handers. In addition to forced hand switching, there are inherent environmental constraints in which a left-handed individual is forced to adapt to living in a world designed for right handers [18, 19, 77]. This, in turn, may influence the extent to which individuals consider themselves right- or left-handed. Furthermore, individuals who were predisposed to using their left hand for writing, but successfully switched to using their right hand, may have continued to use the left hand for other tasks. If the classification of hand preference relies exclusively on individuals indicating what hand they write with, then these individuals are classified as right-handed rather than ambidextrous and significant details about hand use are omitted when these individuals may be equally skilled at using both hands for other tasks. Overall, clinical studies rarely consider the effects of forced right-hand use in determining the predominance of right or left-hand use in other tasks.

Determining Hand Preference

Earlier classifications of hand preference were typically based on a single dimension, such as an individual's self-report of hand dominance [10, 25, 104]. The term “hand preference” has also been associated with one hand being considered more skilled [8] or stronger [31] than the other. More recently, however, hand preference has been considered multidimensional because relying only on one measurement was found to be ambiguous. When taking into account various findings from handedness inventories, hand preference questionnaires [8, 72, 75] and hand performance tasks, inconsistencies in classifying one as right- or left-handed [24, 38] have been revealed. Thus, additional classifications such as mixed handedness [78, 94], ambidextrous [93], left-handedness (extreme) and left-handedness (force choice) [70], inconsistent left [90] were employed. A limitation associated with classifying individuals to one category is highlighted by Shiri et al. [92]. Shiri et al., [92] classified individuals who were able to use both hands equally well as right handers rather than ambidextrous [92]. They suggested that this introduced a limitation in their study, as it was difficult to ascertain if the prevalence of a right or left-hand musculoskeletal disorders existed when comparing differences between two equally proficient hands.

Self-reports and handedness questionnaires/inventories offer two common methods for obtaining hand preference. Self-reported handedness is often determined by asking an individual which hand they prefer to use to perform a task whereas handed inventories inquire as to the frequency one hand is used over the other to perform various unimanual tasks [10, 22, 35, 59, 68, 73]. Not surprising, self-reports show a strong correlation with handedness inventories [10, 22]. These are considered easier, take less time to administer than performance based measures and may be used to assign individuals to a group when conducting research studies. However, there are considerable variations in the sensitivity of handedness inventories in determining the degree of handedness. For example, Corey et al. [30] showed that separation between left and right hand preference groups were greater when using the Hand Preference Inventory that combined items from the Briggs and Nebes [22] and Edinburgh [68] assessments than when using each assessment independently [38]. The authors found that adding four items (drawing, knife use, spoon use, opening a box) to the 12-item Briggs and Nebes measure offered a practical solution to reducing the ambiguity associated with using two-hand preference inventories.

In addition to using handedness inventories, the ability to perform a specific task with one hand or the other may also be used to determine hand preference. Hand-performance assessments are based on quantifying arm/hand differences in motor output when performing, for example, a finger tapping, manual aiming, and peg placement tasks. These tests are performed with each hand separately and then together. Performed under a time constraint, participants are required to tap their finger [71] or pick up pegs from a shallow cup and place them sequentially into aligned holes on a board [24, 38]. However, the faster or better performing hand may not be the same as the self-reported dominant hand. In fact, studies have shown that performance-based assessments are dis-associated from self-reports [24, 38, 71, 75, 106]. In other studies, measures of manual dexterity and grip strength have been used independently [39, 63, 99] and in combination with handedness inventories and self-reports [24, 38, 93] to help define and distinguish ones' hand preference. Corey et al. [30] found that performance-based measures, when considered independently, were not predictive of hand preference [38]. Rather, it required the combination of results from both the finger-tapping and peg placement tasks to more clearly distinguish hand preference. In addition, combining the results from a handedness questionnaire and a series of performance measures showed that performance on the Wathand Box™ and peg placement task were the best predictors of hand preference [24]. Overall, these findings show that using multiple measures to determine hand preference is a stronger predictor for determining hand preference than relying on a single measure.

Dynamometry is another method used to determine hand preference. Dynamometers are hand-held mechanical or electronic devices embedded with strain gauges and adjusted to fit an individual's hand size. Grip strength measurements are typically obtained by requesting an individual gradually increases and maintains their maximum grip force exertion for a brief time. The greater of two maximum voluntary grip exertions performed by each hand determines the maximum grip strength for that particular hand. However, variations between methodologies including the time taken to rest between consecutive trials and the posture of individuals during testing have made it difficult to compare group differences and establish appropriate normative data [52]. Of particular interest is the use of grip strength as an independent measure of hand preference by identifying the stronger hand as the dominant hand, then correlating dominant hand with cognitive performances [93]. However, this strategy may potentially introduce a confounding variable since the stronger hand does not consistently correlate with the preferred hand despite its association with some cognitive measures. Grip strength differences between the hands may vary as much as 40% [31, 41] and the type of work pursued or long-term engagement in racket sports, for example, is rarely considered a factor when accounting for differences in hand grip strength. Generally, right-handed individuals tend to use their right hand to manipulate and the left hand to hold an object and, are often stronger in their right than the left hand [31, 41]. However, this delineation of preferred hand as a function of its strength is not found in left-handers. There tends to be smaller differences between hand strength in left-handers [49, 62] due to a more even distribution of performing tasks requiring strength with either hand.

