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## Does hand skill asymmetry relate to creativity, developmental and health issues and aggression as markers of fitness?

Fleur E. van der Feen<sup>a</sup>, Nele Zickert<sup>b</sup>, Ton G.G. Groothuis<sup>b</sup> and Reint H. Geuze<sup>a</sup>

<sup>a</sup>Clinical and Developmental Neuropsychology, University of Groningen, Groningen, Netherlands; <sup>b</sup>Behavioral Biology, the Groningen Institute for Evolutionary Life Sciences, University of Groningen, Groningen, Netherlands

### ABSTRACT

A remarkable feature of human handedness at the population level is specialization of the hands, the right hand performing usually better than the left. This specialization might have an evolutionary advantage, because it provides the individual and population with a wider range of skill. We therefore investigated the relationships between hand skill asymmetry and potential markers of Darwinian fitness that have been hypothesized to explain the bias in hand preference: creativity, aggression and developmental and health problems. Over twenty thousand participants (56% left-handers) completed an online survey, including a finger-tapping task to measure hand skill asymmetry. Left-skilled individuals were overall more aggressive than right-skilled individuals and rated themselves as more artistically creative. However, when assessed with a questionnaire, they were less creative on problem solving and equally artistically creative compared to right-skilled individuals, who reported more health problems. Conclusion: we found some evidence for current selection on the direction of lateralization of hand skill although the effect sizes were rather low. Strength of lateralization of hand skill showed only a few associations with fitness proxies. We suggest that Darwinian selection on hand preference (Zickert, Feen, van der Geuze, & Groothuis, 2018). Fitness costs and benefits associated with hand preference in humans: A large internet study in a Dutch sample. *Evolution and Human Behavior*, 39, 235–248) and hand skill asymmetry (present study) may be attenuated in modern society.

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**KEYWORDS** Finger tapping; lateralization; fitness; number of offspring; problem solving

**CONTACT** Reint H. Geuze  [r.h.geuze@rug.nl](mailto:r.h.geuze@rug.nl)

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## Introduction

Handedness—both hand preference and specialization of the hands—is a salient characteristic in humans, with a bias to the right at the population level. Specialization refers to the difference in skill between the hands as the outcome of biological factors, experience and training, whereas preference is a psychological construct (Geuze et al., 2012). Handedness is not a unique human characteristic, as paw preference and specialization is present in a range of vertebrate species at the individual level, and it has been estimated that some 50% of species show paw preference also at the population level (Ströckens, Güntürkün, & Ocklenburg, 2013). In humans an extreme population-level asymmetry exists for hand preference; 87–90% of all individuals prefer using their right hand for the gross majority of manual tasks, while only 10–13% prefer to use their left hand (Corballis, 2009). While it may vary across cultures (Raymond & Pontier, 2004), dimorphism in handedness is present in all human cultures (Perelle & Ehrman, 1994) and is rather stable over time, as evidence from archaeological artefacts and historical statues and drawings suggests (Bradshaw & Rogers, 1996). Specialization of the hands, also known as hand skill asymmetry, is known to be biased to the right too. Hand skill asymmetry is apparent from the difference in performance between the hands when both hands are tested on a unimanual task (Annett, 1985). In the majority of the population the right hand is more proficient, but this bias is much weaker than for hand preference. Moreover, the distributions of hand skill asymmetry and hand preference are fundamentally different, the first having a normal distribution with some bias to the right, the latter being U-shaped with high frequencies for strong left and even more so for strong right hand preference (Hiscock & Chapiesski, 2004, p. 358). The relationship between hand preference and hand skill asymmetry is complex and not well understood (Bryden, Mayer, & Roy, 2011). The correlation between hand preference and hand skill asymmetry depends on the task and its complexity and is generally moderate to low (Peters, 1998), with some 10–30% of human subjects having disparate hand preference and hand skill asymmetry (see Geuze et al., 2012).

It has been suggested that the strong dimorphism in human hand preference is the outcome of an evolutionary selection process (Groothuis, McManus, Schaafsma, & Geuze, 2013). If left and right hand preferences are associated with different cost–benefit functions affecting fitness, and some of these depend on their frequencies in the population, this may result in a dimorphism in hand preference in the population; this has been the topic of a large internet study by Zickert, Feen, van der, Geuze, & Groothuis (2018). Alternatively, such fitness traits might be linked not to hand preference but to hand skill asymmetry. Specialization of the hands may have an additional evolutionary advantage, because it provides the individual and

the population with a wider range of skill, which may promote survival. In the present study we therefore focused on the relationships between hand skill asymmetry and potential markers of Darwinian fitness, including health (Groothuis et al., 2013; Schaafsma, 2012, Chapter 7), creativity (Nicholls, Chapman, Loetscher, & Grimshaw, 2010) and aggression (Faurie et al., 2011; Pollet, Stulp, & Groothuis, 2013). Based on the literature, and similar to the hand preference study of Zickert et al. (2018), we hypothesized that left-skilled individuals are more creative, more aggressive, and have more developmental and health problems.

Creativity is a rather wide concept, and several types of creativity are distinguished. Sawyer (2012, Chapter 3) reviewed the concepts of creativity and distinguished between artistic creativity and problem solving creativity, the latter being separated in divergent thinking and convergent thinking (Sawyer, 2012, Chapter 3). Convergent thinking refers to the ability to provide a standard solution to a given problem using an analytical procedure. Divergent thinking: involves creative generation of multiple answers to a set problem. A number of studies report an association between handedness and artistic creativity (e.g., Peterson, 1979), and between handedness and problem solving creativity defined by divergent (Coren, 1995) and convergent thinking (Coren, 1995; Croyley, 2006; Mihov, Denzler, & Förster, 2010), left-handers being more creative. There is evidence that women find creativity in men attractive, especially during the most fertile phase of the menstrual cycle (Haselton & Miller, 2006), and that poets and visual artists have more sexual partners than controls (Nettle & Clegg, 2006). Problem solving creativity may enhance chances for survival and contribute to social status. Creative behaviour is associated with better coping skills in school-aged children when facing a threatening situation (Carson, Bittner, Cameron, Brown, & Meyer, 1994). Creativity may be subject to negative frequency-dependent selection, because when the trait is rare, chances for reproduction are higher for individuals with rare creative capacities.

It has been reported that the preferred hand is more often used when dealing with difficult manual tasks (Steenhuis & Bryden, 1989, 1999), as may be the case for the production of creative artwork. Alternatively, for tool use, individuals will generally use their most skilled hand, and it is possible that specialization of the hands more directly contributes to the expression of creativity. This brief literature review supports the notion that hand specialization and creativity may be associated. One of the costs associated with left-handedness is an increased level of developmental and health problems. Elevated frequency of left-hand preference has been found in individuals who were born prematurely (Domellöf, Johansson, & Rönqvist, 2011; Ross, Lipper, & Auld, 1992). Early risk factors such as prematurity (Bailey & McKeever, 2004) may lead to atypical organization of the brain. Tønnesson, Løkken, Høien, and Lundberg (1993) found that the percentage of dyslexia is twice

as high among left-handers, and the prevalence of immune disorders is slightly increased (Moffit & Weeks, 2001). Further, it has been hypothesized that prenatal brain damage also leads to a shift of dominance to the right hemisphere and a greater susceptibility to developmental or health problems (Coren, 1992; Johnston, Nicholls, Shah, & Shields, 2013). The shift in dominance to the right hemisphere would promote both left-hand preference and affect hand skill asymmetry. In addition to the developmental health issues, general health issues may also be associated with handedness (Steenhuis, Bryden, & Schroeder, 1993). For example, Bryden, Bruyn, and Fletcher (2005) found associations between left-handedness and epilepsy, heart disease, thyroid disorders, circulation problems and allergies in a sample of undergraduate students. However, there is no previous research on the relationship between hand skill asymmetry and the above health issues. Therefore, we included general health and developmental measures in our study, including dyslexia, allergies and prematurity.

A major theory that explains the persistence of a minority of left-handers in the population by negative frequency-dependent selection is the fighting hypothesis (Llaurens, Raymond, & Faurie, 2009; Raymond, Pontier, Dufour, & Molier, 1996). This theory assumes an advantage for left-handers due to a surprise effect in one-to-one fights, right-handers having little experience with a left-handed opponent, whereas left-handers having ample experience against right-handers. The higher winning chances of left-handers compared to right-handers as found in many direct interactive combat sports (Grouios, Haralambos Tsorbatzoudis, Alexandris, & Barkoukis, 2000; Loffing & Hagemann, 2016, table 12.1) is compatible with this. An alternative explanation for this pattern of winning chances is a greater tendency to engage in fights in the first place, as suggested by Dinsdale, Reddon, and Hurd (2011; see also Groothuis et al., 2013; Pollet et al., 2013). Given the moderate correlation between hand preference and the bias in hand skill, in the present study we will explore the relation between winning fights and aggressive tendencies and hand skill asymmetry.

