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Genetic and Environmental Influences on Perceptual-Motor Abilities

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Abstract

Ability poses limitations on a person's potential for success in a given task. Perceptual-motor abilities are thought to be traits regarded as having been either genetically determined or developed through motor experience. This study examined genetic and environmental influences on perceptual-motor abilities in twins (13 sets of monozygotic and 18 sets of dizygotic, mean age = 17.2 ± 3.5 years) by measuring the performance on tasks whose main underlying perceptual-motor abilities are rate control, simple reaction time, hand-eye coordination, finger dexterity, and manual force control. The results suggest that little support was given to Turkheimer's Laws of Behavior Genetics, as high proportions of variance on the performance were attributable to 1) additive genetic factors for rate control only, 2) shared family environment for finger dexterity and hand-eye coordination, and 3) nonshared environment for rate control and simple reaction time.

Keywords

Behavior Genetics, Heritability, Twins, Motor Ability, Motor Behavior

1. Introduction

Performance on a motor skill (i.e., forehand, cartwheel) is limited by underlying abilities (i.e., vision, anticipation, reaction, and attention), which are enduring requisites an individual must possess to perform successfully. Defined by Schmidt and Lee (2011) as a hypothetical construct that underlies performance in a number of tasks or activities, ability is usually thought to be a relatively stable characteristic or trait which is not easily modified by practice or experience and is typically regarded as having been either genetically determined or developed during growth and maturation. Thus, individuals could have the same performance level at a specific time in a given motor skill, but some could have far greater potential due to greater abilities for that specific skill (Fairbrother, 2010; Magill & Anderson, 2015).

The early notion of abilities in the motor domain is that performance is based on a single, general ability (Brace, 1927; McCloy, 1934). However, this view was challenged by two research programs centered on individual differences. The first program generated Henry's specificity hypothesis (Henry, 1968), according to which abilities are independent of each other, great in number and specific to a given skill. As a result, transfer among skills would be low, that is, similar motor tasks will tend to correlate little with each other. The second program was conducted for the development of military aircraft pilots: Edwin Fleishman identified, through correlational techniques (a differential approach in which each individual performs several tests), perceptual-motor abilities (PMAs) such as aiming, arm-hand steadiness, control precision, finger dexterity, force control, hand-eye coordination, multilimb coordination, rate control, and reaction time (Fleishman, 1972; Fleishman & Quaintance, 1984). PMAs have been associated with organization, control and regulation of limbs and whole body movements. Similarly, Fleishman found out physical proficiency abilities that are thought as underlying physical fitness (e.g., static and dynamic strength, static and dynamic flexibility, speed, gross body coordination, gross body equilibrium, stamina), but they are not the focus of the present study.

Although several studies have been devoted to estimate "nature and nurture" factors in other motor variables (*regular physical activity*—Beunen & Thomis, 1999; Fermino, Garganta, Seabra, & Maia, 2007; Maia et al., 2010; Rankinen et al., 2006; *stamina*—Bouchard et al., 1999; Williams & Folland, 2008; *muscular strength*—Tiainen et al., 2004), genetic and environmental influences seem to be neglected with regard to PMAs. Taking Schmidt and Lee's (2011) definition of ability, which regards it as having been either genetically determined or developed during growth and maturation, the current study is aimed at examining the contributions of genetic and environmental factors in the performance of tasks whose primary underlying PMAs are rate control, simple reaction time, hand-eye coordination, finger dexterity, and manual force control.

By estimating the amount of variance attributable to genetic (A), shared (C) and nonshared (E) environmental factors in a twin sample, the ACE model was used, given that known differences in genetic similarity in conjunction with a testable assumption of similar environments for monozygotic/identical (MZ) and dizygotic/fraternal (DZ) twins. Identical twins develop from a single fertilized egg and thereby share 100% of their alleles, whereas fraternal twins develop from two fertilized eggs and thereby share 50% of their alleles. The correlation (r) between identical twins provides an estimate of A + C. Given that fraternal twins share C and half of the genes, their correlation (rDZ) is equal to (A + C)/2. From these equations [rMZ = A + C; rDZ = (A + C)/2], we can derive the following: A = 2 (rMZ − rDZ); C = rMZ − A; E = 1 − rMZ (Falconer, 1990; Plomin, DeFries, Knopik, & Neiderhiser, 2012).

