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Riitta Simonen

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A Study of Monozygotic Twins

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''Olemme olleet huomaavinamme ainakin kaksi katkeran lohdullista lakia: perinnöllisyyden ja kehityksen, joiden, varsinkin ensinmainitun, inhimillinen tuntemus vasta ottaa ensiaskeliaan. Nämä lait voivat kyllä sallia ihmisten vähitellen, polvi polvelta tietoisestikin, opetuksen mukaan, pyrkiä elämän kultapuulle, aina sen latvaan asti, josta kerran lopulliset taivaat aukenevat ihmissuvulle, johon kuulumme.''

F. E. Sillanpää. Enkelten suojatit, 1923

ABSTRACT

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The determinants of hand and foot psychomotor speed were investigated in monozygotic twins 35 to 69 years of age. First, the reliability study was conducted to investigate the consistency of the reaction time measurements using the method selected. Second, the effects of exercise, smoking and driving were examined by contrasting co-twins discordant for the factor studied. Finally, the contribution of these factors and others suspected of influencing psychomotor speed were studied using a multivariate model. Recruited from the population-based Finnish Twin Cohort, including 2,050 male monozygotic twin pairs, were 61 relatively healthy twin pairs. Psychomotor speed was determined by simple and choice visual signal tests using the hand and foot, yielding measurement of decision time, movement time, and their sum, reaction time. The consistency of the within-test and between-test sessions was acceptable (r=.49-.99) for both hand and foot measurements. Twins with a history of strenuous and frequent exercise had faster psychomotor speed than their co-twins with histories of moderate, occasional lifetime exercise. Twins with a history of smoking, as well as twins with histories of excessive vehicular driving tended to have slower psychomotor speed than their less exposed co-twins. The major determinant of psychomotor speed, however, was familial aggregation, a combination of genetic and shared early environmental influences, which explained 18-52% of the variation in psychomotor speed, depending on the extremity and psychomotor speed outcome measured. Other determinants accounted for 0-17% of the variation, with age alone explaining up to 13% of the variation in psychomotor speed. Other factors which had more minor effects were cardiovascular morbidity, associated with impaired psychomotor speed, and strenuous exercise and sedentary work which were associated with slightly faster speeds. These results suggest that promoting a healthy lifestyle that includes vigorous exercise and minimal cardiovascular disease may have a modest effect on reducing the age-related decline in psychomotor speed. A combination of genetics and family environment influences appear to have considerable effect on psychomotor speed in later adulthood, yet much of the variability in psychomotor speed remains unexplained.

Keywords: genetics, age, exercise, occupational loading, cardiovascular disease, decision time, movement time, reaction time

LIST OF ORIGINAL ARTICLES

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

I. Simonen RL, Videman T, Battié MC, Gibbons L. Comparison of foot and hand reaction times among men: a methodologic study using simple and multiple-choice repeated measurements. Perceptual and Motor Skills 80: 1243-1249, 1995.
https://doi.org/10.2466%2Fpms.1995.80.3c.1243

II. Simonen RL, Videman T, Battié MC, Gibbons L. The effect of lifelong exercise on psychomotor reaction time. A study of 38 pairs of male monozygotic twins. Medicine and Science in Sports and Exercise, in press.
https://doi.org/10.1097/00005768-199809000-00015

III. Gibbons L, Simonen RL, Videman T, Battié MC. Psychomotor reaction time differences in male identical twins discordant for lifetime cigarette smoking. Perceptual and Motor Skills, 83:1219-1225, 1996.
https://doi.org/10.2466%2Fpms.1996.83.3f.1219

IV. Simonen RL, Videman T, Battié MC, Gibbons L. Differences in hand and foot psyhomotor speed among 18 pairs of monozygotic twins discordant for lifelong vehicular driving. Submitted.
https://doi.org/10.1007/s004200050219

V. Simonen RL, Videman T, Battié MC, Gibbons L. Determinants of psychomotor speed among 61 pairs of adult male MZ-twins. Submitted.
https://doi.org/10.1093/gerona/53A.3.M228

This thesis also contains data which has not been previously published.

CONTENTS

1 GENERAL INTRODUCTION

Fast psychomotor speed requires good central and peripheral neuromuscular functioning. It indicates the subject's central information processing capacity for fast and coordinated motor performance. Reaction time is suspected of playing an important role in injuries, particularly related to traffic accidents; it is related to occupational activities, as well as to sports and to most daily activities.

Being one measurement of cognitive performance, psychomotor speed is related to intelligence and education. It is impaired by age, several diseases, and exposure to neurotoxic substances. Because whole-body vibration in driving has been documented to have degenerative effects on connective tissues and the nervous system, it could be hypothesized that it would impair psychomotor speed, as well. It also has been hypothesized that smoking may affect reaction time, although there is no clear evidence at present. The effect of exercise in enhancing psychomotor speed has been extensively studied; controversial findings exist regarding both exercise interventions and associations with physical activity measured retrospectively.

Retrospective studies may include several biases; genetics may influence involvement in exercise selection and selection of occupation and social activities. Thus, it may be difficult to differentiate a factor that directly influences psychomotor speed from a covariate. Memory and recall bias also may introduce measurement error. Long-term exposure to such factors can be studied in relatively aged subjects. Subject selection may influence representativeness of the sample, a well.

This study investigates the effects of common exposures - exercise, smoking, driving - on psychomotor speed in monozygotic twin pairs with substantial discordance in lifetime exposures. This study design enables the control of the effects of genetics and many extraneous factors on psychomotor speed. Furthermore, these and other suspected determinants of psychomotor speed were studied with a multivariate model using a sample of 61 monozygotic twin pairs. Factors investigated were familial aggregation, representing genotype and shared early environmental effects, age, lifelong participation in strenuous exercise, sedentary work, cardiovascular morbidity, smoking and driving with its associated whole body vibration. An improved understanding of the effects of factors leading to impaired motor control or maintainance of motor control, would provide a foundation on which to develope improved strategies for minimizing age-related psychomotor speed decline.

2 REVIEW OF THE LITERATURE

2.1 The concept of psychomotor speed

Visual psychomotor speed

Psychomotor speed indicates a subject's ability to perform a rapid motor response to a sudden signal. During the task the subject maintains a high alertness in order to react rapidly to predefined stimulus events, and maintains the readiness to respond to the events over extended periods with high speed and accuracy demands (Wesnes & Parrot, 1992). The performance is considered more skillful when less time is required to complete a given movement (Schmidt, 1988). Visual psychomotor speed measurements consist of simple- and choice reaction time tests. In the latter, there are multiple choices for the response, the range of choices depending on the construction of the device.

Learning can be observed throughout a repetitive psychomotor task (Dickie & Kerr 1987, Fishman & Lim 1991). Psychomotor speed also is sensitive to diurnal variation (Payne 1989, Smith 1992), and loss of sleep (Tilley & Brown 1992), fatigue and stress (Welford 1980), as well as neurostimulants like caffeine (Lieberman, 1992). Such factors should be minimized or controlled in reaction time measurements.

Psychomotor speed terminology

Different psychomotor speed terminology has been used between studies. The term psychomotor speed has been used synonymously with the terms psychomotor behavior and psychomotor response (Birren & Schaie 1990). The total motor response is usually divided into two parts: *decision time* and *movement time*. The time from the onset of the stimulus light to the lifting of the finger from the waiting button has been called *decision time* (e.g. Ghozlan & Widlocher 1987, Smith & Carew 1987, Taimela et al.1993, Finkel et al. 1995), *initiation time* (e.g. Houx & Jolles 1993) or *reaction time* (e.g. Mendryk 1960, Henry 1961). The time from the onset of the finger movement to touching of the target button has almost consistently been called *movement time* (e.g. Mendryk, 1960, Ghozlan & Widlocher 1987, Smith & Carew 1987, Houx & Jolles 1993, Taimela et al. 1993). The whole performance, indicating the time from the appearance of the light stimulus to the termination of the finger movement, has been called *reaction time* (e.g. Welford 1971, Ghozlan & Widlocher 1987, Rabbit & Maylor 1991, Houx & Jolles 1993, Taimela et al. 1993), *total reaction time* (e.g. Finkel et al. 1995) or *total response time* (e.g. Smith & Carew, 1987).

Psychomotor speed is usually measured with the dominant hand, but some exceptions exist. An age effect on simple decision time has been measured with the jaw and foot (Birren & Botwinick 1955). Lotter (1960) used a modified baseball throw and a football kick resembling a simple reaction time task. His main goal was to provide information about the laterality of motor skills and task-specificity of reaction time. Recently, Kauranen and Vanharanta (1996) collected reference data for a multifunctional performance system also including a hand and foot reaction time test. With two separate devices for the hand and foot they studied the repeatability of the method, and compared sex differences as well as reaction time differences between extremities; referred to as motor skill laterality.