The general beliefs that left handedness is associated with being more creative, aggressive, and being less healthy, as well as most literature on the matter, are concerned with the direction of handedness, that is, being either left or right (Denny, 2008). However, as hand preference and hand skill asymmetry are continuous variables, the strength of handedness might be subject to evolutionary selection as well. Dinsdale et al. (2011) found that the degree of lateralization, also known as strength of lateralization, was more predictive of aggressiveness than the direction of lateralization. Although we found no previous research on the strength of lateralization and creativity, one could argue in this case too that the strength, rather than the direction of hand skill specialization is related to creativity. Therefore,

not only the direction, but also measures of strength of hand skill asymmetry have been included in the analysis.

The research question for the present study is: Do direction and/or strength of hand skill asymmetry relate to creativity, developmental and health issues and aggression as markers of fitness? We expect greater fitness costs in developmental and health issues and fitness advantages in creativity and aggression among individuals who are more skilled with their left hand as compared to right-skilled individuals. Additionally, we will explore if strength of hand skill asymmetry relates to these markers of fitness. Individuals having greater hand skill asymmetry are hypothesized to be more creative and more aggressive. As sex differences have been reported (Coren, 1995; Kilshaw & Annett, 1983), and strength of handedness may change with age (Davis & Annett, 1994; Kilshaw & Annett, 1983), we took age and sex into account. We used a nation-wide online survey ( $n > 20000$ ) that assessed participants' creativity, aggression and health problems. The survey included a tapping task to measure hand skill asymmetry.

## Methods

An internet survey was available to the Dutch speaking public from October 2014 to May 2015. The questionnaire was designed and presented on research platform Qualtrics (Provo, Utah). We informed the public about the project and the survey through interviews in national papers and on the radio, press releases, social media, and the Weekend of Science Activities (Weekend van de Wetenschap) at NEMO Amsterdam ([www.nemosciencemuseum.nl](http://www.nemosciencemuseum.nl)). The ethical committee of the Department of Psychology, University Groningen approved the project (registration ppo013056).

## Participants

Initially, 32,305 respondents participated in the internet survey. Strict exclusion criteria were applied to ascertain valid data. Participants were excluded who

- had missing data on age, sex or the five self-assessment scales
- were under the age of 15, or above the age of 100
- specified their sex as other than male or female
- gave nonsense answers, such as having 3 grandchildren by the age of 20.

In addition, we applied specific exclusion criteria concerning the tapping task. Participants were excluded who

- reported to have a limitation in using their hands or arms

- reported procedural mistakes in tapping task execution
- had less than 6 or more than 50 cycles in one of the 20s trials
- had an zAI of  $-4$  to  $+4$  (AI being the asymmetry index of the hands).

After applying the exclusion criteria, we had a reliable dataset of 20,539 participants (56% left-handers). [Table 1](#) shows the sex and age characteristics of our sample.

## Questionnaire

The questionnaire was organized in sections. In the first section of the questionnaire participants completed the informed consent and general information on sex, birthdate, limitations in upper limbs, number of children and the hand preference of both parents (Appendix 1 section 1a).

In the second section, the participants were asked to rate themselves on artistic creativity, problem solving creativity, health problems and irritability by setting a slider on a scale from 0 to 100. The midpoint of the scale was described as being equal to the average of the respective trait of others. Next, the participants were asked to indicate their hand preference on a scale from  $-100$  (extremely left) to  $100$  (extremely right) (Appendix 1 section 1b). Subsequently, the individual scores of the participant were presented relative to average scores of the sample of a pilot study ( $n \approx 150$ ).

In the third section measures of hand preference and hand skill were collected. For hand preference a Dutch translation of the Edinburgh Handedness Inventory was used (Oldfield, 1971; Van Strien, 1992, 2003). Participants were asked which hand they use to perform a specific every day task, such as brushing teeth. They could choose one out of 5 answer possibilities: Left, mostly left, no preference, mostly right and right (Appendix 1 section 1c). The hand preference data have been presented in a separate paper (Zickert et al., 2018).

Hand skill was measured by an alternating key press task (“tapping task”). The participants were required to alternate with their index finger between two keys of a keyboard as accurate and as fast as possible, during 20 s (“gk” for the right hand and “gs” for the left hand). After one training trial of five seconds both hands were tested twice in random order. From the correct pairs an asymmetry index (AI) was calculated as  $(nR-nL)/(nR+nL)$ , with nR and nL the mean of the number of correct pairs (gk or gs) tapped with the right and the left hand respectively. As some participants executed the task

**Table 1.** Mean age and age range for male and female participants.

	<i>n</i>	Mean age	Range
Male	8889	43.2	15–91
Female	11650	39.5	15–87

on a regular keyboard, whereas others used a mobile device, the distance between the keys may differ; therefore a z-score of the asymmetry index was calculated (zAI) per type of input device (mobile device versus desktop computer). The distribution zAI is close to normal (see Appendix 2).

In the fourth section of the questionnaire the participant's artistic creativity, irritability and health problems were assessed in more detail. To assess artistic creativity, we asked the participants how often they engage in specific artistic activities. The questions consisted of six different categories: Creating images, music, writing and storytelling, plastic arts and performing arts. Participants responded on a 5-point Likert scale, ranging from "I never do this" to "I do this very often". A sum score was calculated ranging from 0, meaning no artistic activities, to 30, meaning a lot of artistic activities very often (see Appendix 1 section 1d).

Irritability was assessed in two parts. Firstly, participants were asked to indicate how they would respond to different hypothetical situations that typically would evoke a strong emotional response on a 5- or 6-point Likert scale, ranging from "I would do nothing" to non-verbal, verbal or physical reactions to the situation. Secondly, the participants were asked how often they participated voluntarily in physical or verbal fights in the past ten years, or in their childhood, responding on a 5-point Likert scale ranging from "never" to "more than ten times". A composite irritability score was calculated from the weighted ordinal scores of all questions besides the assessment of winning (the questions and formula can be found in the Appendix 1 section 1e).

To assess health problems, the participants were asked how often they had been ill in the past 12 months (5-point Likert Scale, ranging from "never" to "more than five times"). Subsequently, if the participants had been ill one time or more, they could answer on a 7-point Likert scale how many days they had been ill ranging from "1-3 days" to "long term illness". Here an additional option was "I don't want to answer the question"; these participants were excluded from the statistical analysis of health problems. From the number times being ill and the number of days being ill a score was calculated (health composite score) that could range from 0 (never ill) to 13 (very often or chronically ill). (For health related questions see Appendix 1 section 1f).

Next, the participants were asked about the occurrence of allergies, being born prematurely (before 8 months) and the occurrence of dyslexia, with alternative answers: yes, no and I don't know. If a participant reported to have allergies, he/she was asked to indicate the number of different allergens being sensitive to, on a 6-point Likert scale, ranging from 1 to "more than 5" (for complete questions and response scales, see Appendix 1 section 1g).

After this part of the questionnaire, the participants received feedback about their hand preference, hand skill scores and about their creativity and irritability scores.

At this point, the participants could choose to submit the questionnaire or to continue. This part of the questionnaire focussed on problem solving creativity, that is divergent thinking (DT) and convergent thinking (CT). Divergent thinking was assessed with an alternate uses task (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Piffer, 2012) in which the participant is asked to name as many uses for a common object within a limited time frame. We asked for as many uses for a book within two minutes. The participants typed their answers in separate boxes. When the two minutes had passed, the next page of the questionnaire was automatically presented. Convergent thinking was assessed with twelve questions that require “thinking out of the box”. Six of these required mathematical thinking and six verbal reasoning (full questions in Appendix 1 section 1h). The participants had to choose the correct answer from five alternatives, with the option to enter an alternative if they thought the right answer was not listed. In addition, the participants were asked to indicate whether they were already familiar with the question; if so, the question was skipped.

### **Data analysis**

To calculate the scores for divergent thinking, multiple steps had to be taken. We corrected typing errors, removed invalid or incomprehensible answers, converted multi-word entries to a representative single keyword, and converted synonyms into a single entry (both within and between subjects). Next we calculated the frequency of each unique answer in the data base, and derived an originality score for each answer by assigning a score of 10 to extremely rare answers in the lowest decile and a score of 1 to the most frequent answers, that is in the highest decile. Finally, we calculated three divergent thinking scores per participant: a fluency score, which was the amount of valid answers given; a combined score, which was the sum of the originality scores; and an originality score, which was the average originality score per valid answer. The details of the calculation and analysis can be found in Appendix 3.

