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Investigating heritability of laterality and cognitive control in speech perception

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ABSTRACT

Several studies analyzing the ontogenetic origin of cerebral lateralization provide evidences for a genetic foundation of handedness in humans that is modulated by environmental influences. Since other forms of behavioral lateralization are less investigated, it is unclear as to how far different functions display similar heritability. But deeper knowledge is necessary to understand if and how developmental coupling of different functions is based on a shared genetic background or on the impact of environmental influences. Here, we investigated the heritability of language lateralization assessed with the dichotic listening task, as well as the heritability of cognitive control processes modulating performance in this task. Overall, 103 families consisting of both parents and offspring were tested with the non-forced, as well as the forced-right and forced-left condition of the forced attention dichotic listening task, implemented in the iDichotic smartphone app, developed at the University of Bergen, Norway. The results indicate that the typical right ear advantage in the dichotic listening task shows weak and non-significant heritability ($h^2 = 0.003$; $p = 0.98$). In contrast, cognitive factors, like attention focus (forced right condition: $h^2 = 0.36$; $p < 0.01$; forced left condition: $h^2 = 0.28$; $p < 0.05$) and cognitive control (Gain forced right: $h^2 = 0.39$; $p < 0.01$; Gain forced left: $h^2 = 0.49$; $p < 0.01$) showed stronger and significant heritability. These findings indicate a variable dependence of different aspects of a cognitive function on heritability and implicate a major contribution of non-genetic influences to individual language lateralization.

1. Introduction

One of the most controversial topics in laterality research is the question, to what extent functional hemispheric asymmetries are heritable (Collins, 1975; Francks et al., 2007; McManus, Davison, & Armour, 2013; Ocklenburg, Beste, Arning, Peterburs, & Güntürkün, 2014; Ocklenburg, Beste, & Güntürkün, 2013; Rentería, 2012). For handedness, evidence from adoption (Carter-Saltzman, 1980) and twin studies (Ooki, 2014) convincingly suggests that it is at least partly controlled by genetic factors. Interestingly, different aspects of handedness seem to have differential heritability, since Lien, Chen, Hsiao, and Tsuang (2015) found that degree of handedness showed higher heritability than a hand-preference index and direction of handedness. This suggests that different functional neuronal systems are involved in determining these aspects, all of them having their own gene-dependent pattern. To this respect, it would be useful to compare heritability of handedness with other lateralized functions to understand which aspects are most likely under genetic control and which are influenced by environmental factors. A shared genetic background may cause developmental coupling of different lateralized functions. Unfortunately, for all other forms of laterality (such as lateralization of language, emotion or spatial abilities), experimental evidence supporting or disproving a relation of children's and parent's left-right preferences is extremely scarce.

As a rare exception, Bryden (1975) published a study in which he used the dichotic listening task to investigate how language lateralization runs in families. Familial correlations in 49 families revealed somewhat puzzling results. While there was a significant positive correlation between the dichotic listening lateralization quotient (LQ) of mothers and offspring, no such relation was found

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between the LQs of fathers and offspring. Moreover, there was a stronger LQ correlation between the mother and father than between any parent and child, which is somewhat inexplicable. Also, there was a significant negative correlation between siblings, which would argue against genetic control of the trait. Bryden (1975) concluded that his dataset was too small to allow for definitive conclusions about the heritability of the trait and that further research on the topic was warranted. Unfortunately, in the decades after the publication of this paper no one followed up on this suggestion, with the exception of Somers et al. (2015) who recently performed a genetic linkage study in 355 subjects from 37 families. The estimated heritability of language lateralization measured with functional transcranial Doppler sonography during speech production was 31%, indicating moderate heritability of the trait. One factor that could explain the somewhat stronger heritability in the Somers et al. (2015) study compared to Bryden's (1975) work is the fact that Somers et al. (2015) investigated speech production, while the dichotic listening task used by Bryden (1975) targets speech perception. Moreover, performance in the dichotic listening task is not a 100% 'pure' measure of language lateralization. For example, Westerhausen, Passow, and Kompus (2013) showed that speech-related cognitive processes impact non-forced dichotic listening. One way of experimentally assessing the role of cognitive processes in the dichotic listening task is the forced-attention version (Hugdahl & Andersson, 1986; Hugdahl et al., 2009; Kompus et al., 2012). This version of the paradigm also includes two so called forced-attention conditions, one in which the subject is instructed to only attend to input from the left ear ('forced-left', FL) and one in which the subject is instructed to only attend to input from the right ear ('forced-right', FR), in addition to the classic, so called non-forced, NF condition with no instruction about attention focus. As suggested by Hugdahl et al. (2009), the FR condition taps the ability to shift attention when the bottom-up, non-instructed, and top-down, instructed processing strategies work synergistically, while the FL condition taps the ability for cognitive control, since the bottom-up and the top-down processing strategies are antagonistic, and induce a cognitive conflict situation. The forced-attention version of the task has recently been implemented in a smartphone app named 'iDichotic' (Bless et al., 2013, 2015), allowing for easier access to large samples of participants outside of traditional laboratory setting. Bless et al. (2013) recently evaluated the retest reliability and concurrent validity of this app under controlled laboratory settings, finding both reliability (intraclass correlation coefficient r_{ICC}: 0.78) and validity (r_{ICC}: 0.76–0.82) to be high. Moreover, these authors explored the ecological validity of the iDichotic app by releasing the app to the iTunes App Store and collecting data from the general public. Comparable to the laboratory version of the Dichotic listening paradigm, they found a significant right ear advantage. Based on these findings, Bless et al. (2013) concluded that the iDichotic app presents a valid and reliable method for administering the dichotic listening paradigm.