Laterality of motor skills

The laterality of motor control reflects hemisphere lateralization. Right-handed subjects have shown a right foot motor skill preference, measured in reaction time tasks (Lotter, 1960), tapping tasks (Peters & Durding 1979, Augustyn & Peters 1986), kicking (Annett & Turner 1974, Peters & Durding 1979, Dargent-Pare et al. 1992), and in everyday activities measured by survey (Chapman et al. 1987). The foot preference is not consistently on the same side as the dominant hand (Dargent-Pare et al. 1992, Gabbard & Hart 1995), and the limb preference may be task-specific (Carson 1993). Inconsistencies in laterality studies may partly be explained by mixed-handedness, which affects about one-third of the population (Annett 1972). Also, there is a trend for handedness to shift to the right in aging, possibly due to genetic and cultural factors (Annett 1972). Motor skill laterality may thus be one source of interlimb variability in psychomotor speed differences, but it can be avoided by comparing the same extremities among the subjects studied, when handedness is known.

2.2 Risk factors for psychomotor speed based on epidemiologic studies

Genetics

A clear genetic dependency in psychomotor speed has been found in twin and family studies, although the results yield a wide range for heredity estimations. In an EMG study by Komi et al. (1973) genetics explained 86% of the variation in visual simple reaction time in 15 male adolescent monozygotic and dizygotic twin pairs. In a family study (Wolanski & Kasprzak 1979), the correlation of visual simple reaction time of parents and offspring was .70. In another family study (N=1630) of middle-aged parents and their children, Pérusse et al. (1987) estimated the effect of genetics and shared environmental effects for a visual simple psychomotor speed test using the hand. For simple decision time, a combination of genetics and shared environmental factors explained 27% of the variation, whereas 73% of the variation remained unexplained. Genetics was found to have a stronger influence than environmental factors, explaining 20% and 7% of the variation, respectively. For simple movement time, environmental effects explained only 18% of the variation, with the rest of the variation (82%) remaining unexplained.

Unfortunately, these studies have explored only simple reaction times. Only Boomsma and Somsen (1991) have used monozygotic and dizygotic twins to study the heritability of choice reaction times in adolescents, but their test consisted of an auditory stimulus with different interstimulus intervals, and included mixed conditions with arithmetic tasks. Their main findings were that genetics accounted for relatively little of the variance (7%-23%) in performance of reaction time tasks with 2 to 5 seconds of interstimulus intervals. However, when the reaction time test of arithmetics was considered, genetics explained 48% of the variance in performance.

Although genetic effects on psychomotor speed are evident, twins also share similar environments during childhood, adolescence, and to a lesser degree in adulthood. These environmental similarities are likely to influence the degree of familial aggregation seen in psychomotor speed, as well. Apparently there are no studies that have investigated more thoroughly the relative influences of genetics and other determinants.

Aging

Age-related deterioration in psychomotor performance is well established (Birren & Fisher 1995). Determined in a longitudinal study by Fozard et al. (1994), slowing begins around the age of 20 at a rate of 0.5 ms per year for auditory simple reaction time and 1.6 ms per year for auditory choice reaction time. The role of genetic factors in the decline of cognitive performance with aging has been documented in a twin study by Swan et al. (1992), who found a 45% concordance for decline in psychomotor performance (Digit Symbol) for monozygotic twin pairs and an 8% concordance for decline for dizygotic twin pairs during the 5-year interval. These studies did not, however, control for the effects of health status on the age-related decline in psychomotor speed. Hence, the decline in the performance may be a combined effect of aging and disease.

Diseases

Psychomotor speed is affected by morbidity which impairs the neurologic functioning of the brain or peripheral nervous system, such as traumatic brain damage (Nettelbeck 1980, Roy 1990), Parkinson's disease (Stelmach et al. 1986) and diabetes (Deary, 1992). Subjects with cardiovascular disease - hypertension and coronary heart disease - have performed reaction time tasks more poorly than subjects without clinical cardiovascular diagnoses (Hertzog et al. 1978, Light 1978). In fact, reaction time decrement has been seen in middle-aged Type A subjects - predisposed behaviorally to coronary heart disease (Abrahams & Birren 1973).

There is some evidence that chronic low back pain subjects have slower hand psychomotor speed than those without chronic pain (Taimela et al. 1993, Venna et al. 1994, Luoto et al. 1995). It has been suggested that subjects with a slow psychomotor speed may be more prone to repeated spinal microtraumas, which could lead to chronic low-back pain. Whether slower psychomotor speed is a cause or effect of chronic low back pain, or simply a covariate of another associated factor in unclear.

Exercise

Studies of the effects of exercise on psychomotor speed have yielded controversial results. Comparing athletes and inactive controls, Era et al. (1991) found a faster choice reaction time in the exercise or athlete group. Retrospective studies comparing elderly physically active subjects with less active controls have shown faster psychomotor speed in exercise groups (Sherwood & Selder 1979, Rikli & Edwards 1991, Lupinacci et al. 1993), but contradictory results also have been found (Roberts 1990). The inconsistencies in results of exercise interventions may be due to study designs, where the effects of reaction time have often been studied comparing sportsmen with inactive subjects, or aged physically active with inactive subjects. In such retrospective studies the subjects have either already adopted and maintained a regular exercise regimen or have chosen an inactive way of life. Those choices may be affected by physical abilities, of which psychomotor speed may be a part. Because genetics affects exercise participation (Wolanski 1986), aerobic capacity (Bouchard et al. 1986), and psychomotor speed (Komi et al. 1973, Wolanski & Kasprzak 1979, Pérusse et al. 1987), retrospective studies of exercisers versus inactive controls contain a selection bias due to genotype. Moreover, inconsistency of the relationship between reaction time and exercise may be explained by other uncontrolled factors such as education, disease or health habits - particularly with older subjects.

In intervention studies, older adult subjects who had been involved in a three-year exercise program had a faster choice reaction time after one year of follow-up as compared to controls (Rikli & Edwards 1991); four months of training improved simple but not choice reaction time (Dustman et al. 1984). On the other hand, neither a six-week walking program (Roberts 1990), seven weeks of aerobic exercise (Powell et al. 1983), six months of aerobic and strength training (Panton et al. 1990), or ten months of endurance training (Paas et al. 1994) significantly improved psychomotor speed.

Smoking and alcohol use

Recent smoking has clearly been shown to improve the cognitive performance of smokers and impair that of nonsmokers (Wesnes & Parrot, 1992). However, the effects of chronic smoking, in terms of regular lifetime smoking, are unclear. Adults who smoked over an average of 16 years had slower choice reaction times than did age-matched non-smokers. Yet, this finding was present only for women, and not for men (Knott 1984). In a population sample of men, the effect of smoking on psychomotor speed was 'negligible' (Era et al. 1986). Smokers have, however, shown a poorer performance in other types of cognitive function tests (Cross Off, Digit Symbol) as compared to nonsmokers (Hill et al. 1989).

Male and female alcoholics recruited from alcoholism treatment centers showed poorer perceptual-motor test results than did nonalcoholic controls (Glenn & Parsons 1992). The history of alcohol use in the alcoholics was in mean 10 and 13 years, at 386 g and 456 g per day for men and women, respectively. The study also provided some evidence for a dose-response relationship between motor skill impairment and amount of alcohol used per day, as well as the maximum amount of alcohol consumed per day. Such results give some evidence that chronic excessive alcohol intake may impair motor performance.

Occupational factors

Occupational status reflects subjects' educational backgrounds as well as the physical demands of the work. In general, the more physically heavy a job is, the less education is required. There may also be some natural selection for different jobs (Pullum 1975). Fast psychomotor speed is associated with intellectual ability (Jensen & Munro 1979), which is determined partly by education (Heath et al. 1985) and genetics (Plomin & DeFries 1980). Cross-sectional studies have shown faster psychomotor speed with educated subjects (Era et al. 1986), and faster perceptual-motor speed with managers as compared to manual laborers (Suvanto et al. 1991).

One occupational exposure is vehicular whole-body vibration. Because whole body vibration impairs the nervous system and related structures (Seidel & Heide 1986, Hulshof & van Zanten 1987, Wasserman 1987), subjects exposed to substantial driving at work may have impaired psychomotor speed. Acute whole-body vibration seems to impair psychomotor reaction time (Grether et al. 1971, Shoenberger 1972), but the chronic effects of vibration exposure on psychomotor speed have not been documented. There is a theory that vibration may lead to impaired motor function based on evidence that it impairs nerve conduction velocity (Nilsson et al. 1994), delays brainstem auditory evoked potentials (Murata et al. 1990), and delays somatosensory evoked potentials (Araki et al. 1993).