From the twelve questions in the convergent thinking questionnaire, three scores were calculated: a total score, and subscores for mathematical and verbal questions. For each the number of correct answers was divided by the number of questions the participant was not familiar with.

### **Statistical analysis**

We used SPSS version 20.0 for all statistical analyses.

#### *Reliability of the tapping task*

To test the reliability of the tapping task, the score of the first trial was correlated with that of the second trial for the left and right hand respectively.

### Principal component analysis

Our main hypotheses concern the relation between hand skill asymmetry and the three clusters: creativity, health, and aggression. These clusters are composed of multiple variables. To reduce the amount of dependent variables in the analysis, a principal component analysis (PCA) was performed within each cluster (as in Zickert et al., 2018—please note that sample selection differs between the two studies). The principal components (PC) were calculated from setting covariance matrix, factor Eigenvalue >1 and varimax rotation. For creativity three principal components were extracted and for health and aggression one component each (see Table 2). These five components were used in the analysis of our main hypotheses, with alpha set to  $0.05/3 = 0.017$  for creativity, and alpha set to 0.05 for health and aggression variables.

### General linear model

The components extracted from the PCA were used as dependent variables in the linear regression analyses. The zAI, as calculated from the tapping tasks

**Table 2.** Principal component analysis for creativity, health and aggression measures. Explained variance per principle component: Creativity 74.3% [convergent thinking 31.6%, divergent thinking 26.0% and self-assessed + artistic creativity 16.7%]; Health: 70.2%; Aggression: 50.0%.

Creativity	Principal Components		
	1	2	3
Convergent thinking—total	.997		
Convergent thinking—verbal	.846		
Convergent thinking—math	.841		
Divergent thinking—originality		.979	
Divergent thinking—combined		.909	
Divergent thinking—fluency		.774	.152
Artistic—self-assessment			.869
Artistic—questionnaire		.149	.860
Problem solving—self-assessment			.530
Health			
Principal Component	1		
Health problems composite score	.985		
Days being ill (>12months)	.894		
Times being ill (>12months)	.882		
Health problems—self-assessment	.513		
Aggression			
Principal Component	1		
Aggression—sum score	.857		
Verbal fights	.743		
Aggression—self-assessment	.660		
Childhood fights	.644		
Fights (past 10 years)	.643		

and zAI squared (zAI<sup>2</sup>), were entered as independent variables to check for linear and quadratic effects of hand skill asymmetry. When a significant relation between a component and hand skill asymmetry was found, we repeated the analysis for the separate variables that constitute the component. The number of allergens—not included in the PCA—was analyzed in the same manner. In case of significant effects, we plotted the relationships using the slope and the intercept.

### *Generalized linear model*

The variables occurrence of allergies, dyslexia, prematurity, and number of children did not have a continuous scale; therefore, we applied a generalized linear model. For the number of children we used a negative binomial log link, for the other variables a binominal logit link function. The graphs were created in the same manner as for the general linear model.

In these GLM and GzLM analyses sex, age and age<sup>2</sup> were included as covariates, because it is known that tapping is age and sex dependent (Cousins, Corrow, Finn, & Salamone, 1998; York & Biederman, 1990).

## **Results**

### *Reliability of the tapping task*

The correlations (Pearson *r*) between the first and second trial of the tapping task performance were .73 for the left hand and .80 for the right hand, indicating test-retest reliability of the tapping task to be satisfactory.

### *Hand skill asymmetry*

The distributions of the hand skill indices were close to normal (Appendix 2). The mean zAI (range  $-4$  to  $+4$ ) in the complete sample was  $-.0033$ , with 47.8% of the participants having a positive zAI, hence 52.2% was more skilled in tapping with the left hand. Using a *t*-test, no difference was found in age between the more left-skilled participants and the more right-skilled participants ( $p = .096$ ). Also, the female to male ratio did not differ between more left and right-skilled participants (see Table 3; Fisher's exact test  $p = .058$ ).

**Table 3.** Means of zAI and range, percentages negative (%-) and positive (%+) zAI. zAI is the z-score of the hand skill asymmetry index, the range of zAI being  $-4$  to  $+4$ .

	zAI			%–	%+
	<i>n</i>	<i>mean</i>	<i>sd</i>		
Male	8889	.006	.954	51.6	48.4
Female	116850	–.011	.960	52.7	47.3

## Principle components predicted by hand skill asymmetry

### Creativity

*Creativity PC1.* Creativity PC1 represents convergent thinking, and consists of the three convergent thinking scores, mathematical, verbal and total score. The results of the linear regression analysis on creativity PC 1 indicate, that hand skill asymmetry (zAI) predicts convergent thinking, ( $R^2_{\text{model}} = .084$ ,  $F(5,7310) = 134.4$ ,  $p < .0001$ ) (Table 4). No quadratic effect was found. As the regression line in Figure 1 shows, right-skilled participants have higher convergent thinking scores than left-skilled participants.

Next, we analyzed the relationship between hand skill asymmetry and convergent thinking for each of the three convergent thinking measures. The mathematical, verbal and the total measure all contributed to the model:  $R^2_{\text{model}} = .060$  to  $.086$ ,  $p < .0001$  (Table 4). The regression lines of the three measures show the same pattern as the regression line of creativity component 1: Right-skilled participants show slightly higher scores on mathematical convergent thinking, verbal convergent thinking and the total convergent thinking score than left-skilled participants.

*Creativity PC2.* The second creativity component represents divergent thinking, and consists of the variables fluency, originality and a combined score. The regression analysis shows that hand skill asymmetry positively predicts divergent thinking ( $R^2_{\text{model}} = .036$ ,  $F(5,7310) = 55.1$ ,  $p = <.0001$ ; Table 4, Figure 2). No quadratic effect of hand skill was found. As with creativity PC1, right-skilled participants show higher scores on the divergent thinking component than the left-skilled participants.

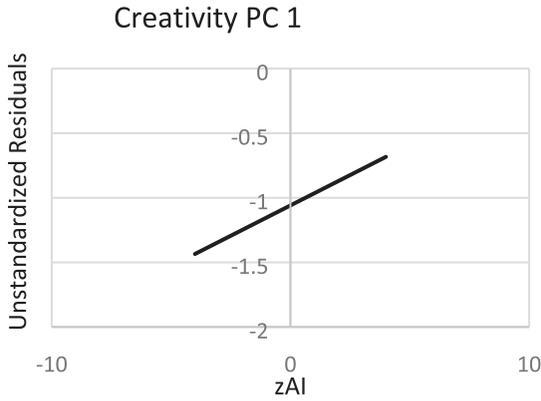
The separate measures of divergent thinking were also predicted by hand skill ( $R^2_{\text{model}}: .020$  to  $.049$ ,  $p < .00001$ ; Table 4). The effects of each correspond with the regression line of the divergent thinking component (Figure 2). None of the models indicated a quadratic effect.

*Creativity PC3.* The self-assessments of artistic creativity and problem solving creativity, and the score on the artistic creativity questionnaire constitute the third creativity component. In contrast to the first two creativity components, a quadratic effect of hand skill asymmetry on creativity PC3 was found ( $R^2_{\text{model}} = .008$ ,  $F(5,7310) = 13.6$ ,  $p = .007$ ). The more extreme right-skilled and left-skilled participants scored higher on this component than the participants with less asymmetry between the two hands (Figure 3(A)).

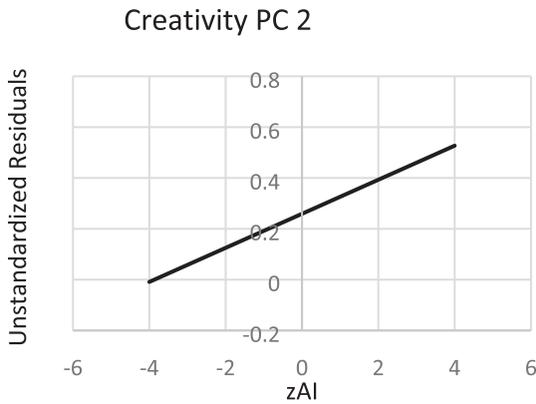
However, for the separate variables of creativity PC3 results differ (Figure 3 (B)). The relationship between hand skill and the self-assessment of artistic creativity was linear ( $R^2_{\text{model}} = .026$ ,  $F(5,20533) = 109.5$ ,  $p = .010$ ). Left-skilled participants evaluate themselves as slightly more (artistically) creative than the right-skilled. For the self-assessment of problem solving creativity a linear effect was found ( $R^2_{\text{model}} = .031$ ,  $F(5,20533) = 133.3$ ,  $p = .005$ ). However, contrary to the self-assessment of artistic creativity, right-skilled

**Table 4.** Results of GLM for hand skill asymmetry (zAI). Linear and quadratic effects of zAI on creativity, health and aggression traits correcting for age, age2 and sex. [PC—principle component; CT—convergent thinking; DT—divergent thinking. Self refers to self-evaluation of the trait on a 0–100 scale].