Although the vast majority of studies report greater right than left grip strength for right-handed individuals, this is not always the case. Lewandowski et al. [58] showed that 19% of young right-handers had a stronger left- than right-hand grip strength and 36% of left-handers had a stronger right than left hand grip strength [58]. Furthermore, Incel et al. [49] showed that out of 149 individuals, where the dominant hand was defined as the one preferred for daily activities such as eating and writing, 128 were determined to be right-handed and 21 left-handed. For right-handed individuals, 10.93% showed a stronger left than right hand and for left-handed individuals, 33.3% showed a stronger right than left hand [49]. In other words, the left hand was 10% stronger than the right hand in right-handers; and the right hand was 33% stronger than the left hand in left-handers. Overall, there were greater strength differences between dominant and non-dominant hands for right (8.2%) than left (3.2%) handers [49]. Similar findings were reported by Petersen et al. [73] who found that for right-handers, the dominant right hand was 12.7% stronger than the left hand, and for left-handers, right/left differences in grip strength were negligible [73]. Gender has also shown to be a factor associated with hand preference and grip strength. Schmidt and Toews [88] showed that 15% of their female participants and 23% of their male participants were stronger in their non-dominant than dominant hand [88]. Petersen [73] found that right handed females showed a 15.8% difference in grip strength between their hands [73].

Modifiers That may Contribute to Ones' Hand Preference

Task-specific training effects may influence the extent to which one identifies and describes preferred hand use [4]. Habitual use of the right or left hand is typically observed during the performance of everyday tasks. Previous studies have shown that each hand adopts a particular function when executing bimanual tasks. In right-handed individuals, the right hand tends to perform tasks requiring force (opening a jar) and performing a series of rapid movements (peeling an apple) whereas the left hand tends to offer stabilization and support. Furthermore, habitual use of one hand contributes to "laying down" specific motor programs and promotes skilled hand use. However, highly skilled hand use does not appear to transfer to other tasks, suggesting that continued practice of specific tasks leads to the concurrent commitment of specific motor programs related to these tasks but does not transfer to other tasks. This is most evident in work tasks where one may gain proficiency in the use of certain tool but this level of proficiency does not transfer to other tools with similar physical properties.

Levels of expertise in performing specific sensorimotor tasks may contribute to limb differences in performing simple motor tasks. Studies comparing limb differences in performing simple tapping tasks in musicians and non-musicians offer insight into the role of specific training on hand preference and hand performance measures [51, 57]. Jancke et al. [51] were interested in determining if hand skill asymmetry, based on outcomes of a tapping task, was different between right-handed musicians and control subjects [51]. Findings from this study showed that although musicians demonstrated right hand superiority, they revealed a lesser degree of hand asymmetry than consistent right-handed non-musicians [51]. It was explained that these outcomes resulted when musical training commenced at an early age as a function of cerebral maturation during childhood. Furthermore, these differences were related to better performance on the left hand rather than a loss of function in the right hand. Movement control and motor coordination improve gradually and the interaction between hand skill development and cortical organization of hand motor dominance lead to improvements in non-dominant hand performance [40, 87]. Furthermore, these improvements can be trained to increase efficiency for task related objectives. Novice left-handers performed better with a reversed keyboard in which the pitch decreased from left to right than using a traditional keyboard in which pitch decreases from right to left [47]. Nevertheless, with practice, experienced left-handers were able to perform comparable to right-handers in their performance on a traditional keyboard. This study further implicates the importance of training for specific skill sets in order to maximize performance and efficiency in tasks for constructive right or left-handers.

Task-specific training effects can also be observed in work environments. Employees are often trained to a specific skill set to improve their level of efficiency to perform a manual or bimanual task. Tasks such as use of machinery, gearshifts, or scissors often favor right-handed individuals. As a result, left-handers are often found to be at a higher risk for accidental work injuries [33]. Thus, in the work place, left-handed individuals may have to work harder to adapt specific skill sets that are often biased towards right handers.