The following hypotheses were tested according to the Three Laws of Behavior Genetics (Turkheimer, 2000): human behavioral traits are heritable (A), shared family environment (C) has a minimal impact on individual differences in behavior, and nonshared environment (E) exerts a major influence on individual differences in behavior. The ACE model assumes that 1) the genetic control is determined by additive effects of a number of indeterminate genes, 2) genetic and environmental effects are additive, 3) environments show normal distribution and are randomly distributed by genotypes (Bouchard, Malina, & Pérusse, 1997; Falconer, 1990; Lynch & Walsh, 1998; Maia et al., 2010; Maia, Silva, Seabra, & Lopes, 2004; Plomin, DeFries, Knopik, & Neiderhiser, 2012). In summary, this study examines genetic and environmental (shared and nonshared) influences on perceptual-motor abilities in MZ and DZ twins by measuring the performance on motor tasks whose main underlying abilities are rate control, simple reaction time, hand-eye coordination, finger dexterity, and manual force control.

2. Methods

Thirty-one Brazilian (São Paulo, SP) twin sets from a middle class background volunteered to take part in the experiment (mean age = 17.2 ± 3.5 years). The zigosity questionnaire was used to determine MZ and DZ twins. This questionnaire was proposed by Maia et al. (2007), a validated Portuguese version of the Peeters, Van Gestel, Vlietinck, Derom and Derom (1998). Its questions about twin similarity and confusion were responded by either the twins' mother (for those under 18 years of age) or the twins themselves (for those above 18 years of age). The questionnaire bears high concurrent validity with direct methods of DNA and blood markers (Maia, Silva, Seabra, & Lopes, 2004).

Thirteen sets (6 male and 7 female) were classified as monozygotic (MZ) and eighteen (10 male and 8 female) as dizygotic (DZ). The sample sets shared the same gender and family environment. Participants had no prior experience with the experimental tasks. Each participant and/or parent/tutor read and signed an informed consent form before participating in the experiment. The study was approved by the university ethics committee.

Data collection was administered individually, twin #1 (the oldest) followed by twin #2 (the youngest), respectively (Maia et al., 2010). After having read and signed the informed consent form, the zigosity questionnaire was responded and the participant was submitted to five tests in a random order. It is believed that the motor tasks performed on each test were underlain by the following primary PMAs: rate control, simple reaction time, hand-eye coordination, finger dexterity, and manual force control. Participants were assessed three times at each task and the average value was considered for analysis. Intertrial interval was set at 20 s.

Simple reaction time was measured using a computer, a keyboard, and custom software written in Clipper language. Participants were required to react as fast as possible to a visual stimulus displayed on the computer screen, leaving the right index finger from the left "shift" button and pressing the right "shift" button (for right-handed participants); for left-handed participants, leaving the left index finger from the right "shift" button and pressing the left "shift" button. Prior to the appearance of the green rectangle (which allowed the participant to move), a red rectangle followed by a yellow rectangle were displayed on the screen. The time lag for these two preparatory stimuli was of 1 to 4 seconds. Reaction time was defined as the time spent from the appearance of the green rectangle and the release of the first "shift" button. Its value was recorded in milliseconds for further analysis.

Finger dexterity was measured with the Lafayette Pegboard Test (Lafayette Instrument Co.), consisting of 25 round holes (five lines and five columns) on a board and 25 pegs positioned in a tray immediately above the board. The unit was placed in mid-line with the participant (who was sat on a chair) with the board at the edge of the table. Participants received the following instructions: "This is a pegboard and these are the pegs (the examiner points out each and then picks up one of the pegs and continues). All the pegs are the same. What you must do is put these pegs into the holes like this (the examiner demonstrates by filling the top row and removes the pegs, putting them back into the tray). When I say go, begin here and put the pegs into the boards as fast as you can, using your dominant hand. Fill the top row completely from this side to this side; do not skip any. Fill each row the same way you filled the top row. Any questions? (the examiner answered any questions). Ready, as fast as you can, go." The time (in seconds) to complete the test was taken with a chronometer and registered.