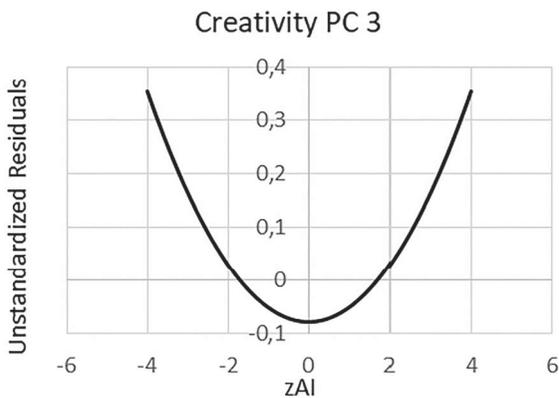
	<i>n</i>	<i>F</i> (df, df)	zAI		zAI <sup>2</sup>		Sex		Age		Age <sup>2</sup>		<i>R</i> <sup>2</sup> <sub>model</sub>
			<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	
Creativity PC 1	7316	134.4 (5, 7310)	<.0001	.094	.897		<.0001	.476	<.0001	.034	<.0001	-.001	.084
CT_math	8794	112.3 (5, 8788)	<.0001	.018	.106		<.0001	.091	<.0001	.005	<.0001	-.00001	.060
CT_verbal	9793	112.1 (5, 8787)	<.0001	.018	.240		<.0001	.092	<.0001	.009	<.0001	-.0001	.064
CT_total	9788	167.2 (5, 8782)	<.0001	.018	.113		<.0001	.091	<.0001	.007	<.0001	-.0001	.086
Creativity PC 2	7316	55.06 (5, 7310)	<.0001	.067	.367		.018	.347	<.0001		<.0001	-.0002	.036
DT_fluency	8353	86.28 (5, 8347)	<.0001	.305	.215		.638		<.0001	.134	<.0001	-.002	.049
DT_originality	8353	70.28 (5, 8347)	<.0001	1.424	.171		.257	.008	.221	<.0001		-.005	.040
DT_Combined	8353	34.44 (5, 8347)	<.0001	.052	.803		.002	-.066	.035		.923		.020
Creativity PC 3	7346	13.59 (5, 7310)	.246		.007	.027	<.0001	-.165	.009	.012		.037	.008
Artistic_self	20593	109.5 (5, 20533)	.010	-.507	.024		<.0001	-8.750	.038		.129		.026
Problem solving_self	20593	133.3 (5, 20533)	.005	.309	.272		<.0001	4.172	<.0001	.591	<.0001	-.006	.031
Artistic_questionnaire	20593	73.47 (5, 20533)	.042		<.0001	.104	<.0001	-1.063	.001	-.035	.007	.00033	.017
Health PC 1	12517	50.28 (5, 12511)	.015	.022	.053		<.0001	-.235	<.0001	-.027	<.0001	.00034	.019
Health_self	20593	69.05 (5, 20533)	<.0001	1.703	.001	.507	<.0001	-3.812	.928		.009	.0020	.016
Times ill	20408	242.5 (5, 20402)	<.0001	.046	.006	.020	<.0001	-0.296	<.0001	-.041	<.0001	.00029	.056
Days ill	12517	42.09 (5, 12511)	.223		.292		<.0001	-.257	<.0001	-.021	<.0001	.00034	.016
Health_composite	12517	47.04 (5, 12511)	.069		.089		<.0001	-.519	<.0001	-.068	<.0001	.0010	.018
Number of allergies	7417	22.37 (5, 7412)	.851		.154		<.0001	-.413	.023	.017	.068		.014
Aggression PC 1	20539	123.4 (5, 20533)	.010	-.019	.193		<.0001	.298	.016	.006	<.0001	-.00014	.029
Aggression_self	20539	34.76 (5, 20533)	.680		.269		<.0001	-2.690	<.0001	.624	<.0001	-.0070	.008
Aggression_sum	20539	181.9 (5, 20533)	.009	-.089	.342		<.0001	1.839	<.0001	.135	<.0001	-.0020	.042
Fights (<10years)	20539	407.7 (5, 20533)	.013	-.009	.313		<.0001	.116	<.0001	-.032	<.0001	.00026	.090
Childhood fights	20539	180.5 (5, 20533)	.092		.395		<.0001	.273	<.0001	.008	.001	-.0010	.042
Verbal fights	20539	118.9 (5, 20533)	.057		.696		<.0001	.153	.012	.006	<.0001	<.001	.028



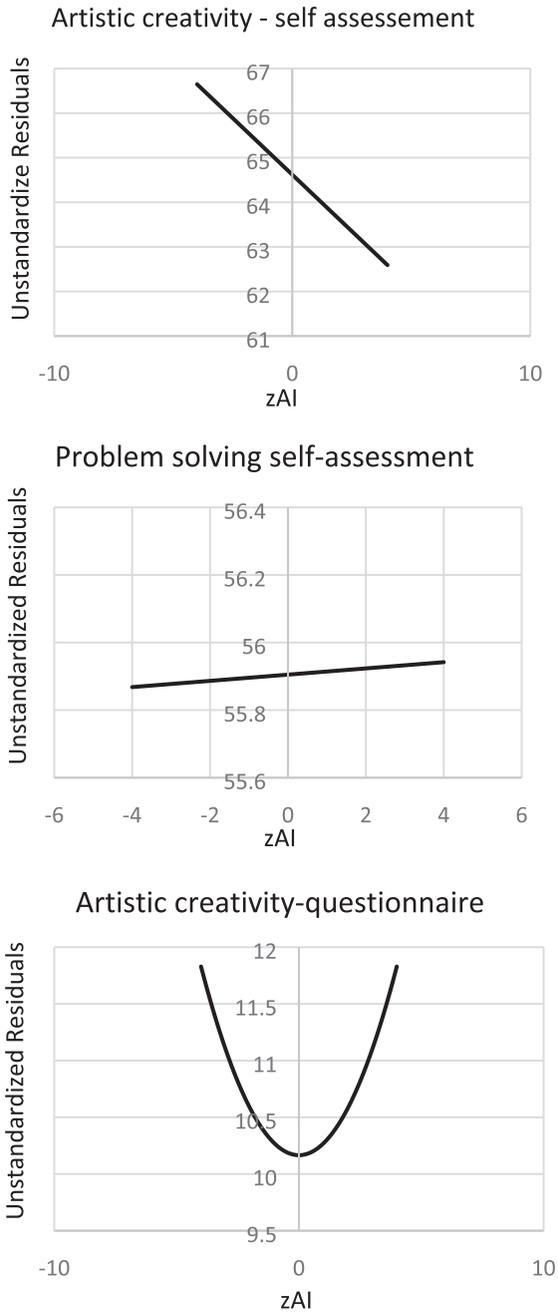
**Figure 1.** Regression line of creativity principle component 1 (PC 1)—convergent thinking.



**Figure 2.** Regression line of creativity principle component 2—divergent thinking.



**Figure 3.** (A) Regression line of creativity principal component 3—artistic creativity (B) Regressions lines for the relationships between zAI and the three measures that constitute principal component 3, i.e., artistic creativity—self-assessment, problem solving—self assessment, and artistic creativity—questionnaire.



**Figure 3.** *Continued*

participants evaluate their problem solving creativity slightly higher. For artistic creativity the questionnaire scores shows a quadratic effect hand skill asymmetry ( $R^2_{\text{model}} = .017$ ,  $F(5,20533) = 73.5$ ,  $p < .0001$ ) similar to that of creativity PC3.

### *Health problems*

All separate health problems measures were included in one principal component. The regression analysis of this component shows a positive relation between zAI and health problems ( $R^2_{\text{model}} = .019$ ,  $F(5,12511) = 50.3$ ,  $p = .015$ ). No quadratic effect was found, but zAI2 approached significance ( $p = .053$ ). As shown in [Figure 4](#), health problems are associated with right-skilled.

The separate measures contribute differently to the results of the health problems PC1. The relations between hand skill asymmetry and self-assessment of health problems and times being ill respectively show the same pattern ( $R^2_{\text{model}} = .016$  and  $.056$  respectively,  $p < .0001$ ). The more extreme right-skilled participants evaluate their health as worse than left-skilled, and also report more times being ill ([Figure 4](#)).