Furthermore, there is thought to be a relationship between hand preference and performance in various sports. Left-handed athletes participating in interactive sports in which players have direct contact with each other may have a higher advantage in reaching their target than right-handed athletes. It has been inferred that there is a higher proportion of left-handed top level international athletes in sports such as baseball [34], cricket [3], and fencing [20]. In sports, such as boxing or fencing, individuals can often predict the direction or pattern of attack and safeguard appropriately. On the contrary, patterns of attack of left-handed individuals strategize to allow for unpredictable patterns of attack. Additionally, it has been suggested that superior spatio-motor skills reflect the high performance of left-handed athletes [3].

Establishing Hand Preference in Clinical Populations

When hand use is compromised, clinical research studies investigate functional differences between the involved and non-involved hand when available and monitor these changes over time to determine the effectiveness of treatment interventions. Some clinical studies report hand preference [21, 98, 111] but may limit this assessment to a simple question, such as "Are you right handed or left-handed [92]?" Little attention is given to the evaluation of hand preference and whether shifts in hand preference occur particularly with the progression of a disease. Changes in behavior patterns may mask the progression of a disease as individuals adjust to subtle, undetected changes in sensory and motor functioning that otherwise may serve as precursors for identifying the stage of disease progression. If, for example, individuals seem to be dropping hand-held items, they may begin to use the other hand or both hands to transport objects to compensate for undetected sensory losses rather than consider how behavioral changes in hand use may be indicative of further evaluation. Combining hand preference and hand performances measures during the early onset of a disease process such as carpal tunnel syndrome, osteoarthritis, and progressive neurological disorders may help to monitor its progression and, if recognized early, help offset further complications. However, it is also acknowledged that some clinical measurements lack sensitivity in detecting subtle changes and that more precise diagnostic tools may be required to accurately track the progression of disease.

Gender differences, showing a higher prevalence for musculoskeletal disorders for women than men [100] and types upper extremity musculoskeletal disorders have been well documented [26, 74] with fewer studies addressing the role of hand preference. This is surprising given the interest in investigating the role of the dominant hand once the diagnosis has been established or the injury has occurred [89, 92, 98]. Zambelis et al. [111] investigated laterality and risk for developing carpal tunnel syndrome (CTS) in those identified as right or left-handed [111]. Hand dominance was determined by asking the participants what hand was used in daily activities and to complete Porac's and Coren's handedness questionnaire. Left-handers were predisposed to an increased risk to developing CTS in their left-dominant hand than right handers were in their dominant right hand. Furthermore, a higher prevalence for CTS was found for females [21, 66, 92] in their dominant hand [21, 67, 98]. However, other studies have shown that handedness is not a factor in determining risk for CTS [82]. Reinstein [82] reported that 5.2% of his 155 right-handed patients had CTS exclusively in the left hand, and that another 5.8% presented greater involvement of the left than right hand [82].

Shiri et al. [92] and others [69] found that lateral epicondylitis is more common in the right dominant elbow. However, Shiri et al. [92] expanded these initial findings to report that when the dominant arm is the left arm, the prevalence for lateral epicondylitis is greater. These differences were thought to be due to individuals using tools primarily designed for right-handed individuals that, in turn, may be poorly fitted for a left-handed individual.

For the most part, health-related questionnaires are designed to focus on functional deficits for a specific disease process/injury [5, 17, 80, 96]. When reporting functional changes in hand use, few studies report whether the left-dominant/right non-dominant or right-dominant/left non-dominant hand combinations acquired greater losses or if patients had to switch hands in order to accomplish a specific task. As indicated by Schuind et al. [89], “when expressing the results in percents of the value of the contralateral side, do we take into account the differences related to hand dominance [89]?” Alternatively, the Michigan Hand Outcomes Questionnaire [30] requests individuals to identify hand-specific differences in functional tasks such as, turning a door knob, picking up a coin, and holding a glass of water by assigning a numerical rating (1–5) associated with a verbal descriptor (not at all difficult–very difficult), respectively. In addition to assessing each hand separately, this tool addresses the contribution of each side to deficits in performing bilateral tasks [5] as well as changes in participants' perception of improved function after treatment [29]. However, despite its specificity to identifying left and right hand ability, participants are only asked whether they are right handed, left-handed, or both. There was no indication of any additional measures used to determine hand preference. Perhaps, clearly identifying hand preference along with such an assessment would provide valuable information in tracking the progression or recovery of an injury or disease.