The effects of exposure to occupational chemical agents on psychobehavioral performance have been widely studied. Poorer cognitive performance has been found in painters exposed to solvents (Kishi et al 1993, Cherry et al 1985), although studies have not detected an effect on reaction time performance (Maizlish et al 1985, Fidler et al 1987). Neither was performance of some psychomotor tests impaired in monozygotic twins exposed to solvents for 13 years in mean, as compared to their unexposed co-twins' (Hänninen et al 1991). Despite the conflicting results of research in this area, it has been generally concluded that exposure to organic solvents impairs reaction time performance, but the acute and chronic effects should be more clearly distinguished (Stollery 1992).

Workers exposed to road traffic pollutants, such as drivers, may also show impaired functioning of nervous system. In a time series analysis over two months by Bullinger (1989), reaction time performance was impaired with increased air sulphur dioxide concentration. Neurobehavioral functioning may also be impaired by exposure to traffic air pollutants, such as lead (Needleman et al. 1990; Liu and Elsner 1995).

3 PURPOSE OF THE STUDY

The purpose of this study was to increase our understanding of the determinants of psychomotor speed. The consistency of hand and foot psychomotor speed was determined, the effect of lifestyle factors was investigated, and the contribution of these factors and other suspected determinants of psychomotor speed was explored using a multivariate model.

The specific aims of this study were to:

1. Determine the within-test session reliability and between test session repeatability of the psychomotor speed measurement method for the hand and foot, and to compare hand and foot psychomotor speed (I).

2. Compare monozygotic twins discordant for exercise (II), smoking (III) and occupational driving (IV) with respect to psychomotor speed to investigate the possible effects of these exposures.

3. Assess the relative effects of familial aggregation, age, cardiovascular morbidity, smoking, regular strenuous exercise, sedentary work, and occupational driving on psychomotor speed (V).

4 MATERIAL AND METHODS

4.1 Study design and subjects

Study I

Intra- and inter-session repeatability for the dominant hand and the ipsilateral foot was studied in 34 heathy men aged 25 to 61 years (mean age = 39 years). The subjects were staff members of the Faculty of Physical Education in Jyväskylä University. They performed two tests within a period of two weeks at the same time of the day for each test session.

Within-test session repeatability, evaluation of different mean value computing methods, and a comparison of hand and foot psychomotor speed were studied in the Finnish Twin Cohort subjects used in studies II-V. The subjects were 153 men, aged 35 to 67 years (mean age = 48 years).

Studies II - V

Monozygotic twins were selected from the Finnish Twin Cohort. This population-based cohort consists of 2,050 male monozygotic twin pairs born before 1958, who were alive in 1975. The estimated probability of misclassification of zygosity was estimated at 1.7% (Sarna et al. 1978). The data was collected in 1992-1994 at Kuopio University Hospital as part of a larger study of common musculoskeletal symptoms. 232 monozygotic twins volunteered to participate in the study, 82% of those solicited. The preliminary selection was based on co-twin discordance in lifetime exposure to common behavioral and environmental factors, such as exercise, smoking, driving, and occupational physical loading as revealed from survey information from 1975 and 1981. The twin pair discordance to the factors studied was verified and updated in an interview (explained in Methods). Subjects in whom confounding factor affecting psychomotor speed were identified, were excluded (=75 subjects). Such factors were acute disease, severe pain, extremity impairment, medication delaying psychomotor speed (except for cardiac medication in study V) and substance abuse. Because analyses included pairwise comparisons, subjects whose co-twin had met some exclusion criteria (35 subjects) were also excluded. The final sample size, consequently, was 61 pairs. The pair selection criteria were the within pair discordance for the factors studied: two levels of exercise discordance, smoking and driving. The exposed and unexposed co-twins had very similar lifestyles except for the factor for which they were discordant.

4.2 Methods

Interview

Medical history, and history of exercise, smoking, alcohol consumption, and occupational exposures were obtained from an extensive structured interview lasting about 2.5 hours. Each subject was asked to recall his medical history, and leisure and occupational lifestyle and health-related factors by connecting them with certain meaningful events, such as graduation, military service, marriage, and childbirth. The interviews were conducted by the same examiner for a twin pair.

Medical history included past and present diseases as diagnosed by a physician. The year diagnosed, current status, medication and hospitalization data were collected for each disease. Current smoking status was recorded, as well as smoking history, which was further summarized in pack-years (number of packs per day times number of years smoking when averaged daily use is 20 cigarettes). Alcohol consumption was estimated in grams of absolute alcohol per month on the basis of consumption frequency, amount and type of reported alcohol products. Coffee and tea consumption were recorded as cups per day, and number of years drinking.

Physical activity referred to sports and exercise activities, other physical leisure time activities, and physical activity at work. The information collected from the exercise and physical leisure time activities included activity type, age span, months of participation per year in mean, frequency per week, duration of the session, and perceived intensity (1=light, 2=moderate, 3=strenuous) in mean. Every event lasting at least three months was coded separately, but all exercise activities from the age of 12 to the present age were finally coded to an accuracy of one year. Physical leisure time activities other than sports were recorded in the same manner. Subjects' lifetime occupational physical loading was evaluated in the interview on the basis of the physical demands of each job, including work posture, materials handling, weight lifted, walking, and bending or twisting. Jobs were coded using one of 18 descriptive categories which were later reduced to 4 (1 = sedentary work, 2 to 4= progressive degrees of material handling, where 4 was heavy physical work), and the mean job code was weighted by the number of years spent in each job category. The occupational physical loading characteristics were also summarized by the mean years in every loading category, mean hours sitting per day, and the time spent in twisted and bent positions per day. Mean lifting load was computed by multiplying the weight of the most commonly lifted object by the frequency of lifts per day, weighted by the number of years at a job. Also, occupational driving was determined as on-job driving hours per day, kilometers per year, and the vehicle type. Types of work-related chemical exposure and time span were also recorded.

Psychomotor speed

Psychomotor reaction time was measured with the dominant hand, ipsilateral foot, and contralateral foot. The measurements were obtained within two hours for both co-twins in order to avoid possible effects of diurnal variation in reaction time. Prior to testing the examiner checked, that possible confounding factors for reaction time were not present, such as excessive loss of sleep, acute infection, severe pains, and substance abuse. Separate devices were used for the hand and feet, with the distance of the movement termination from the waiting button being 10 cm for the hand and 20 cm for the foot. Otherwise the two devices were constructed similarly to maintain the same level of complexity (Fig. 1.).

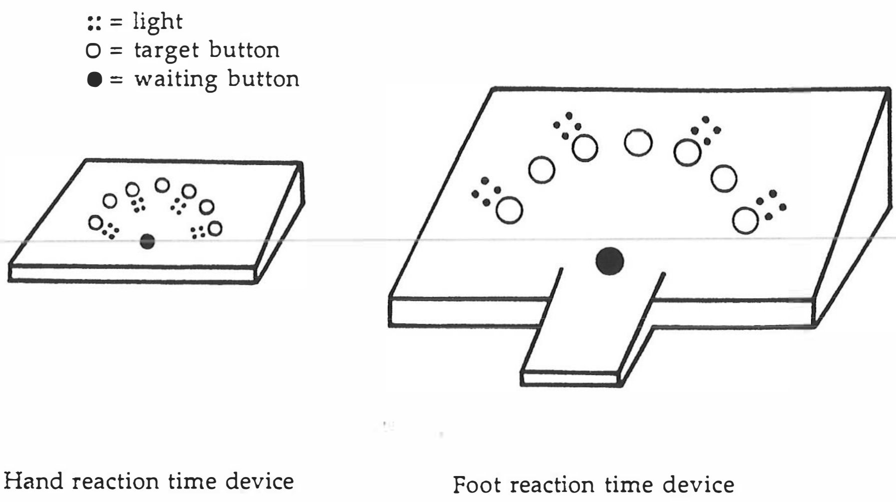

FIGURE 1 Hand and foot reaction time devices.

With each extremity, the subjects performed both simple and seven-choice reaction time measurements. Subjects were instructed to perform as fast and as accurate a movement as possible. Based on a visual signal after a randomly assigned period of 1 to 4 seconds, the subject lifted his forefinger or big toe from the waiting button (= decision time) and moved it to the target button as fast and accurately as possible (= movement time). The sum of the decision and movement time was called reaction time. The accuracy of the measurement was ± .001 ms. After three practice trials the subjects performed 12 actual trials in the simple and choice tasks with each extremity. The testing took about 20 minutes for each subject.