The analyses show no relation between hand skill and the number of days ill and the health problems composite score ( $p = .22$  respectively  $p = .086$ ; [Table 4](#)). In addition, the number of allergies that participants reported is not related to hand skill asymmetry ( $p = .85$ ; [Table 4](#)).

### *Dyslexia, prematurity, allergies and number of children*

Occurrences of dyslexia, prematurity, allergies, and the number of children of participants were analyzed with generalized linear models. The results indicate that the frequency of both prematurity and dyslexia increase with zAI, (prematurity mean =  $.04$ ,  $B = .087$ ,  $p = .016$ ; dyslexia mean =  $.07$ ,  $B = .116$ ,  $p < .0001$ , [Figure 5](#), [Table 5](#)). The occurrence of allergies and the number of children was not associated with hand skill asymmetry ([Table 5](#)).

### *Aggression*

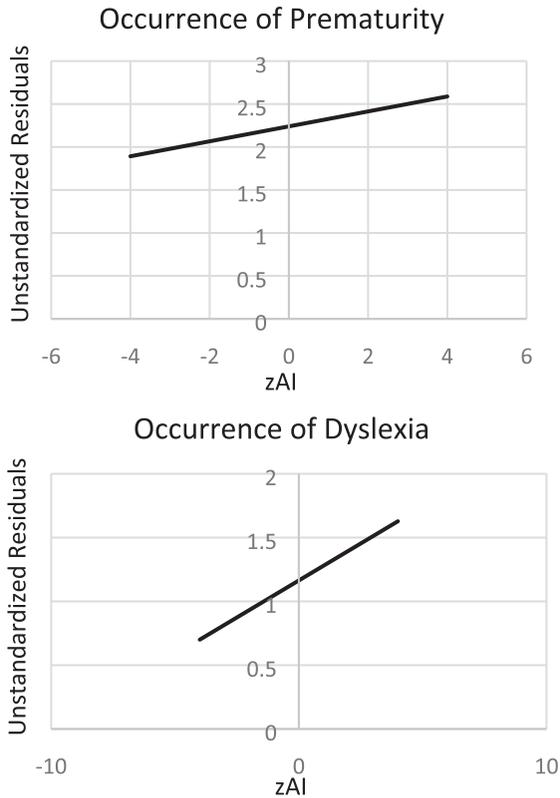
The regression analysis showed a negative linear effect of zAI on the aggression principle component ( $R^2_{\text{model}} = .029$ ,  $F(5,20533) = 123.4$ ,  $p = .010$ ), meaning that the left-skilled participants had slightly higher aggression scores than the right-skilled participants ([Figure 6](#)). The analysis of both the sum score of aggression ( $R^2_{\text{model}} = .042$ ,  $F(5, 20533) = 181.9$ ,  $p = .009$ ) and the amount of fights ( $R^2_{\text{model}} = .090$ ,  $F(5, 20533) = 407.7$ ,  $p = .013$ ) showed the same trend as the component, with left-skilled participants showing a slightly higher aggression score. We found no effects of hand skill asymmetry on the aggression self-assessment, the amount of childhood fights, and the amount of verbal fights ([Table 3](#)).



**Figure 4.** Regression lines of the relationships between zAI and health problems component 1, health—self assessment, and number of times being ill over the last year.

***Principle components predicted by strength of hand skill asymmetry***

We repeated the analyses above for strength of hand skill asymmetry (independent of its direction), using the absolute asymmetry index (Abs\_zAI,



**Figure 5.** Regression lines of the relationship between zAI and prematurity and zAI and dyslexia.

range 0–4). The mean Abs\_zAI was .784 for the total sample and equal for left and right-skilled participants. The distribution is skewed to the left, which means that most participants have only a slight asymmetry of tapping skill between the right and the left hand, and relatively few participants a large difference (for the distribution see Appendix 2). Table 6 lists the significant results of the analysis.

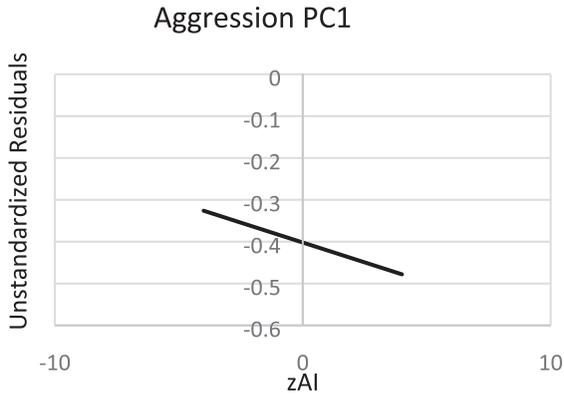
### **Creativity**

*Creativity PC1.* The regression analysis indicates both a linear and a quadratic relationship between convergent thinking component 1 and strength of hand skill asymmetry ( $R^2$ model = .077,  $F(5, 7310) = 123.1$   $p = .007$ , respectively  $p = .009$ ). Participants with extreme asymmetry show lower scores for all the separate measures (Figure 7).

Next, we performed regression analyses on the separate measures of convergent thinking. The mathematical and verbal measures and the total score show similar linear-quadratic trends as the component above (see Table 6).

**Table 5.** Results of the GzLM for linear and quadratic effects of hand skill asymmetry (zAI) on prevalence of dyslexia, prematurity, allergies, and number of children.

	<i>n</i>	zAI		zAI <sup>2</sup>		Sex		Age		Age <sup>2</sup>	
		<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>
Dyslexia	19783	<b>&lt;.0001</b>	.116	.525		<b>&lt;.0001</b>	.443	<b>&lt;.0001</b>	.046	<b>.005</b>	−.00033
Prematurity	19925	<b>.016</b>	.087	.633		.903		.335		.598	
Occurrence allergies	19004	.668		.253		<b>&lt;.0001</b>	−.405	<b>&lt;.0001</b>	−.025	<b>&lt;.0001</b>	.00035
Number of children	10572	.744		.533		.163		<b>&lt;.0001</b>	.273	<b>&lt;.0001</b>	−.002



**Figure 6.** Regression line of the relationship between zAI and aggression principle component 1.

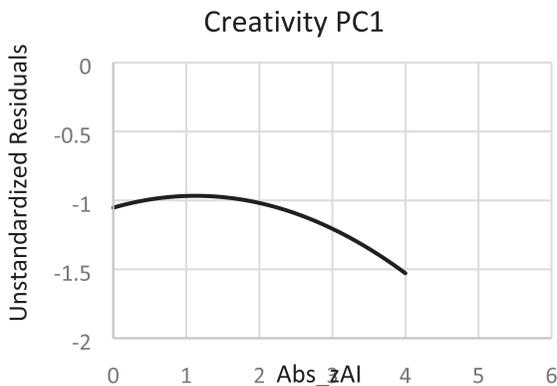
*Creativity PC2 and PC3, Heath and Aggression.* For the creativity principle components 2 and 3 and for health and aggression principle components no effects were found (Table 6). Therefore, we did not analyze the separate variables for these components.

#### ***Occurrence of dyslexia, prematurity, allergies and number of children***

Absolute hand skill was not related to the occurrence of dyslexia, prematurity, allergies, and the number of children.

## **Discussion**

In order to explore support for hypotheses concerning the evolutionary selection for human handedness, the present study analyzed relationships



**Figure 7.** Regression line of the relationship between abs(zAI) and creativity principal component 1.

**Table 6.** Results of GLM for strength of hand skill asymmetry (Abs\_zAI) for principal components (PC) and separate variables.