In the present study, this app was used to test families (parents and offspring) in their homes in order to disentangle heritability and cognitive factors from performance on the dichotic listening task.

2. Materials and methods

2.1. Participants

Overall, we tested 103 families consisting of one offspring, one mother and one father. All parents were biological, not adoptive parents, as evidenced by self-report. Offspring were mostly university students. All participants were fluent German speakers and indicated that they were neurologically and psychiatrically healthy adults. Mean age of the offspring group was 25.97 years (SD: 8.10), mean age of the mothers was 53.86 years (SD: 7.52) and mean age of fathers was 56.59 years (SD: 7.30). Within the offspring group, 60 participants were female (58%) and 43 participants were male (42%). As a pretest, all prospective participants were instructed to take a simple hearing test administered within the iDichotic app (Bless et al., 2013, 2015). In this pretest, participants listen to a continuous pure tone of 1000 Hz and are asked to reduce the sound level by sliding a bar on the iPhone display to the left until they are unable to hear the sound. The sound level when the participants cannot longer hear the tone is stored. Only participants with normal hearing capabilities and no more than 20% hearing difference between the ears were included in the sample. All participants gave written informed consent prior to testing, and they were treated in accordance with the declaration of Helsinki. The study was approved by the local Ethics Committee of the Faculty of Psychology at Ruhr-University Bochum, Germany.

2.2. Behavioral testing

Participants were tested in the comfort of their own home. After the experimenter had explained the aim of the study and participants had signed the informed consent form, handedness was assessed using the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971). This ten-items questionnaire yields a laterality quotient, indicating the individual strength and direction of handedness from consistent left-handedness (−100) to consistent right-handedness (+100). Afterwards, dichotic listening performance was assessed using the iDichotic app for iOS (available free of charge on Apple's App Store). Participants were tested with an iPod touch (Apple Inc., Cupertino, CA) and over-the-ear headphones outfitted with disposable hygienic sleeves. The stimuli used within the app were based on the standard Bergen dichotic listening paradigm (Hugdahl, 2003) and consisted of six consonant-vowel syllables (/ba/, /da/, /ga/, /ta/, /ka/, /pa/). The stimuli were presented simultaneously in pairs, resulting in 30 dichotic and 6 homonym stimulus pairs, yielding a total of 36 pairs. As testing took place in Germany, the German language stimulus set within the app was used. Stimuli were spoken by a male speaker with constant intonation and intensity. The stimulus duration was between 400 and 500 ms and the inter-stimulus interval was 4000 ms. Onsets of the initial stop-consonants were temporally aligned to each other syllables within each pair.

All three family members were tested individually one after the other in a room without background noise. The total stimulus set was presented three times, each time with a different instruction. The non-forced condition (NF), implemented as "Listen" in the application, was always presented first, and included the instruction to report the syllable they heard best after each trial. In the forced-left condition (FL), implemented as "Concentrate Left" in the app application, participants were instructed to only concentrate on the left ear and report the syllable they heard on that ear. In the forced-right condition (FR), implemented as "Concentrate Right" in the app application, participants were instructed to only concentrate on the right ear and report the syllable they heard on that ear. Participants reported which stimulus they heard best by touching one out of six syllables on the touchscreen of the mobile device. The order in which the syllables appeared on the screen was randomized between the three instruction conditions.

2.3. Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 20. For the handedness data, an lateralization quotient (LQ) was calculated based on the formula $LQ = [(R - L)/(R + L)] * 100$, with