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Evidence for general right-, mixed-, and left-sidedness in self-reported handedness, footedness, eyedness, and earedness, and a primacy of footedness in a large-sample latent variable analysis

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ABSTRACT

Lateral preferences are important for the study of cerebral lateralization and may be indicative of neurobehavioral disorders, neurodevelopmental instability, and deficits in lateralization. Previous studies showed that self-reported preferences are also concordantly interrelated, suggesting a common genetic or biological origin, sidedness. However, with regard to the assessment and classification of lateral preferences, there is a dearth of psychometric studies, but a need for psychometrically validated instruments that can be reliably used in applied research. Based on three independent large samples (total $N > 15{,}100$), this study investigated the psychometric properties of widely-used lateral preference scales of handedness, footedness, eyedness, and earedness. Preferences were consistently and replicably categorical, consisting of right, mixed, and left preferences each, underlining that primarily qualitative, rather than quantitative, differences differentiate lateral preferences. Right-, mixed-, and left-sidedness underlay the individual preferences, but sidedness alone could not fully explain the observed interrelations. Footedness was the single most important indicator of sidedness. Our data were further consistent with predictions of right shift theory and corroborated a 'pull-to-concordance' in hand–foot preferences. We recommend the use of psychometrically validated scales and of a trichotomous classification of lateral preferences in future research, but conclude that handedness may be a biased indicator of underlying sidedness. Footedness needs to be examined more closely with regard to cerebral lateralization, neurodevelopmental disorders, and neurodevelopmental instability.

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1. Introduction

The preference for one side of the body with regard to limbs (hand and foot), eyes, and ears is of long-standing interest for the study of cerebral lateralization, but also in its own regard. Handedness, probably the most investigated of these so-called functional lateralizations or asymmetries, is indicative of language lateralization in the brain (Szaflarski et al. 2002; Szaflarski, Holland, Schmithorst, & Byars, 2006) and is of ubiquitous importance in every-day life. With regard to its distribution, it is well-known that right-hand preference is dominant in the population, with prevalences around 90% (Coren, 1993; Peters, Reimers, & Manning, 2006).

Footedness refers to the dominant or preferred foot when performing manipulative or mobilizing actions in a bilateral context (Chapman, Chapman, & Allen, 1987; Gabbard & Iteya, 1996; Sadeghi, Allard, Prince, & Labelle, 2000), like kicking a ball (skilled movement) or standing on one foot (unskilled/stabilizing/balancing movement). Footedness is of importance in sports (e.g., Carey et al. 2009), but has also been reported to be an indicator of language and other cerebral lateralizations, even superior to handedness (Chapman et al., 1987; Gabbard & Iteya, 1996; Elias & Bryden, 1998; Elias, Bryden, & Bulman-Fleming, 1998; Searleman, 1980; Strauss, 1986), probably because of less social pressure regarding side preference (Chapman et al., 1987). Right-foot preference is considerably lower than right-hand preference in the population, averaging around 80% (Porac & Coren, 1981), but remarkably independent of foot skills (Carey et al., 2009).

Eyedness (ocular or sighting dominance) refers to the preference of one eye for monocular activities, such as looking through a telescope, and must be distinguished from sensory dominance in binocular activities and acuity dominance (visual acuity differences between the eyes), with both of which it is uncorrelated with (Porac & Coren, 1976). Only about two thirds of the population is right-eyed (Bourassa, McManus, & Bryden, 1996; Porac & Coren, 1976). Earedness refers to the preference of one ear in monaural activities, such as placing an ear against a closed door to listen in to a conversation, and appears to be the least investigated

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of the lateral preferences that are of concern here (Porac & Coren, 1981). Similarly to eyedness, sensory dominance or differences in acuity in binaural activities need to be conceptually distinguished from earedness (Noonan & Axelrod, 1981). Earedness is only weakly functional asymmetric, about 60% of the population being right-eared (Porac & Coren, 1981), but is apparently a better predictor of language lateralization than handedness, footedness, or eyedness (Strauss, 1986).

A plethora of studies has provided evidence that, overall, lateral preferences in handedness, footedness, eyedness, and earedness are concordantly interrelated with associations between handedness and footedness being often strongest (Bourassa et al., 1996; Dellatolas, Curt, Dargent-Paré, & De Agostini, 1998; Dittmar, 2002; Kang & Harris, 2000; McManus, Porac, Bryden, & Boucher, 1999; Noonan & Axelrod, 1981; Porac, 1997; Reiss, 1999; Reiss & Reiss, 1999; Suar, Mandal, Misra, & Suman, 2007). Thus, lateral preferences may share a common genetic or biological origin, primary or overall sidedness (Annett, 2002; Corballis & Morgan, 1978; McManus, 1985; Previc, 1991). While family and genetic studies suggest (strong) familial aggregations and (weak) genetic associations (Bourassa et al., 1996; Dellatolas et al., 1998; McManus et al., 1999; Reiss, 1999; Reiss & Reiss, 1999; Warren, Stern, Duggirala, Dyer, & Almasy, 2006), some twin studies have failed to confirm the genetic determination of sidedness (Reiss, Tymnik, Kögler, Kögler, & Reiss, 1999). To date, a complex multigenetic and multifactorial model of lateral preferences and their interrelations appears most likely (McManus, Davison, & Armour, 2013; Reiss, 1999; Warren et al., 2006).