	<i>n</i>	<i>F</i> (df, df)	zAI-abs		zAI_abs <sup>2</sup>		Sex		Age		Age <sup>2</sup>		<i>R</i> <sup>2</sup> <i>model</i>
			<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	
Creativity PC 1	7316	123.1 (5, 7310)	<b>.007</b>	.153	<b>.009</b>	−.068	<b>&lt;.0001</b>	.464	<b>&lt;.0001</b>	.031	<b>&lt;.0001</b>	−.00048	.077
CT—math	8794	103.6 (5, 8788)	.029		<b>.011</b>	−.014	<b>&lt;.0001</b>	.091	<b>&lt;.0001</b>	.004	<b>&lt;.0001</b>	−.000077	.055
CT—verbal	8793	113.4 (5, 8787)	.023		<b>.014</b>	−.014	<b>&lt;.0001</b>	.092	<b>&lt;.0001</b>	.008	<b>&lt;.0001</b>	−.00012	.060
CT—total	8788	154.5 (5, 8782)	<b>.007</b>	.029	<b>.003</b>	−.014	<b>&lt;.0001</b>	.092	<b>&lt;.0001</b>	.006	<b>&lt;.0001</b>	−.00010	.080
Creativity PC 2	7316	49.76 (5, 7310)	.084		.161		<b>.006</b>	−.066	.612		<b>.001</b>	−.00016	.033
Creativity PC 3	7316	13.16 (5, 7310)	.550		.646		<b>&lt;.0001</b>	−.163	<b>.006</b>	.012	<b>.029</b>	−.00011	.008
Health PC 1	12517	49.08 (5, 12511)	.970		.437		<b>&lt;.0001</b>	−.235	<b>&lt;.0001</b>	−.028	<b>&lt;.0001</b>	.00035	.019
Aggression PC 1	20539	122.3 (5, 20533)	.306		.164		<b>&lt;.0001</b>	.297	<b>.009</b>	.006	<b>&lt;.0001</b>	−.00015	.029
Number of allergies	7417	22.35 (5, 7412)	.873		.502		<b>&lt;.0001</b>	−.413	<b>.022</b>	.017	.066		.014

between hand skill asymmetry and creativity, aggression, developmental and health issues, using a very large sample with about equal numbers of left- and right-handers. To the best of our knowledge this is the first study addressing these issues with hand skill instead of hand preference. The main findings are: (1) left-skilled individuals rated themselves on a 0–100 scale as more artistically creative, but scores on the artistic creativity questionnaire showed that their artistic creativity is comparable to that of right-skilled individuals; and opposite to our hypothesis, the left-skilled individuals were on average less creative on divergent and convergent thinking; (2) individuals who are more skilled with their left hand have slightly higher aggressive scores, which is consistent with our expectation; (3) those who are more skilled with the left hand report to have better health, against our expectation. Additionally, results showed that mostly the direction of hand skill asymmetry, rather than strength of asymmetry, was predictive of creativity, aggression and health problems. Explained variances of the models of the relationships corrected for age and sex are below 10%, suggesting weak associations for Darwinian selection to act on.

### **Creativity**

We assessed both problem solving creativity and artistic creativity (see Sawyer, 2012). We predicted that the more left-skilled individuals would be more creative than the more right-skilled individuals. In contrast to our hypothesis, we found evidence that the more right-skilled individuals are on average better problem solvers than the more left-skilled, both for convergent thinking and for divergent thinking. Additionally, the self-assessment of problem solving creativity showed the same pattern. We conclude that right hand rather than left hand specialization is, although weakly, associated with better problem solving creativity.

The artistic creativity measures show a mixed outcome. Interestingly, the association between hand skill asymmetry and artistic creativity is different for the self-assessment of artistic creativity and the artistic creativity questionnaire (see Figure 3(B)). For self-assessment, the more left-skilled individuals rate themselves as more artistically creative than the individuals with a rightward asymmetry between the hands. The results of the self-assessment are in agreement with common beliefs that left-handed people generally are more creative, which is a factor that could have biased the participants' perception of their own creativity (Baas et al., 2015). In addition, myths about creativity might specifically concern artistic creativity, as the myth might be amplified by the numerous—although biased—accounts of famous left-handed artists, such as Leonardo da Vinci, Rembrandt van Rijn and Pablo Picasso. The artistic creativity questionnaire asks more

specifically about the involvement in different artistic activities. It shows equal scores for left and right-skilled persons, and a lesser score for those with weak hand skill asymmetry, which points at strength of hand skill asymmetry being more important than direction. This may be interpreted as greater specialization of the hands in the artistically gifted, irrespective of being more skilled in the left or the right hand. This is not in agreement with the hypothesis that the more left-skilled individuals are more artistically creative (e.g., Peterson, 1979). This finding is also incompatible with the idea of a frequency-dependent selection process that acts on creativity that would explain left-handedness not going extinct. The above results also contradict earlier research about lateral dominance and creativity. In a systematic meta-analysis, covering several methodologies for evaluating lateral dominance and creative thinking (problem solving creativity), Mihov et al. (2010) found that the right hemisphere (implicating a more skilled left hand) is dominant in creative processing. Nonetheless, there are also studies that do not find any associations between right hemisphere activation and creativity (Gu et al., 2015), and studies that suggest a relationship between creativity and both the left and the right hemisphere (Lindell, 2011). Furthermore, it is important to keep in mind that for most cognitive processes, both hemispheres contribute in completing a task (Chiarello & Maxfield, 1996).

### **Aggression**

The analysis of PCA component Aggression showed that left-skilled individuals had higher aggression scores, which is in line with our hypothesis. Additionally, the more left-skilled individuals reported to have won (slightly) more fights in the past ten years than the more right-skilled individuals. This is in line with the fighting hypothesis (Raymond et al., 1996), although that theory is based on hand preference. Our data suggest that the direction of hand skill asymmetry is associated with aggression. This is contradictory to the results of a study by Dinsdale et al. (2011) who found that strength is more predictive of aggression than direction of hand skill asymmetry.

The evolutionary relationship between handedness and aggression is up for debate. The explained variance of our significant aggression measures are small (3–9%). One could argue that the current fitness value of aggression is low for our sample population, because in our modern society aggression and the ability of winning fights do not increase an individual's fitness as much as it used to do. Earlier research suggests that the importance of frequency-dependent selection is of less influence on fitness in cultures that put less pressure on winning fights (Groothuis et al., 2013; Raymond et al., 1996).

## **Health**

Creativity and aggression are both traits that over time could have enhanced the individual's chances of survival and reproduction, and are therefore thought to countervail the possible negative health outcomes that are associated with left-handedness, together invoking negative frequency-dependent selection explaining the stable low frequency of lefthanders in human populations. However, our overall results on general health problems and its relationship with hand skill asymmetry show that the more left-skilled individuals have fewer health problems than the more right-skilled individuals, which is completely contradictory to our hypothesis. This unpredicted relationship was found for the number of times the individuals were ill, and the self-assessed health problems. Additionally, slightly fewer reported health problems were found for individuals with low hand skill asymmetry. This unexpected outcome, however, does not mean that there never has been a relationship. Arguably, the increasing quality of healthcare in our modern society diminishes or may have solved the health problems associated with left-handedness.

## **Dyslexia, prematurity, allergies**

We hypothesized that the chance of being born premature, having dyslexia and having allergies would be higher in left-skilled individuals. As with the general health problems, our results are completely opposite to this hypothesis. No relationships at all were found between hand skill asymmetry and having an allergy or the number of allergens. Moreover, the results show that both self-reported prematurity and dyslexia were more common among the more right-skilled individuals compared to the more left-skilled individuals. This is a surprising finding, as the review and meta-analysis of Domellöf et al. (2011) concluded that prevalence of non-right hand preference, that is, left and/or ambiguous hand preference, is twice as high in preterm children than in full-term children, but these data come from selected samples of prematurely born individuals and controls. Dyslexia was reported to be up to 50% more common among left-handers (Tønnesson et al., 1993). The evidence for the reverse relationship between hand skill asymmetry and dyslexia in our data is quite strong, but for the occurrence of prematurity the relationship being only just significant ( $p = 0.016$ ,  $\alpha = 0.017$ ).

## **Number of children**

We found no associations between hand skill asymmetry and number of offspring. This is different from the parallel study of Zickert et al. (2018) who report that people with strong hand preference have slightly more

children. This implies that the population bias in hand skill asymmetry is not under selection pressure through number of offspring.

### ***Comparison with our earlier study on hand preference***

The present study focused on hand skill asymmetry, whereas the parallel study by Zickert et al. (2018) addressed hand preference, both studies using the same dataset, albeit with a slightly different selection of data. In both studies it is tested whether asymmetry in handedness may be related to measures of Darwinian fitness. Both hand skill asymmetry and hand preference have a rightward population bias although the first has a near normal and the second a bell-shaped distribution.

When we compare the two studies on the main findings we find the following: The principle component analyses yielded an identical set of principle components. For creativity the principle components of convergent and divergent thinking are related to hand preference and to hand skill asymmetry in a similar way. For the artistic creativity questionnaire, however, the relation was an inverted U for hand preference and a U-shape for hand skill asymmetry, indicating a different relationship for these two measures of handedness. For health the relationships were similar in direction and size. For aggression the relationships were different: inverted U shaped for hand preference and negative linear for hand skill asymmetry.

This comparison between the two studies leads to the conclusion that fitness factors relate to hand preference and to hand skill asymmetry in similar ways for health and convergent and divergent thinking measures, but differently for artistic creativity and aggression as measured. Such dissociation may contribute to the specific bias characteristics of human hand preference and hand skill asymmetry through different evolutionary selection forces/processes acting on hand preference and hand skill asymmetry, leading to different distributions of handedness for each.

### ***Strength and limitations***

Among the strengths of the study are the large number of participants, the near equal number of right and left handed participants, and the inclusion of four major direct (health and number of children) and indirect fitness markers (creativity, aggression) in one and the same study.