A hand dynamometer (Lafayette Instrument Co.) was used to assess manual force control. The aim was to apply half of the maximum force with a prehension movement in the upright position. Participants received the following instructions: "Grasp the dynamometer with your dominant hand, elbow extended, and apply half of your maximum force which is xx kgf. Any questions? (the examiner answered any questions). Ready, go." Prior to the first trial, the dynamometer was adjusted to the hand of the participant, who performed two pre-trials applying the maximum force; the higher value was considered as the baseline to calculate the target force to be applied. After finishing each of the three main trials, the dynamometer was delivered to the experimenter, who did not provide feedback about performance. The difference between the actual performance and the criterion (absolute error) was considered for analysis.

Hand-eye coordination was measured using a photoelectric rotary pursuit (Lafayette Instrument Co.). The participant had to follow, as long as possible, a rotating light along a triangle with a photocell tipped wand. The equipment provides the examiner with a keypad interface and LCD display which shows the speed of the disk (30 rpm), direction of rotation (clockwise), trial time (20 seconds), and sensitivity of the photocell wand (default). Time on target, in seconds, was shown on the display. No feedback was provided to participants, who received the following instructions before starting each trial: "When I say go, you must begin here at the top of the triangle and follow the light for 20 seconds, clockwise, grabbing hold the wand with your dominant hand, as much time as you can. Any questions? (the examiner answered any questions). Ready, as fast as you can, go."

Bassin Anticipation Timer (Lafayette Instrument Co.) was used to assess rate control (coincident timing). The participant was instructed to watch a light as it traveled down a 48 red leds runway, with the aim of anticipating the light reaching the target (last led) by pressing a pushbutton to coincide with the arrival of the light at the target. The speed of the leds was set at 5 mph (first half) and 4 mph (second half). Prior to the lightening of the first led, a time lag of 0 to 2 seconds was set. Values were recorded and the absolute error, in milliseconds, was considered for further analysis. Participants received the following instructions: "As the red lights approach down the runway, you must press the button at the exact moment the last red light flashes. Any questions? (the examiner answered any questions). Ready, go."

Data were recorded, typed, calculated, and organized in electronic sheets for further analysis using the Statistical Package for Social Sciences (SPSS), version 24. Normal distribution of values was found and there were no missing data, typing errors or outliers. Subsequently, data were submitted to a descriptive analysis followed by the calculation of intraclass correlation indices for estimating heritability (genetic factor) and shared and nonshared environment factors, according to ACE model (Maia et al., 2004, 2010; Plomin et al., 2012).

3. Results

Means, standard deviations and intraclass correlation coefficients for monozygotic (MZ) and dizygotic (DZ) twins are displayed in **Table 1**. The descriptive values of simple reaction time, hand-eye coordination, finger dexterity, and manual force control were similar between MZ and DZ twins. Rather, the errors of rate control were higher in DZ twins. The analysis compared values of intraclass correlation coefficients between zygosities. Higher values of correlation (i.e. finger dexterity and hand-eye coordination) mean that the performance between twins was similar. Lower values of correlation (i.e. simple reaction time and rate control) mean different performance levels between twins.

Table 2 shows the ACE model estimated parameters to describe genetic (A), shared environment (C) and nonshared environment (E) effects of the phenotypes. The values indicate almost null additive genetic influences on finger dexterity, whereas high heritability on rate control. Shared environment influence was null for rate control and very high for finger dexterity and hand-eye coordination. Nonshared environment influence was low on hand-eye coordination but very high on simple reaction time.

Table 1. Means ± standard deviations and intraclass correlation coefficients for monozygotic (MZ) and dizygotic (DZ) twins.

	MZ	DZ
Finger dexterity (s)		
Twin 1	45.35 ± 5.91	46.47 ± 11.03
Twin 2	46.26 ± 6.30	46.73 ± 6.09
ICC	0.78	0.77
Hand-eye coordination (s)		
Twin 1	18.45 ± 6.34	17.30 ± 5.87
Twin 2	18.89 ± 6.75	15.86 ± 6.41
ICC	0.88	0.75
Manual force control (*absolute error*)		
Twin 1	2.68 ± 2.13	2.64 ± 2.45
Twin 2	2.31 ± 1.96	2.97 ± 1.65
ICC	0.59	0.49
Rate control (*absolute error*)		
Twin 1	45.36 ± 15.95	73.14 ± 31.52
Twin 2	64.69 ± 32.88	90.88 ± 51.24
ICC	0.44	0.18
Simple reaction time (ms)		
Twin 1	346.15 ± 37.96	345.52 ± 60.03
Twin 2	365.46 ± 63.83	373.91 ± 43.48
ICC	0.29	0.19

Values of finger dexterity and hand-eye coordination are expressed in seconds; values of simple reaction time are expressed in milliseconds; values of manual force control and rate control are expressed in absolute error. Twin 1 is older than twin 2.