The mean of five fastest among all 12 trials was used in the analysis. The selection of the five fastest trials yielded highest reliability within a test session (Cronbach's alpha = .99) and between test sessions two weeks apart (ICC=.49 to .68) than using other mean value computing methods (Study I).

Data Analysis

Study I:
Repeatability between the two test sessions was analyzed with intraclass correlation coefficients and the different data sampling methods with Cronbach's alpha. Pearson correlation coefficients were used to compare decision time, movement time and reaction time between extremities. Linear regression analysis was used to assess the effects of weight, height, and body fat (%) on psychomotor speed, and multivariate regression analysis to explain the effect of age, height, weight and musculoskeletal impairments on the variance in psychomotor speed

Study II-IV:
For each twin pair, the psychomotor speed of the unexposed twin was subtracted from the psychomotor speed of the exposed twin. T-tests were used to test the hypotheses that the mean paired differences were zero. Possible confounders were controlled in a linear regression model to predict the difference in psychomotor speed. The hypothesis of no difference in psychomotor speed was tested using the Wald test for the intercept. Studied confounders were occuptional loading (study II), alcohol and coffee consumption (study III), occupational exposure to solvents (III), exercise (IV) and low back pain complaints (IV).

Study V:
Multivariate linear regression was used to assess independent predictors of psychomotor speed. Age, cardiovascular disease, smoking, strenuous exercise, occupational sitting, occupational driving, as well as genetics and shared environmental factors were evaluated as determinants. Plausible interactions were examined, and the effect of every outlier was evaluated. The adjusted R^2 indicated what percent of the variability in an outcome was explained by the variable or variables of interest, and it was adjusted for the number of variables in the model.

5 RESULTS

5.1 The reliability of the method to assess psychomotor speed (I)

The reaction time values for the hand were 73-74% of those for the foot in the simple reaction time task, and of 84% of those for the foot in the choice task (Table 1). Decision and movement times made up approximately equal parts of the reaction times (49-51%) in the ipsilateral and contralateral foot, whereas the hand decision times were 54% and 60% of the reaction times in simple and choice tasks, respectively.

TABLE 1 Descriptive statistics for hand, ipsilateral foot, and contralateral foot psychomotor speed using mean of 12 trials, in milliseconds (N=153). Decision time and movement time are presented as percentage of the reaction time.

	Decision time		Movement time		Reaction time
	Mean	% of RT	Mean	% of RT	Mean
Dominant Hand					
Simple	265 (67)*	54	222 (75)	46	487 (104)
Choice	403 (101)	60	268 (101)	40	670 (138)
Ipsilateral Foot					
Simple	322 (83)	49	339 (122)	51	661 (155)
Choice	403 (93)	51	392 (139)	49	795 (166)
Contralateral Foot					
Simple	324 (78)	49	344 (127)	51	669 (162)
Choice	397 (96)	50	402 (142)	50	799 (174)

* Standard Deviations in parenthesis

Mean values across the 12 trials for hand, ipsilateral and contralateral foot simple reaction times improved through the trial sessions. In contrast, no learning effect emerged across the trials in choice reaction times. (Fig. 2.)

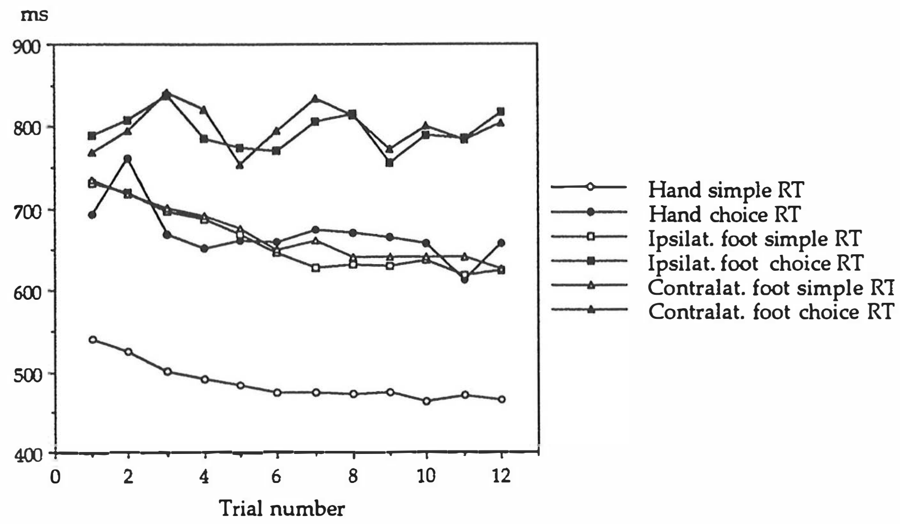

FIGURE 2 Mean values across the twelve trials for hand, ipsilateral and contralateral foot simple and choice reaction times (ms).

Repeatability between the test sessions held two weeks apart showed correlations of .49-.68 for the means of the five fastest values, .51-.61 for the means of all twelve values, .38-.60 for the means of last five values and .40-.57 for the means of the first three values (Table 2). Correlations between the right and left foot were better (.76-.81) than correlations between the hand and either foot (.39-.65), when the fastest five values were used in computing the mean values.

TABLE 2 Within test session repeatability (Intraclass Correlation Coefficient) for psychomotor speed measured by different value computing methods.

	Decision time	Movement time	Reaction time
Fastest five	.97-.99	.99-.99	.99-.99
Last five	.82-.88	.85-.95	.92-.95
All 12	.88-.93	.89-.97	.95-.97

5.2 Effect of exercise, smoking and driving on psychomotor speed

Exercise (Study II)

Two groups of twin pairs were selected based on their degree of lifetime exercise involvement and the contrast between co-twins. The psychomotor speed of 'frequent' exercisers (lifetime exercise of four times per week at moderate intensity, for 1.3 hours per exercise session in mean) was compared with that of their co-twins who had been involved in 'occasional' exercise (lifetime exercise of 1.6 times per week at less than moderate intensity, for 1.2 hours per exercise session in mean) (N=29 pairs). Another group was selected with less lifetime exercise involvement (N=9 pairs). In this group 'regular' exercisers (lifetime exercise of 2.9 times per week in mean, at light intensity, for 1.3 hours per session) were contrasted with their co-twins who exercised infrequently (lifetime exercise of 0.7 times per week in mean, at light intensity, for 1.5 hours per session). Subject characteristics of the 'frequent' versus 'occasional' and 'regular' versus 'infrequent' exercise twin pairs are presented in Table 3.

Psychomotor speed tended to be faster among the 'frequent' than the 'occasional' exercisers, particularly in the choice tasks (5-51 ms, 2-11%). After controlling for occupational physical loading the frequent exercisers showed faster hand choice decision time (21ms, $p<.01$) and contralateral choice reaction time (51ms, $p<.05$). The age effect on the influence of exercise was found in the ipsilateral foot simple and choice reaction times (both $p<.05$) (Fig 3). The predicted slowing for every 10 years was 46 ms for both simple and choice reaction times. In the hand and contralateral foot no age effect on the magnitude of reaction time differences was found. Nore was there a trend for a systematic effect of age on the differences in psychomotor speed for 'regular' versus 'infrequent' exercisers.

TABLE 3 Characteristics between the co-twins discordant for lifetime exercise, smoking, and driving (in means).

	EXERCISE				SMOKING		DRIVING	
	Frequent vs. Occasional		Regular vs. Infrequent		Smoker vs. Non-smoker		Driver vs. Less-Driver	
Number of MZ twin pairs	29		9		8		18	
Age range	35-69		35-69		35-63		39-62	
Mean age	50		47		48		50	
Elementary school education (%)	83	86	89	89	88	88	94	94
Occupational code [a]	2.3	2.7	3.1	2.9	3.5	3.3	2.3	2.4
Smoking (pack years)	10	11	8	9	32	1	16	15
Alcohol consumption [b]	411	238	212	164	529	222	357	350
Exercise (times per week)[c]	4.0	1.6	2.9	0.7	1.9	1.7	2.0	2.8

Note: MZ = monozygotic

[a] occupational physical loading coded with 1 (= light) to 4 (= heavy physical work)