As the sample is enriched for lefthanders, a concern is whether this biased responses to other questions about handedness. For example, lefthanders may be inclined to present themselves as more creative. We argue that this is unlikely, partly on the grounds that our results often go against prevailing notions, and partly because in presenting the study we took care to avoid eliciting competition between left- and right-handers.

One limitation concerns the generalizability of hand skill asymmetry across motor skills. Previous research has found that the laterality indices of most hand skill tests correlate only weakly to moderately (Brown, Roy, Rohr, Snider, & Bryden, 2004). The finger tapping task was apt for our internet study as this task was easy to implement. Since the repeatability of the test was high, we view the tapping task as a reliable measure of this specific fine motor skill. However, it would be worthwhile to repeat the study with other unimanual tasks. Another limitation is that, due to the nature of an internet study, the data are largely based on self-report, either as a single entry on a continuous scale or as answers to qualitative or quantitative types of questions. Because participants did not know the hypotheses being investigated, and outliers and insufficient data were removed prior to analysis, we believe these self-report results are strong and unbiased.

### **Conclusion**

These outcomes do not support the hypotheses that left hand specialization would be associated with higher creativity and poorer health status. There is, however, support for left hand skill asymmetry being associated with a somewhat higher level of aggression. The low amounts of variance explained indicates that other factors may play a role in the evolution of human handedness. We suggest that Darwinian selection on hand preference (Zickert et al., 2018) and hand skill asymmetry may be greatly attenuated or overruled in our modern society, as winning fights does not increase fitness as much as it used to do, and because our highly developed healthcare may counteract the influence of health problems.

### **Acknowledgements**

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### **Disclosure statement**

No potential conflict of interest was reported by the authors.

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## Appendices

### Appendix 1. The internet questionnaire

(Answers alternatives are given in brackets or as bullet points, \*- facultative question)

#### 1a—General Questions

Q1.1 Dear participant, how nice of you to participate! The test consists of a number of shorter questionnaires and tests on different subjects. In total it will take about 10 min to fill in everything. We advise you to fill in this questionnaire on a computer. If you fill in the test on a tablet, you should set the page orientation to Landscape and turn off autocorrect. You can stop the questionnaire at any time and continue later on the same computer or tablet. PLEASE NOTE: this test is not designed for appliances smaller than tablets, such as mobile phones. Have fun!

Q1.3 We ask you to fill in some personal details. These details are anonymous and will be used solely for this survey.

Q2.1 What is your year of birth? (1900–2014)

Q109 Do you have a functional limitation in one of your arms or hands? (yes, temporarily; yes, chronically; no; no, but I used to)

Q114 Do you have children whose biological mother/father you are? (yes; no; don't know)

Q111\* How many sons do you have? (0–10)

Q112\* How many daughters do you have? (0–10)

Q113\* How many grandchildren do you have? (0—more than 25)

#### 1b—Slider Questions

Q3.1 We start with the short part of the test: quick answers and brief feedback! After that follows the more extensive part. The following applies to the questions below: move the arrow to the spot that you think fits you best. You will see the number of your choice to the right of the bar.

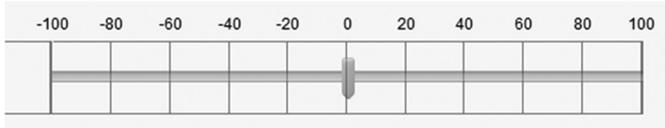
Q3.2 How right- or left handed are you? For example: if you consider yourself 100% left-handed, move the arrow to the far left to –100. (left-handed—no preference—right-handed)

Q3.3 How artistically creative are you? (think of painting, drawing, dancing, sculpting, acting etc.) (not creative—no more or less creative than others—very creative)

Q3.4 How creative are you in problem solving? (not creative—no more or less creative than others—very creative)

Q3.5 How short-tempered are you? (not short-tempered—no more or less short-tempered than others—very short-tempered)

Q3.6 How healthy are you? (no health problems—no more or less health problems than others—many health problems)



**Figure A1.** Slider as it appeared in the online questionnaire. The bar could be moved in increments of 1; the number was displayed right of the scale once the bar was moved.

*Ic—Edinburgh Handedness Questions* (after Van Strien, 1992, 2003)

- Q5.2 Met welke hand schrijf je?
- Q5.3 Met welke hand teken je?
- Q5.4 Welke hand gebruik je om met een tandenborstel te poetsen?
- Q5.5 In welke hand houd je een flesopener vast?
- Q5.6 Met welke hand gooi je een bal weg?
- Q5.7 In welke hand houd je een hamer vast als je ermee op een spijker slaat?
- Q5.8 Met welke hand houd je een racket (zoals een tennisracket) vast?
- Q5.9 Welke hand gebruik je om met een mes een touw door te snijden?
- Q5.10 Welke hand gebruik je om met een lepel te roeren?
- Q5.11 Welke hand gebruik je om met een gummetje iets uit te vlakken?
- Q5.12 Met welke hand strijk je een lucifer aan?

*Id—Artistic creativity Questions*

- Q14.1 How creative are you? Indicate for each activity how many times you do it. (I do it a lot; I do it often; I do it sometimes; I hardly ever do it; I never do it)
- Q14.2 Portraying think of: painting, (digital) drawing, photography, graphic work, drawing cartoons
- Q14.3 Music think of: playing an instrument, composing, singing, DJ
- Q14.4 Writing & storytelling think of: making up stories, writing poetry, writing books
- Q14.5 Styling & design think of: designing objects (clothing, jewellery, houses), creating layouts, Photoshop
- Q14.6 Sculpturing think of: modelling, cutting, making spatial constructions, sculpturing
- Q14.7 Theatre, performing think of: ballet, dance, acting, cabaret

*Ie—Aggression Questions*

- Q15.1 How short-tempered are you? Indicate how you will react in each of the situations below.
- Q15.2 Suppose someone deliberately bumps into you hard, what do you do?
  - Nothing (0)
  - It is clear from your attitude that you are annoyed (for example: sighing, looking angrily, shaking your head) (1)
  - You say something, but not in an angry tone (2)
  - You say something angrily (3)
  - Push back (4)
- Q15.3 Suppose someone clearly flirts with your new partner who does not (yet) respond to that. What do you do?
  - Nothing (0)
  - It is clear from your attitude that you are annoyed (1)

- You stand possessively next to your partner (but say nothing about it) (2)
- You say something, but not in an angry tone (3)
- You say something angrily (4)
- You react physically, for example: hitting or pushing (5)

Q15.4 You are in a silence (train) compartment and someone next to you keeps talking loudly on the phone, even though you have already said something about it. You cannot leave! What do you do?

- Nothing (0)
- It is clear from your attitude that you are annoyed (1)
- You say something, but not in an angry tone (2)
- You say something angrily (3)
- You react physically, for example: nudging or taking away the mobile phone (4)

Q15.5 You see someone deliberately puncture your bicycle tire. What do you do?

- Nothing (0)
- It is clear from your attitude that you are angry (1)
- You say something, but not in an angry tone (2)
- You say something angrily (3)
- You react physically, for example: pushing or hitting (4)

Q15.6 Someone jumps the queue at the till. What do you do?

- Nothing (0)
- It is clear from your attitude that you are annoyed (1)
- You say something, but not in an angry tone (2)
- You say something angrily (3)
- You react physically, for example: pushing or moving in front of this person in the queue (4)

Q15.7 You are about to grab the last article in a shop when someone snatches it from under your nose and looks at you triumphantly. What do you do?

- Nothing (0)
- It is clear from your attitude that you are annoyed (1)
- You say something, but not in an angry tone (2)
- You say something angrily (3)
- You take it away (4)

Q15.8 Out of the blue someone calls you names on the street. What do you do?