Table 2. Estimated parameters to describe additive genetic (A), shared family environment (C) and nonshared environment (E) effects.

	A (genetic)	C (shared environment)	E (nonshared environment)
Finger dexterity	0.02	0.76	0.22
Hand-eye coordination	0.26	0.62	0.12
Manual force control	0.20	0.39	0.41
Rate control	0.49	0.00	0.51
Simple reaction time	0.20	0.09	0.71

4. Discussion

This study aimed to test the Three Laws of Behavior Genetics (Turkheimer, 2000) by addressing genetic and environmental influences in the performance of tasks underlain by PMAs of rate control, simple reaction time, hand-eye coordination, finger dexterity, and manual force control. As values above 0.40 are considered to be of high genetic effect (Plomin et al., 2012), the remarkable heritability of 0.49 means that approximately half of the variance in the rate control (coincident timing) scores might account for inherited factors. This finding seems to corroborate the First Law of Behavior Genetics, according to which behavioral traits carry a strong genetic factor. The absence of shared environment effect in the total variance of rate control values seems to indicate that the family has little influence on the expression of this PMA. Yet the contribution of 51% for the nonshared environment suggests that the external environment is important for its development. According to a modular approach of individual differences, general timekeeping ability seems to be a centrally organized function in the nervous system to account for the temporal aspects of movements (Jones, 1993; Keele, Ivry, & Pokorny, 1987; Keele, Pokorny, Corcos, & Ivry, 1985). The high heritability of rate control seems not to be in line with a strict interpretation of similar behavioral phenotypes in the motor domain (Fermino et al., 2007; Maia et al., 2010; Plomin et al., 2012). In fact, the phenotypic variance which account for genetic effects is a low proportion of the total variance as indicated by the other PMAs tested in the present study: 0.20 for simple reaction time and manual force control, 0.26 for hand-eye coordination, and 0.02 for finger dexterity.

Parents not only transmit genes to descendants but also values, habits, and attitudes (Maia et al., 2010). Indeed, family as a social agent on behaviors seems to play an important role in the shared environment factor. Great permeability to family influence was found in the data for finger dexterity and hand-eye coordination, whereas little might be attributable to family in regard to simple reaction time and rate control.

High values of nonshared environment parameters may suggest that there is a major contribution of external environment for simple reaction time, manual force control, and rate control. This environmental influence is thought to be uniquely built by the individual, that is, something exclusively belonging to the outer familiar ring. As this unique environment is permeable to a number of influences (i.e., friends, teachers, social media, other social groups), it is likely that the specific factors that underlie nonshared environmental factors are idiosyncratic and specific to the individual, and hence difficult to interpret at a population level (Turkheimer, 2011).

The additive genetic factor in the ACE model is the ratio between genetic variation and total variance so that it refers to what extent genetic differences influence the variability of a characteristic in a given population. Therefore, the genetic factor is not a sole and permanent attribute of a characteristic or individual (a heritability of 0.75 does not mean that this trait in an individual be determined in 75% by genetic factors). In other words, high values of heritability are meaningless about the capacity to change in a given characteristic. For instance, high heritability does not imply insensitivity to environmental changes, as demonstrated by height, generation over generation (Silventoinen et al., 2003).

The findings of the present study allow us to assume that genetic factor does not seem to fully account for determining PMAs. There is compelling evidence to suggest that a small number of PMAs are genetically determined and that these abilities might be more developed during growth and maturation. From a practical standpoint, it is arguable that genetic differences have little influence on the variability of abilities that underlie motor skills. Therefore, it seems plausible to believe that PMAs are not prime requisites a learner must possess to perform masterfully in the sense that the potential performance level at a specific time in a given motor skill might not be due to its underlying abilities' performance levels.

5. Conclusion

Despite limitations of sample size and intervening factors, such as other PMAs underlying the experimental tasks, the findings of this study suggest that partial support was given to the three Laws of Behavior Genetics (Turkheimer, 2000), as high proportions of variance on the performance were attributable to 1) genetic factors for rate control only, 2) shared environment for hand-eye coordination and finger dexterity, and 3) nonshared environment for rate control, simple reaction time, and manual force control.

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