[b] lifetime average grams absolute alcohol per month

[c] lifetime weighted exercise frequency per week

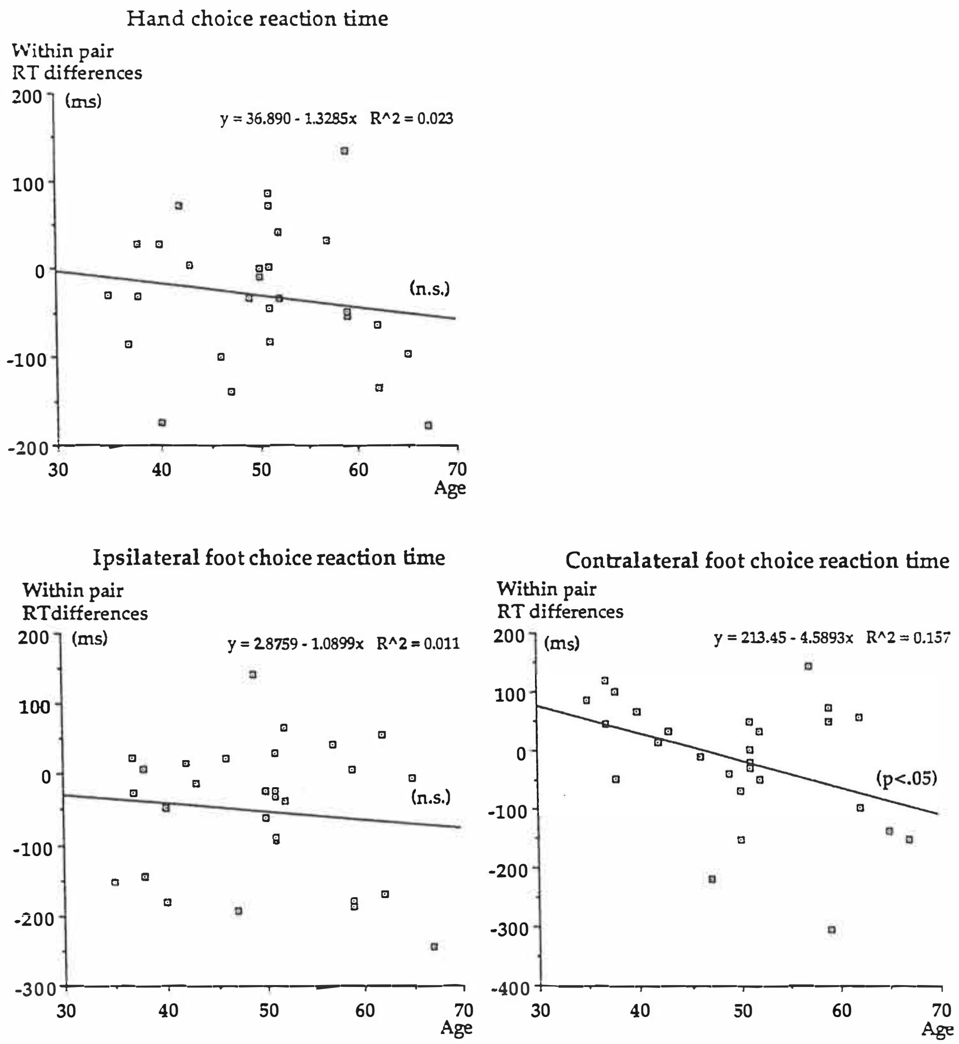

FIGURE 3 Age effect on the influences of exercise on hand, ipsilateral and contralateral foot psychomotor speed among frequent versus occasional exercisers.

Smoking (Study III)

The psychomotor speed of co-twins (N=8 pairs) with a mean lifetime history of 32 pack years of smoking versus one pack year were compared. The heavy smokers had a systematically slower psychomotor speed (15-45 ms) than their non-smoking co-twins, but only the differences in contralateral foot simple decision time and hand choice decision time were statistically significant (p=.05). Controlling for coffee and alcohol consumption did affect the outcomes, nor did occupational exposure to solvents.

Driving (Study IV)

The psychomotor speeds of co-twins (N=18 pairs) with contrasting lifetime histories of 22 years in driving jobs versus two years in driving jobs in mean were compared. Co-twins with less lifetime occupational driving tended to have faster hand psychomotor speed (4-10%) and foot decision times (1-6%). However, only hand choice decision times and ipsilateral foot choice decision times were statistically significantly faster (9%, p<.05 and 6%, p<.01, respectively) among those who drove less. These differences were not confounded by lifetime exercise or current low back pain. In contrast, co-twins with more driving had faster foot movement times (2-10%).

5.3 Psychomotor speed determinants (Study V)

Psychomotor speed differences within pairs (N=61 pairs) were smaller than among all subjects (Fig. 4). Familial aggregation (genetic and shared environmental influences) was the greatest single determinant of psychomotor speed, explaining 35-51% of the variation in the hand, 32-38% of the variation in the ipsilateral foot and 18-52% of the variation in the contralateral foot (Fig. 5).

Other factors collectively explained 2-8% of the variation in decision times, 0-17% in movement times and 3-16% in reaction times, depending on the extremity measured. With the exception of familial aggregation age was the greatest single determinant, explaining up to 13% of the variation in psychomotor speed. Cardiovascular morbidity, vigorous exercise, and sedentary work accounted for up to 9%, 5%, and 5% of the variation, respectively (Table 4).

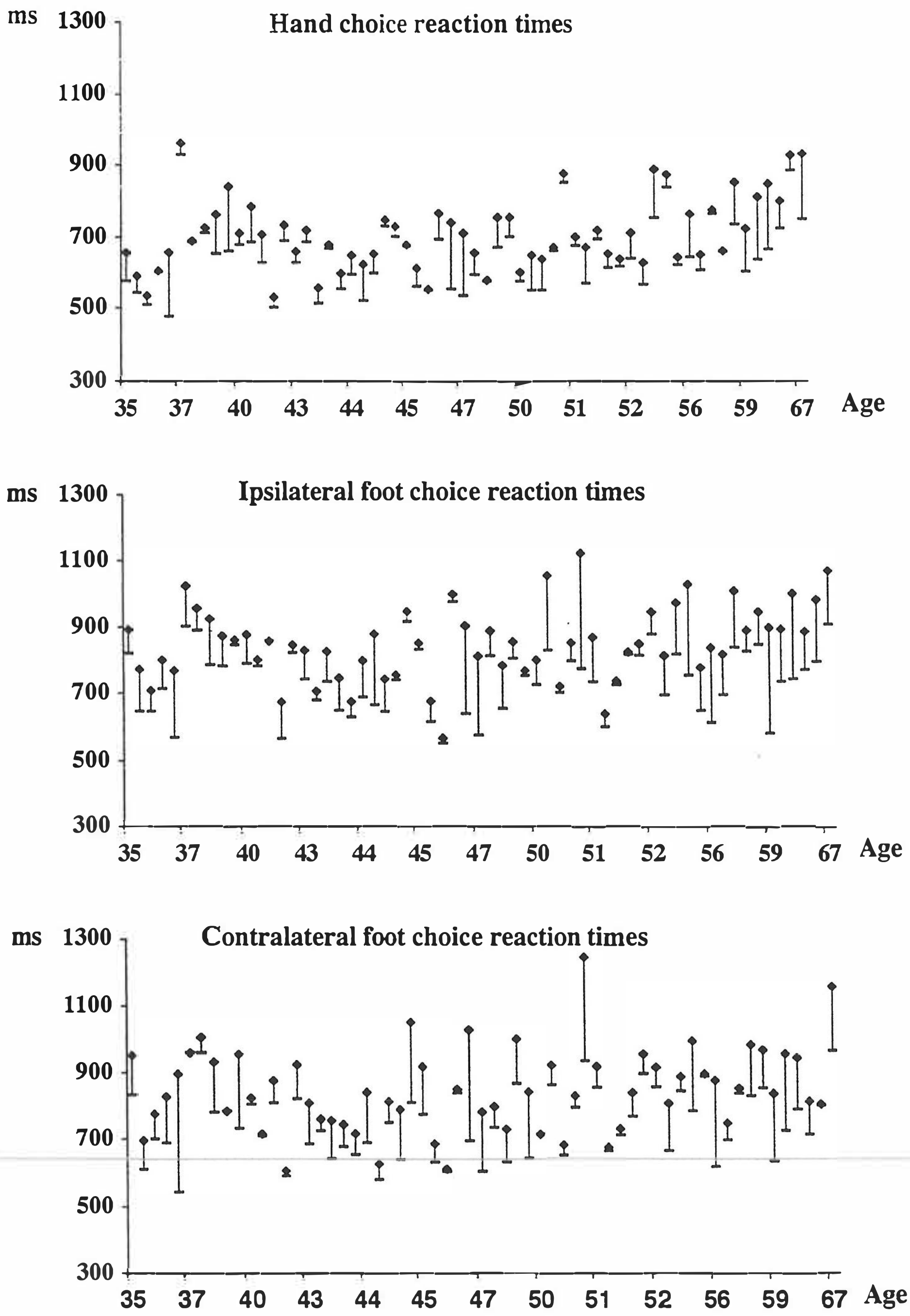

FIGURE 4 Within pair psychomotor speed differences (ms) by age for hand, ipsilateral, and contralateral foot choice reaction times (Δ = choice reaction time for the slower co-twin; – = choice reaction time for the faster co-twin).