However, research into lateral preferences faces some important methodological problems. First, given the skewed distributions of lateral preferences, sample size and study power are an issue. For example, the 10:90 handedness ratio lowers the power of statistical tests by about 50% compared to a 50:50 ratio. Large samples are thus required.

Second, classification of lateral preferences frequently adopts either a dichotomy (right/left and right/non-right) or a trichotomy (right/mixed/left), often based on arbitrary criteria and cutoffs on dimensional, continuous measures. This heterogeneity may prohibit direct comparisons between studies (Beaton, 2008) and may also lead to vastly different results even with the same data (Kelley, 2012). Most of the above reviewed studies used dichotomies for classification (but see Dittmar (2002), Gabbard and Iteya (1996) and Kang and Harris (2000)). However, there is evidence from latent variable analyses that at least for handedness a trichotomy may be more adequate (Dragovic & Hammond, 2007; Dragovic, Milenkovic, & Hammond, 2008).

Third, with regard to assessment itself, the use of multi-item inventories is recommended. The use of single items (such as 'writing hand' for handedness) may entail the underestimation of interrelations of lateral preferences (Bourassa et al., 1996; McManus et al., 1999; Warren et al., 2006) and of associations with other variables, such as sex (Papadatou-Pastou, Martin, Munafòm, & Jones, 2008). Yet, existing multi-item inventories, like the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) and the Lateral Preference Inventory (LPI; Coren, 1993), differ with regard to item composition and response format and rigorous psychometric analyses are scarce. Existing analyses suggest that some items of widely-used self-report inventories are inappropriate for the accurate assessment of handedness (Dragovic, 2004; Dragovic & Hammond, 2007; Milenkovic & Dragovic, 2013; Veale, 2013) and that skilled and unskilled activities may constitute separate factors in handedness (Healey, Liederman, & Geschwind, 1986; Kang & Harris, 2000; Mikheev, Mohr, Afanasiev, Landis, & Thut, 2002; Nicholls, Thomas, Loetscher, & Grimshaw, 2013; Steenhuis & Bryden, 1989) and footedness (Kalaycıoğlu, Kara, Atbaşoğlu, and Nalçacı 2008; Kang & Harris, 2000; Mikheev et al., 2002; Schneiders et al. 2010). However, the reported multidimensionality of handedness and footedness may have been spurious. Studies relied on factor-analytic methods that were not suited for the highly skewed item response distributions that are typically encountered in lateral preference inventories. This may have resulted in an overextraction of factors (see Bernstein and Teng (1989)), caused by the clustering of items with similar distributional properties in different factors. With regard to response format, it is unclear whether three categories, delineating 'right', 'left', and 'no preference' as in the LPI, or five categories, differentiating within 'left' and 'right' between 'always' and 'usually' as in revised versions of the EHI (Veale, 2013), are better suited for the assessment of lateral preferences.

Overall, there is a dearth of psychometric and latent variable analyses with regard to the assessment and classification of self-reported lateral preferences, even though such analyses are of importance for the various and numerous fields of applied laterality research.

Recent studies point out that mixed-handedness may be a risk factor for neurodevelopmental and neurobehavioral disorders (e.g., ADHD and language problems: Rodriguez et al. 2010; schizophrenia: Dragovic & Hammond, 2005; Sommer, Ramsey, Kahn, Aleman, & Bouma, 2001; schizotypy: Somers, Sommer, Boks, & Kahn, 2009), as mixed-handedness is considered an observable manifestation of underlying neurodevelopmental instability (Golembo-Smith et al. 2012; Rodriguez & Waldenström, 2008) and deficits in lateralization (Crow, 2013). Recently, Willems, Van der Haegen, Fisher, and Francks (2014) have advocated specifically including left-handers in neuroscientific and neurogenetic studies, instead of excluding them; this would further knowledge of brain functioning and allow a deeper insight into cerebral lateralization and its genetic underpinnings as it is currently the case. However, there is a need for psychometrically validated instruments that can be reliably used in applied research (Rodriguez et al., 2010).

The present study addressed the above issues. By design, our study comprised three independent, large samples (total $N > 15{,}100$), following recent recommendations to counteract potentially false-positive and thus irreproducible research findings (Asendorpf et al. 2013). In genome-wide association studies, independent discovery and replication samples within the same study are considered best practice, in order to guard against false-positive findings and to demonstrate the robustness of an effect, if the replication is successful (McCarthy et al. 2008). The present study included one sample ($n > 2400$) in which self-reported handedness was assessed with more items than in the other two samples (total $n > 12{,}700$). This sample served for calibration purposes (calibration sample), whereas the other two samples served for the purpose of cross-validation (comparison sample 1 and 2). With regard to all other lateral preferences, the three samples were full replication samples of each other.

First, we investigated the dimensional structure, item properties, and optimal number of response categories of widely-used self-report measures of lateral preferences in handedness, footedness, eyedness, and earedness with structural equation modeling (SEM) and item response theory (IRT). Second, using two independent approaches, latent class analysis and taxometric analysis, we determined whether lateral preferences were categorical or dimensional, providing empirically derived cutoffs that may be used in future research. Third, interrelations between lateral preferences were examined, investigating evidence for underlying overall sidedness, and also investigating the influence of sex and age on lateral preferences and sidedness. Fourth, the observed pairwise associations of lateral preferences were utilized to probe predictions of two specific single-locus genetic models, right shift (RS) theory (Annett, 2000; Annett, 2002) and the dextral and chance allele model (DC model; McManus, 1985) (for background and details, see Section 2.3.6 below).

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