- Nothing (0)
- It is clear from your attitude that you are annoyed (1)
- You say something, but not in an angry tone (2)
- You swear back or say something angrily (3)
- You react physically, for example: pushing, hitting, kicking (4)

Q15.9 During the past 10 years: How often did you fight because you were really angry? (Never; once; 2–5 times; 6–10 times; More than 10 times)

Q15.11 During your childhood: How often did you fight because you were really angry? (Never; hardly; average; often; very often)

Q15.12 During the past 10 years: How often were you involved in an exchange of abuse because you were really angry? (Never; once; 2–5 times; 6–10 times; More than 10 times)

Afterwards, the sumscore was calculated with the following formula:  $Q15.2 + (4/5 * Q15.3) + Q15.3 + Q15.4 + Q15.5 + Q15.6 + Q15.7 + Q15.8 + (4/5 * Q15.9) + (4/5 * Q15.11) + (4/5 * Q15.12)$

*If—Health Problem Questions*

Q16.2 How many times were you ill during the past 12 months? (have not been ill; once; twice; 3 times; 4 times; 5 times; more than 5 times; I do not want to say)

Q16.3 At a rough estimate how many days were you ill during the past 12 months?\*(1–3 days; 4–7 days; more than one week; more than two weeks; more than a month; more than six months; long illness; I do not want to say)

Q16.4 Are you allergic to something? (yes; no; do not know)

Q16.5 How many things are you allergic to?\*(1–5; more than 5; I do not want to say)

Q16.6 Were you born too early, i.e., earlier than 8 months pregnancy? (yes; no; don't know)

Q16.7 Are you dyslexic? (yes; no; don't know)

*Ig—Divergent Thinking Question*

Q19.1 For the following task you need to think of as many applications as possible for an everyday object. Write down several useful ways in which you could use these objects. You have two minutes time. After two minutes the questionnaire will automatically move on to the next part. You can move on sooner if you cannot think of anymore things.

*Ih—Convergent thinking Questions*

(1–6 mathematical, 7–12 verbal)

Q20.1 The Smid family consists of 7 sisters. Each sister has 1 brother. If you include mister Smid, how many men are there in the Smid family? (1; 2; 7; Other namely; I already knew this question)

Q20.2 Water lilies double every 24 h. There is 1 water lily in a lake at the start of each summer. It takes 60 days to fill the lake completely with water lilies. After how many days is the lake half full? (15; 30; 59; Other namely; I already knew this question)

Q20.3 In a drawer are loose brown and black socks, in a 4–5 ratio. How many socks do you have to take out of the cupboard to be sure that you have a pair of the same colour? (2; 3; 4; Other namely; I already knew this question)

Q20.4 Yesterday you went to the zoo and saw giraffes and ostriches. Together the animals had 30 eyes and 44 legs. How many animals were there in total? (12; 15; 22; Other namely; I already knew this question)

Q20.5 A man buys a horse for 600 euros and sells it for 700 euros. He then buys the horse back for 800 euros and sells it again for 900 euros. How much profit does the man make in euros? (100 euros; 200 euros; The man does not make a profit; Other namely; I already knew this question)

Q20.6 A frog falls down a 32 m deep hole. Every day he jumps 2 metres up and slides one metre down. How many days will it take the frog to climb out of the hole? (30; 31; 32; Other namely; I already knew this question)

Q21.1 Together three women—Anna, Betty and Christien—have 3 children—Bart, Lisa and David. Bart enjoys playing with Betty's son. Christien regularly baby sits Anna's children. Who is Lisa's mother? (Anna; Betty; Christien; None of the above; I already knew this question)

Q21.2 A child plays on the beach and has 6 piles of sand to his left and 3 piles of sand to his right. If you join these piles, how many piles would the child have? (0; 1; 9; Other namely; I already knew this question)

Q21.3 A farmer in Drenthe has a beautiful pear tree. He makes sure that the fruit goes to the fruit shop. The owner of the fruit shop calls the farmer to ask how much

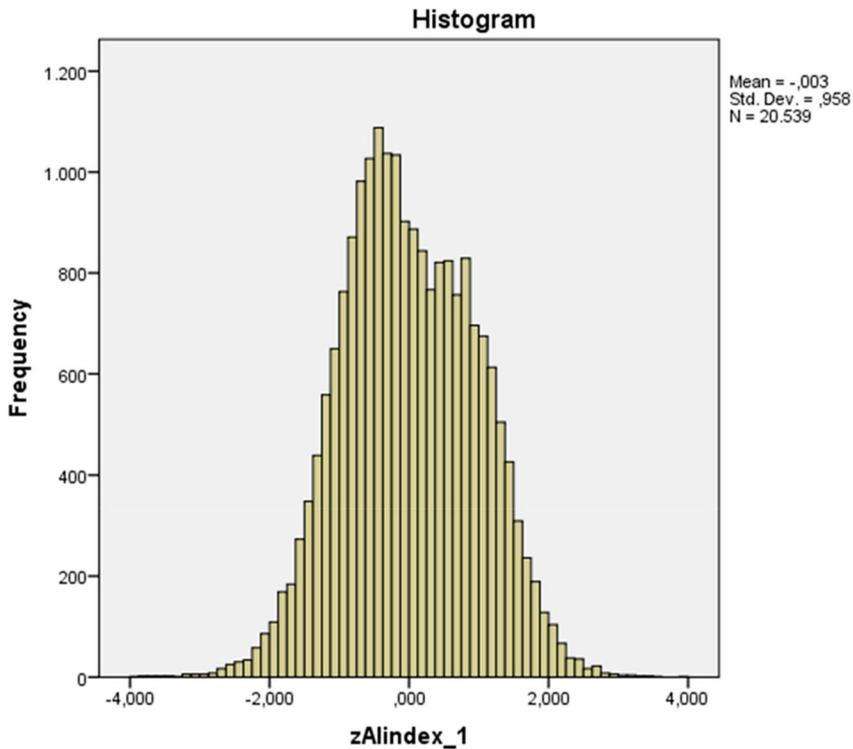
fruit is available to buy. The farmer knows that the tree stem has 24 branches. Every branch has exactly 6 twigs. Each twig carries 1 piece of fruit. How many prunes will the farmer be able to deliver to the shop? (144; 120; 0; Other namely; I already knew this question)

Q21.4 In what year did Christmas and New Year's Day fall in the same year? (not one single year; every year; only in the first year; Other namely; I already knew this question)

Q21.5 How many cubic metres of sand are there in a 6-metre long, 2-metre wide and 1 m deep hole? (6; 12; 24; Other namely; I already knew this question)

Q21.6 Captain Morgan has a boat with a ladder attached to it. At low tide 6 of the 12 sports are under water. How many sports are under water at high tide? (12; 8; 6; Other namely; I already knew this question)

## Appendix 2. Distribution of the hand skill asymmetry index z-scores



**Figure A2.** Distribution of the hand skill asymmetry index z-scores. The distribution is somewhat biased to the left due to overrepresentation of left-handers.

## Appendix 3. Analysis of divergent thinking

### Methods and procedure

The divergent thinking part of the questionnaire consisted of one single question: "what uses can you come up with for a book?" The question invites the subjects to

come up with as many answers as possible, in two minutes. The participants typed each of their answers in a box. Six rows of eight boxes were provided, so a maximum of 48 answers could be entered. Time started as soon as the participants started typing in their answers. When two minutes had passed, further entry was disabled.

#### *Data cleaning and analysis*

Two divergent thinking measures were calculated: fluency and originality. The fluency measure is the number of valid answers given by the participant on the divergent thinking question. The originality measure was developed by assigning a creativity score to these answers based on the frequency of all the answers in the data base. Answers with a high frequency (that is, answers entered by many participants) were assigned a low creativity score and answers with a low frequency (that is, answers that were highly unique) were assigned a high score (see below). In order to calculate the fluency score, and to assign the appropriate creativity score to all the individual answers that were given, we took the following steps to prepare the data for analysis.

In the first step single (13356) and multi-word answers (12437) were each listed alphabetically. Incomprehensible answers were deleted (e.g., due to too fast typing, random letter strings, etc.). In a second step we corrected all typing errors. In a third step we replaced multi-word answers by single keywords. If possible, a keyword from the single-word list was chosen, otherwise a new keyword was created. In the fourth step we made an alphabetic list of all the (now single word) answers including the keywords from step three and assigned synonyms to a single keyword: one of the synonyms was chosen as the keyword. The grouping of the synonyms was agreed upon by three examiners. These steps reduced the number of single word answers to 3527 unique answers. In the fifth step the frequency of every keyword was calculated as a marker of the uniqueness of the answer. The final step was to assign a creativity score to each of the answers, based on their frequency. To do so, a list was created that consisted of all the keywords and their frequencies, with the high-frequency words at the top and the low frequency words (the unique words) at the bottom.

Because the most common answers, such as “to burn” are given by the great majority of the participants and unique answers by only a few, and because there were many unique answers, the distribution of the frequency of the answers per unique word approaches a logarithmic curve. Therefore, a logarithmic transformation on the frequency of the responses was applied.

To create the creativity scores, we divided the logarithms into 10 classes, such that the 10% most common answers were assigned a creativity score of 1 and the 10% least common words were assigned a creativity score of 10. The answer “to read” was assigned a score of 0, and excluded from the analysis because virtually all participants have given this answer.

After all keywords had been assigned a creativity score, the keywords in the database were replaced by their creativity score. Then, for each participant we calculated the individual fluency score by counting the number of valid answers and the originality score by adding the creativity scores of the valid answers.