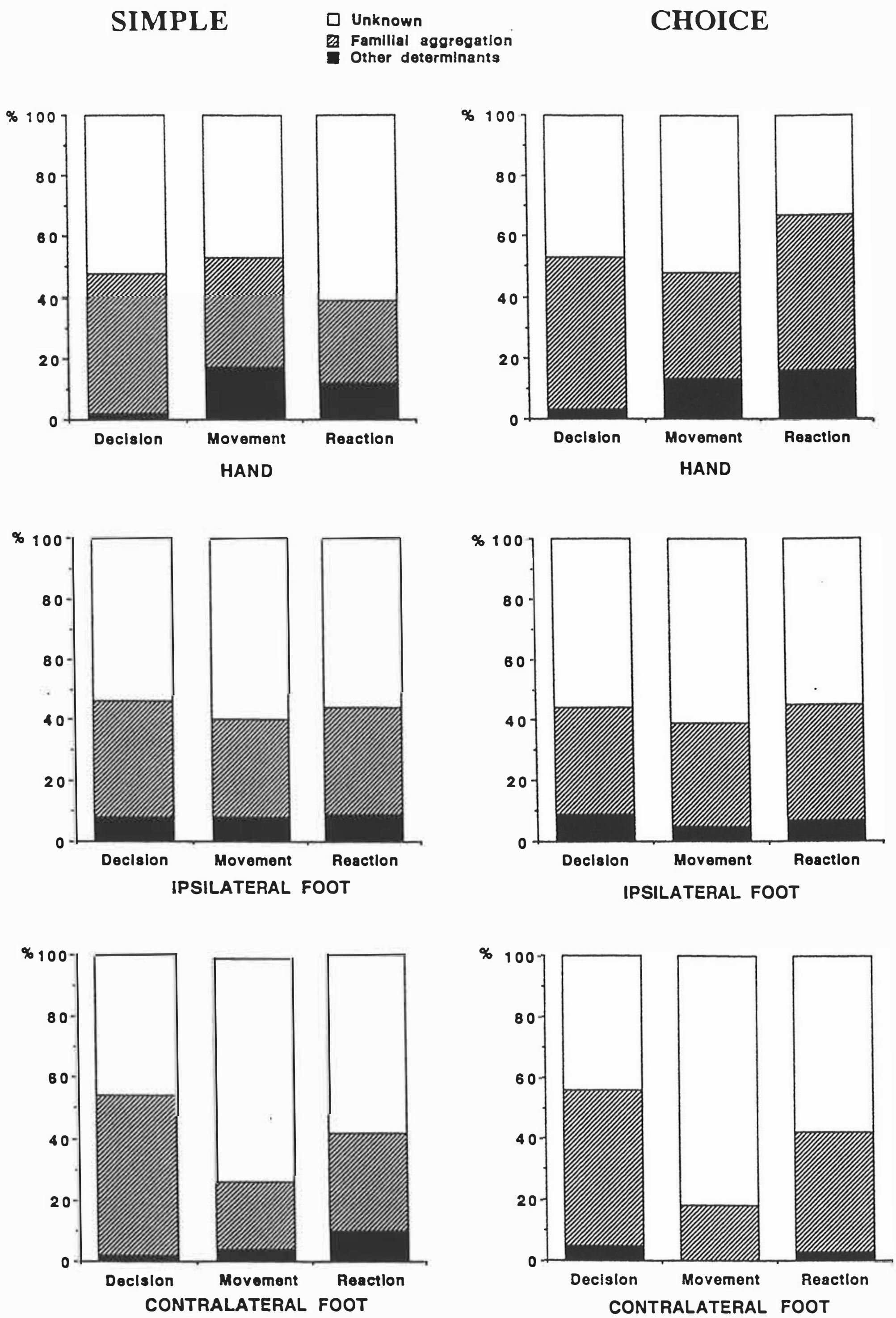

FIGURE 5 The percentage of variablity in hand and foot decision, movement, and reaction times explained by familial aggregation and other factors investigated.

TABLE 4 Determinants in hand and foot psychomotor speed, and the predicted change for each determinant (in ms).

Variable		Determinant	p-value	Explained proportion of the variance	Predicted change (ms)
HAND					
Simple	Decision time	Cardiovascular morbidity	<.05	2%	11 ms
	Movement time	Age*	<.001	13%	22 ms, between ages 45 to 55
		Vigorous exercise	<.05	4%	-2 ms/year
	Reaction time	Vigorous exercise	<.001	5%	-3 ms/year
		Age*	<.05	5%	18 ms, between ages 45 to 55
		Sedentary work	<.05	2%	-6 ms each hr of sitting/day
Choice	Decision time	Cardiovascular morbidity	<.05	3%	27 ms
	Movement time	Age*	<.001	11%	26 ms, between ages 45 to 55
		Sedentary work	<.05	2%	-6 ms each hr of sitting/day
	Reaction time	Age*	<.001	13%	41 ms, between ages 45 to 55
		Sedentary work	<.05	3%	-9 ms each hr of sitting/day
IPSILATERAL FOOT					
Simple	Decision time	Cardiovascular morbidity	<.01	8%	24 ms
	Movement time	Sedentary work	<.01	5%	-9 ms each hr of sitting/day
		Cardiovascular morbidity	<.05	3%	35 ms
	Reaction time	Cardiovascular morbidity	<.01	6%	62 ms
		Sedentary work	<.05	3%	-10 ms each hr of sitting/day
Choice	Decision time	Cardiovascular morbidity	<.001	9%	35 ms
	Movement time	Sedentary work	<.01	5%	-9 ms each hr of sitting/day
	Reaction time	Sedentary work	<.01	4%	-12 ms each hr of sitting/day
		Cardiovascular morbidity	<.05	3%	47 ms

(TABLE 4 cont.)

(TABLE 4 cont.)

CONTRALATERAL FOOT

Simple	Decision time	Cardiovascular morbidity	<.05	2%	16 ms
	Movement time	Sedentary work	<.05	4%	-8 ms each hr of sitting/day
	Reaction time	Sedentary work	<.05	4%	-11 ms each hr of sitting/day
		Cardiovascular morbidity	<.05	4%	43 ms
		Age*	<.05	2%	24 ms, between ages 45 to 55
Choice	Decision time	Cardiovascular morbidity	<.01	5%	27 ms
	Movement time				
	Reaction time	Age*	<.05	3%	29 ms, between ages 45 to 55

* = age-squared

6 DISCUSSION

6.1 Psychomotor speed measurement

The hand and foot psychomotor speed method demonstrated acceptable consistency in both the simple and choice reaction times. Different methods for computing mean value had little effect on test repeatability, but the five fastest values gave the best within-test session and between-two-test-session consistency. The decision and movement times contributed similarly to the reaction times for both the right and left foot, while decision time tended to be slightly greater than movement time for the hand psychomotor speed task.

One possible source of error in decision and movement times occurs when the subject chooses a different strategy to control the movement, which can happen either during the decision time or during the movement time (Smith & Carew 1987). In addition, decision and movement times have different sensitivities to practice effects (Ghozlan & Widlocher 1987), and, as also in this study, they have different determinants. These variables should, therefore, be viewed separately.

Another source of error in the psychomotor speed differences within the twin pairs may have been due to handedness misclassification. Handedness was determined by asking the subject to state his preferred hand. There are, however, some standardized questionnaires for determining handedness (Oldfield et al. 1971, Provins & Cunliffe 1972, Dorthe & Blumenthal 1995) and footedness (Chapman et al. 1987) which may have been useful in classifying subjects as right-, left- or mixed-handed.

Since motor skill laterality between hand and foot is an ambiguous phenomenon at present, comparisons of psychomotor speed between subjects should only be made with respect to the same extremity. In doing pairwise comparisons with opposite-handed pairs, it was presumed that the twin pairs also had crossed footedness. Among monozygotic twins, however, systematic concordance or discordance in the laterality of hand motor performance has not been demonstrated (Jäncke & Steinmetz 1995).

6.2 Determinants

Effect of single determinants

The effects of exercise, smoking and occupational driving were studied using the co-twin control method: by selecting among the sample of monozygotic twin pairs those for which co-twins were highly discordant for the studied factor. The case-control method (Khoury & Beaty 1994) can be applied to evaluate the effect of suspected risk factors retrospectively. At the same time the effect of genetics on the outcome variable - psychomotor speed - is controlled.