Special Consideration Clinical Populations

Individuals who have undergone an amputation and then are fitted with a prosthesis experience significant alterations in limb usage than those with unilateral or bilateral musculoskeletal disorders. For these individuals, the role of handedness and hand performance in recovery is less clear. Loss of a limb contributes to neurological alterations in body schema and subsequent visual–spatial deficits [54]. In a study conducted by Metzger et al. [65], subjects with a unilateral amputation were asked to perform rapid reaching movements with their prosthetic and unaffected arm. An age-matched control group was also tested and findings between the groups were compared. Outcome measures included endpoint error, trajectory error, and variability. End point errors were similar for subjects with the prosthetic arm when compared to the control subjects suggesting that abnormal mechanical properties of the prosthetic device did not contribute to deficits in feedforward control [65]. Compensatory strategies including the combination of a sufficient internal model of the arm and utilization of available proprioceptors in the elbow and shoulder allowed individuals to produce the required torques to move their prosthetic limb towards the target [65].

Interestingly, greater kinematic errors were found in the non-affected than prosthetic arm. Decreased performance in the non-affected arm may be related to alterations in interlimb transfer due to different mechanical properties in each limb. For individuals with both limbs intact, improved performance in novel motor tasks, in which performance in one arm improves performance in the opposite arm, has been reported [102]. Additionally, limb-specific differences in movement strategy, as proposed by Sainburg [84] may not apply to those individuals with amputations due to alterations in limb use. Understanding interlimb transfer effects and limb/hemisphere-specific movement strategies in unaffected individuals emphasizes the significant role of each hemisphere in the control of limb dynamics. Thus, understanding limb specific differences in movement strategy [84] a priori may help to explain alterations in limb movements performed with the prosthetic and unaffected limb and, as such, may be useful in designing specific rehabilitation programs. However, the role of handedness and adaptations in neural control and recovery from an amputation and the subsequent use of prosthetic warrants further investigation.

Relevance of Hand Preference in Training Medical Students on Surgical Techniques

Of interest to the medical community is the relevance of hand preference and performance to assessing manual dexterity skills required during precise surgical procedures. Although questionnaires completed by experienced surgeons may identify a specific skill set needed to perform such tasks [16], recent studies suggest there is an increased demand for a more objective measure of surgical performance [42, 97, 108].

To address this, investigations using hand-held robotic devices [110] and motion analysis systems [86, 108] have been added to traditional techniques of evaluating skill proficiency. Motion analysis systems are capable of collecting kinematic data related task-specific movements. Outcome measures may include the number of hand movements, path lengths of hand movements [86, 108] and the average speed of each hand when using forceps to perform a bilateral task [108].

Although the number of previously performed procedures strongly influenced the level of proficiency in performing specific surgical techniques [16, 86, 108], hand preference and limb differences in performance are not often considered as evidenced in the Saleh et al. [86] study. According to these authors, a previous study using motion analysis [16] did not yield specific limb differences when performing a corneal suturing task, hence they decided to combine performance outcomes from both hands to conduct their current analysis using a similar task. They did not address how differences in methodologies/selected measures may have influenced potentially different outcomes and, as such, may have dismissed important data related to each hand.

In contrast, Yamaguchi et al. [108] found specific limb differences between right-handed novice and experienced surgeons performing a suturing and knot-tying task. Using a motion tracking system, kinematic data related to time taken, hand path lengths, and average speed of forceps use in each hand was recorded. Not surprising, more experienced surgeons completed the suturing and knot-tying tasks faster than novice surgeons. Moreover, when considering specific limb differences for the suturing task, left-hand path lengths were significantly shorter for the experienced than novice surgeons, whereas right-hand path lengths were similar for both groups. For knot-tying tasks, average right-hand speeds were faster for experienced than novice surgeons, whereas average left-hand speeds did not differ between the groups. Limb differences in hand path lengths and average speeds for suturing and knot-tying tasks demonstrate that long-term practice effects associated with experienced surgeons are hand and task dependent. In other words, long-term practice effects do not explain the absence of limb differences where the same level of performance is observed in novice and experienced surgeons. This study also demonstrates that psychomotor skills in surgical procedures may differ with respect to each hand.

Limb differences in hand path lengths and movement speeds may be influenced by a specific mode of control known to exist for each limb/hemisphere system [14, 85, 102]. As indicated earlier, this theory [8] proposes that in right-handed individuals different movement strategies are used for the dominant and non-dominant limb/hemisphere systems. However, applying this theory to the current findings to explain limb differences in a bilateral task as a function of experience/practice effects warrants further investigation.

Summary

Hand preference may be determined by combining the findings associated handedness inventories and hand-performance assessments. Most studies investigating hand functionality do not fully assess hand preference that, in turn, may restrict interpretations and limit the application of their findings in the treatment of individuals recovering from an injury or reducing the effects resulting from the progression of disease. Individuals who have sustained an amputation present special considerations in lieu of handedness and hand performance issues. In the work environment, determining hand preference may better align individuals to perform work tasks that place them at less risk for injury. In the medical community, understanding limb differences in movement strategy may improve training of novice surgeons performing tasks that require a high level of precision and manual dexterity.

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