In the pairs of co-twins with contrasting levels of lifetime exercise, the twins with frequent and vigorous exercise backgrounds tended to have faster psychomotor speed than their co-twins who exercised occasionally, but no differences emerged between twins with histories of regular, moderate exercise versus infrequent exercise. Occupational physical activity appeared to be a confounder when studying the effects of lifetime exercise, and when controlled, fewer differences between the frequent and occasional exercisers were statistically significant.

Several previous studies have concluded that exercise enhances psychomotor speed (Sherwood & Shelder 1979, Era et al. 1991, Rikli & Edwards 1991, Lupinacci et al. 1993). Psychomotor speed has usually been faster with sportsmen (Hoyle & Holt 1983, Taimela et al. 1990, Era et al. 1991), suggesting that psychomotor speed may be enhanced by frequent and vigorous exercise. It has also been suggested that leisure time physical activity, in order to enhance physical fitness among middle-aged men, should be relatively strenuous (Tuxworth et al. 1986). Some psychological traits sensitive to psychomotor speed, such as state anxiety, neuroticism, depression, and stress reactivity, are effected by vigorous exercise (International Society of Sport Psychology, 1992). The findings of the present study are congruent with these hypotheses. Undoubtedly, sportsmen are accustomed to effort and mental challenges in reaching their maximal physical performance (Wolanski 1986), which may influence psychomotor performance, as well. Self-selection into vigorous exercise activities may also occur because of innate attributes which may include psychomotor speed. Controlling the genotype through the study of exercise discordant monozygotic twins should reduce the effects of such self-selection.

No age effects were found on the psychomotor speed differences among the twin pairs discordant for exercise, except for the ipsilateral foot. Among the youngest pairs the occasional exercisers had faster reaction times of the contralateral foot, which magnified the difference in the overall within-pair reaction time decline with age in the regression analysis. Stones and Kozma (1989) have explained the decline in age-and-exercise-related reaction time with two theories; a fast reaction time may be a result of psychological effects or it may result from specific movement and extremity training through exercise. Our study suggests that decline in psychomotor speed is an inevitable result from the aging process despite involvement in strenuous and frequent exercise through life, but that such exercise may nonetheless maintain psychomotor speed at a faster level compared with involvement occasional exercise only.

In this study, twins having a history of 32 years of smoking tended to have a slower psychomotor speed (5% to 14%), particularly in decision time, as compared with their co-twins with a history of less than one year of smoking. Similar results have been found by Knott (1984) with women, who had smoked for 16 years, when comparing their psychomotor speed with nonsmokers. A difference between smoking and nonsmoking men, however, was not found.

The sample size of eight pairs provided limited power to show statistically significant differences in the psychomotor speed between smoking discordant twins. In addition, smoking immediately prior to testing was not controlled and may have had some acute effect on psychomotor speed. Acute smoking may improve psychomotor performance among smokers (Wesnes & Parrot 1992), and therefore recent smoking prior to testing the reaction time may have an acute effect of enhancing test result and dilute negative effects of chronic smoking. On the other hand, smoking deprivation may not have been appropriate either, because it has been shown to impair performance among smokers (Hatsukami et al. 1989, Spilich et al. 1992).

Smoking is often associated with increased morbidity from cardiovascular disease, in general, which in turn - even when the disease is latent - impairs psychomotor performance (Abrahams & Birren 1973, Mazzucci et al. 1986, McCann et al. 1990, Waldstein et al. 1991). Long term smoking reduces cerebral blood flow and advances cerebral arteriosclerosis (Yamashita et al. 1988), which may impair cognitive functioning and psychomotor speed. This is one possible explanation for the speed differences between smokers and non-smokers found in this study.

Twins having a mean lifetime occupational driving history of 22 years tended to have a slower hand psychomotor speed compared to their co-twins with a mean of only 2 years of occupational driving. However, the results for foot movement times were the opposite, the co-twins with more driving showing faster speeds. Vehicular whole body vibration has apparent effects on structures and functions throughout the human body. It delays nerve impulse conduction velocity in peripheral nerves (Nilsson et al. 1994), as well as in the central nervous system (Araki et al. 1993, Murata et al. 1990). Subjects exposed to whole body vibration have shown an increased rate of degenerative changes in the spine (Seidel & Heide 1986, Wilder & Pope 1996). Furthermore, vibration may cause disorders in peripheral veins and the vestibular system (Dupuis & Zerlett 1986, Seidel & Heide 1986, Wasserman 1987). Kjellberg (1990) reviewed studies related to occupational vibration and it's psychological impacts and concluded that the evidence of vibration on tasks reflecting cognitive functions has been rather sparse. This study suggests that hand psychomotor speed may be slightly impaired by high lifetime exposure to vehicular vibration, and that motor practice elements in driving for the foot may dilute possible negative effects of driving on foot psychomotor reaction time. Besides the mechanical stress of vibration in driving, also neurotoxic agents of road traffic air pollution, especially lead, may also influence psychomotor speed decline (Liu & Elsner, 1995).

Contribution of determinants

The genetics and shared environmental influences (familial aggregation) was a major determinant of hand and foot psychomotor speed, accounting for 18% to 52% of the variation, respectively. The other determinants studied, including vigorous exercise, age, sedentary work, and cardiovascular disease, explained 2% to 13% of the variation, depending on the variable and extremity measured. The evident role of genetics in determining psychomotor speed has also been shown in previous studies (Komi et al. 1973, Wolanski & Kasprzak 1979, Pérusse et al. 1987, Boomsma & Somsen 1991), although the range of the magnitude of the hereditary estimations has been wide due to the different methods and subjects used.

Familial aggregation explained more of the variation in decision times (35-52%) than in movement times (18-36%). Foot movement time may be sensitive to environmental effects, such as motor practice in driving (study IV). This finding has been supported by Stones and Kozma (1989), who also presumed that foot tapping performance to be sensitive to motor learning of walking.

Besides familial aggregation age was the greatest single determinant. Despite the fact that the subjects in this sample were relatively healthy cardiovascular disease being the only existing diagnosed disease - age nonetheless emerged as the main explanation for the slowing in reaction time. Cardiovascular morbidity may, however, contribute to the negative relations between age and psychomotor speed, as also suggested by Earles and Salthouse (1995). The negative effect of age on psychomotor speed was expected, as age-related decline has also been documented in longitudinal studies (Fozard et al. 1994). Another interesting finding was that pairwise psychomotor speed differences did not increase with age in the frequent versus occasional exercise contrast groups, suggesting that strenuous exercise does not prevent age-related slowing in reaction times (Study II). This finding is supported by a cross-sectional study by Sherwood and Selder (1979), who found no age-related psychomotor speed slowing among vigorously active 23 to 59 years old runners. Although only vigorous and frequent exercise was found to enhance psychomotor speed in this study, light aerobic exercise prevents cardiovascular disease (Salonen et al. 1982, Paffenbarger et al. 1986) and therefore may be indirectly beneficial in terms of preventing age-related slowing in reaction time. The importance of small changes in psychomotor speed is not clear, but it could be speculated that in certain situations they can be important.

Cardiovascular morbidity explained almost entirely the variation in decision time (2-9%), next to the genetics and shared environmental effects (35-52%). Psychomotor speed is impaired by certain cardiovascular diseases, for example hypertension (Boller et al. 1977, Hertzog et al. 1978, Shapiro et al. 1982, Mazzucci et al. 1986, Light 1978), and coronary heart disease (Light 1978, Hertzog et al. 1978). One methodological difficulty in retrospective studies is the confounding effect of cardiac medication, which presumably improves the cognitive performance of hypertensives (Elias & Robbins 1991). The mechanism of cardiovascular disease in impairing psychomotor speed may be the hypoxia theory, which states that an inadeguate oxygen transport system in the brains (Patel 1977) impairs information processing in the central nervous system.

Sedentary occupation was a determinant which also explained a considerable amount (2-5%) of psychomotor speed, mostly movement times. Sitting may not by itself contribute to a faster performance; rather, sedentary work may include contexts that enhance central nervous system information processing. Why this finding appears only in movement times but not in decision times, remains unclear. However, subjects doing sedentary work also had a faster psychomotor speed than subjects doing physical work in an earlier study (Suvanto et al. 1991).

Traits are effected by inheritance and shared environmental effects. Obviously, in order to estimate separately the possible role of shared childhood environmental effects and genetics on psychomotor performance in the present study, research comparing psychomotor speed in monozygotic twins with that in dizygotic twins is needed. However, monozygotic twins reared apart have been very similar compared with monozygotic twins reared together in terms of their occupational and leisure time interests and personality (Bouchard et al, 1990), indicating that the role of family influence and other forms of cultural transmission in society on behavior may be smaller than previously thought. Further research is needed also to study the trainability of psychomotor speed, particularly among subjects who have inherited slow psychomotor speed.

A major part (33-82%) of the variation in psychomotor speed could not be explained with the studied parameters. Although a part of this is due to inaccuracy of the used parameters, it is also likely that some factors not analyzed could have an effect on psychomotor reaction time. From the results of this study, however, it can be concluded that although psychomotor speed is impaired by aging, this impairment may be delayed by maintaining a lifestyle, which includes frequent, vigorous physical activity and by adhering to health habits that minimize cardiovascular morbidity. Attempts to influence psychomotor speed in adulthood may, however, be difficult because it is strongly influenced by familial aggregation, reflecting genetics and early shared environmental factors, and as yet unidentified influences.

7 MAIN FINDINGS AND CONCLUSIONS

Foot psychomotor speed measurements were comparable with the more common method of hand reaction time measurement. Both methods showed acceptable within-test session and between-test session reliability.

Psychomotor speed was determined in a large part by familial aggregation (the combined effect of genetics and shared environment), which explained 18-52% of the variation. Other studied determinants explained together 0-17% of the variation in psychomotor speed. However, a substantial portion remained unexplained (33-82%).

Psychomotor speed was found to be negatively influenced by aging and cardiovascular morbidity.

Twins with a lifetime history of vigorous exercise of four times per week had slightly faster psychomotor speed than their co-twins who exercised only occasionally (less than two times per week). There was no trend that less vigorous regular exercise (three times per week) enhanced psychomotor speed, as compared with infrequent exercise (less than once a week).

There was a tendency for smoking to be associated with delays in psychomotor speed. Mean values of all measures were consistently slower among smokers. However, statistical power was limited and only a few of these differences achieved statistical significance.

There was a tendency for substantial lifetime driving (20 years discordance) to be associated with delayed psychomotor speed, especially decision time.

Although our chances to influence psychomotor reaction time appear relatively limited from these study findings, even small enhancement to reaction time could have practical importance in motor control of daily activities and injury prevention.

8 TIIVISTELMÄ

Tutkimuksen tarkoituksena oli selvittää psykomotoriseen nopeuteen vaikuttavia tekijöitä keski-ikäisillä miehillä. Ensiksi selvitettiin käden ja jalan psykomotorisen nopeuden mittausmenetelmän toistettavuutta ja vastaavuutta (I osatyö). Osatutkimuksiin (II-IV osatyöt) valittiin kaksospareja, joissa veljekset erosivat toisistaan elämänaikaisen liikunnan harrastamisen, tupakoinnin ja autolla-ajon suhteen. Lopuksi arvioitiin perhettäisen esiintymisen (perimän ja lapsuudenajan olosuhteiden yhteisvaikutuksen) sekä yleisesti tunnettujen determinanttien suhteellinen merkitys psykomotorisen nopeuden selittäjinä (V osatyö).

Väestöotokseen perustuvan suomalaisen kaksoskohortin 2050 identtisen mieskaksosparin joukosta valittiin 61 iältään 35-69- vuotiasta kaksosparia. Tutkittavilla ei ollut reaktionopeuteen vaikuttavaa neurologista sairautta tai lääkitystä. Elämänaikainen sairaushistoria, liikunnan harrastaminen, tupakointi, alkoholinkäyttö sekä työn fyysiseen kuormitukseen liittyvät tekijät kartoitettiin strukturoidulla haastattelulla. Psykomotorinen nopeus mitattiin visualiseen ärsykkeeseen perustuvalla käden ja jalan yksi- ja monivalintamittausmenetelmällä. Tutkittavat suorittivat kolmen harjoituskerran jälkeen 12 varsinaista suoritusta dominoivalla kädellä, samanpuoleisella jalalla ja vastakkaisen puolen jalalla. Mittausmenetelmän toistettavuusmittaukseen osallistui 153 tervettä työikäisiä mieshenkilöä, joilta kaikilta mitattiin saman mittauskerran toistettavuus ja 34:ltä toistettavuus kahden mittauskerran välillä käyttäen erilaisia mittaussarjan arvojen poimintamenetelmiä. Paras toistettavuus mittauskerran sisällä (Cronbachin alpha=.99) ja mittauskertojen välillä (ICC=.49-.68) saatiin käyttämällä viiden nopeimman suorituksen keskiarvoa. Jalan psykomotorisen nopeuden mittaus osoittautui validiksi menetelmäksi tutkittaessa alaraajojen motorista kontrollia ja siihen vaikuttavia tekijöitä. Monivalintatesteissä käden ja jalkojen päätöksentekoajat olivat hyvin samanlaiset.

Intensiivistä liikuntaa elämänsä aikana keskimäärin neljä kertaa viikossa harrastaneilla kaksosilla reaktioajat olivat nopeammat kuin heidän kaksosveljillään, jotka olivat harrastaneet liikuntaa keskimäärin 1,6 kertaa viikossa (29 paria). Työn fyysisen kuormituksen kontrolloinnin jälkeen vain käden monivalinnan päätöksentekoajan sekä kontralateraalisen jalan monivalinnan reaktioajan erot (molemmat 7%) olivat tilastollisesti merkitsevät. Vähemmän kuormittavaa, säännöllistä kolmesti viikossa tapahtunutta liikuntaa harrastaneiden kaksosten ja heidän epäsäännöllisesti (harvemmin kuin kerran viikossa) liikuntaa harrastaneiden kaksosveljien (9 paria) välillä ei ollut tilastollisesti merkitseviä eroja.

Tupakoinnin suhteen eniten diskordanteilla pareilla (8 paria) toinen kaksosista oli tupakoinut keskimäärin 32 'askivuotta' (=tupakointivuodet, kun päivässä on poltettu keskimäärin 20 savuketta) ja kaksosveli keskimäärin alle yhden askivuoden. Tupakoivilla oli 5-14% hitaampi päätöksentekoaika kuin heidän tupakoimattomilla kaksosveljillään; erot olivat tilastollisesti merkitseviä kahdessa kuudesta psykomotorisen nopeuden mittauksesta.

Autolla-ajon suhteen diskordantteja pareja oli 18. Enemmän ajaneella veljellä (22 vuotta työhön liittyvää ajoa) oli hitaampi käden psykomotorinen nopeus kuin vähemmän ajaneella (2 vuotta työajoa), joskin ainoastaan käden monivalinnan päätöksentekoaikojen erot olivat tilastollisesti merkitsevät. Tällä ryhmällä jalkojen psykomotorisen nopeuden systemaattista eroa veljesten välillä ei ollut nähtävissä.

Psykomotoriseen nopeuteen mahdollisesti vaikuttavien tekijöiden suhteellista osuutta tutkittiin monimuuttujamenetelmällä. Merkittävin psykomotorista nopeutta määräävä tekijä oli perhettäisyys (sisältäen perimän ja lapsuudenajan olosuhteet), joka selitti 18-52% psykomotorisen nopeuden vaihtelusta. Muiden tutkittujen determinanttien osuus oli 0-17%. Niistä ikä määräsi suhteessa eniten (2-13%) psykomotorisen nopeuden vaihtelua. Muita tilastollisesti merkitseviä determinantteja olivat kardiovaskulaariset sairaudet, runsas liikunta ja istumatyö, jotka yhdessä selittivät 2-9% psykomotorisen nopeuden vaihtelusta. Psykomotorisen nopeuden vaihtelusta jäi selittämättä käytetyllä mallilla 33-82%, mitatusta raajasta riippuen. Tämä selittyy ainakin osaksi käytettyjen mittareiden epätarkkuudella, mutta on myös mahdollista, että psykomotoriseen nopeuteen vaikuttavat myös sellaiset tekijät, joita ei tässä oltu tutkittu.

Tämä tutkimus osoitti, että psykomotorinen nopeus on todennäköisesti vahvasti perinnöllinen ominaisuus, mutta on mahdollista että lapsuuden ja nuoruudenaikaiset ympäristötekijät vaikuttavat siihen. Iän myötä tapahtuvaa reaktiokyvyn heikkenemistä nopeuttavat sydän- ja verisuonisairaudet, mutta runsas liikunnan harrastaminen hidastaa reaktionopeuden heikentymistä, joskin niiden merkitys on vähäinen suhteessa perimän ja lapsuudenaikaisten ympäristötekijöiden vaikutukseen. Mahdollisuudet vaikuttaa psykomotoriseen reaktioaikaan näyttävät rajoitetuilta tämän tutkimuksen perusteella, mutta vähäisilläkin vaikutuksilla saattaa olla merkitystä jokapäiväisissä toiminnoissa ja tapaturmissa.

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