HUMAN MOTOR PERFORMANCE AND PHYSIOTHERAPY

Effect of strapping, hot and cold pack treatments and strength training

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Department of Physical Medicine and Rehabilitation

OULU 1999

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Non scholae, sed vitae discimus

To my parents, Paavo and Sirkka-Liisa

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Abstract

Human motor performance and motor skills are essential aspects of various daily activities, and their importance is especially great in traffic, sports and unexpected situations. There is evidence that physically active subjects have better performance in some motor tasks (e.g. reaction time) than less active ones, and a few longitudinal intervention studies have shown that training improves certain aspects of motor performance, but there are also contradictory results. Despite the difficulty of improving motor performance, many physiotherapy programs and treatments are expected to do precisely that. However, the previous literature contains little information on these issues.

The aim of the present doctoral project was to examine human motor performance (reaction time, speed of movement, tapping speed and coordination) and the effects of some of the most commonly used physiotherapy treatments on it in normal healthy volunteers. In addition, the reliability of the motor performance measurements performed with the HPM/BEP system is presented.

Study I was a cross-sectional study of the population of Oulu, where 200 healthy randomly selected subjects (100 men and 100 women aged 21-70 years) were stratified by gender and by ten-year age group into ten groups. The test battery consisted of six motor performance tests for both hands and feet.

The studies II, III and V were non-controlled intervention studies, and study IV was a cross-over intervention study. The participants in the studies were healthy, voluntary staff members (n=14-30) of the Oulu University Hospital, and the interventions between the measurements consisted of strapping of the ankle and wrist joints (study II), hot and cold pack treatments of the hand (study III), one-hour hand strength training session (study IV) and a ten -week hand strength training program (study V).

The results showed that motor performance was poorer in the older age groups in both genders. The average speed of movement and tapping speed values were higher for men than for women, but there were no gender differences in the coordination tests or the hand reaction time tests. All values (except the hand reaction times) were better for the dominant than the nondominant side.

The strapping of the ankle and wrist joints decreased some aspects of the motor performance and muscle strength of these joints in healthy subjects. The hot pack treatment of healthy subjects caused only minor changes in the motor performance of the treated area, while the cold pack treatment decreased almost all of the measured aspects, and these changes were especially notable in fine motor movements.

A one-hour hand strength training session decreased acutely muscle strength and EMG activity, but muscle fatigue had no effects on the motor performance functions of the hand. It seems that the feeling of incompetence to perform speed and accurate movements with fatigued muscles is mainly a subjective feeling, and that the real effect of muscle fatigue on motor performance is less than generally expected. A ten-week hand strength training period increased muscle strength and EMG activity in the trained muscles. There was also a suggestion that even non-task-specific training may improve some aspects of the motor performance of the hand, and an increase in the activation of motor units during muscle contraction may improve motor performance in some motor tasks.

In addition, the results indicated that the HPM/BEP system is a potentially useful tool for studying motor performance, and the reliability of the system is acceptable.

Keywords: reaction time, speed of movement, tapping speed, coordination

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Oulu, January 1999 Kari Kauranen

Abbreviations

A	Movement amplitude
A/D	Analog/digital
BEP	Basic Elements of Performance
bits/sec	Bits/second
Ca^{2+}	Calcium $^{2+}$
cm	Centimetre
cm/sec	Centimetre/second
^{o}C	Celsius (degrees)
dB	Decibel
deg/sec	Degree/second
EMG	Electromyography
Fig.	Figure
HPM	Human Performance Measurement
hr	Hour
Hz	Herz
ICC	Intraclass correlation coefficient of reliability
IEMG	Integrated electromyography
I_d	Index of movement difficulty
I_p	Binary Index of Performance
MEMG	Mean electromyography
mm	Millimetre
Mohm	Milliohm
msec	Millisecond
m/sec	Metre/second
n	Number of subjects
Nm	Newton metre
r	Correlation coefficient
RM	Repetition maximum
RMS	Root mean square
sec	Second
SEM	Standard errors of measurement
SD	Standard deviation
W	Width of target
yr	Year

List of original papers

This thesis is based on the following articles, which are reprinted with permission from the copyright holders. They are referred to in the text by their Roman numerals:

I Kauranen K & Vanharanta H (1996) Influences of aging, gender and handedness on motor performance of upper and lower extremities. Percept Mot Skills 82:515-525.

II Kauranen K, Siira P & Vanharanta H (1997) The effect of strapping on the motor performance of the ankle and wrist joints. Scand J Med Sci Sports 7:238-243.

III Kauranen K & Vanharanta H (1997) Effects of hot and cold packs on motor performance of normal hands. Physiotherapy 83:340-344.

IV Kauranen K, Siira P & Vanharanta H. One-hour strength training session: effect on the motor performance of normal upper extremities. Eur J Appl Physiol (in press).

V Kauranen K & Vanharanta H (1998) A 10-week strength training program: effect on the motor performance of an unimpaired upper extremity. Arch Phys Med Rehabil 79:925-930.

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1. Introduction

Human motor performance contains both central and peripheral neuromuscular components, and the human motor system can be seen as a processor of information, with signals received from the environment via the sensory systems, processing at the central level, and output as movements at the peripheral level. There are several motor performance components, such as reaction time, speed of movement, speed/movement accuracy, tapping speed, multi-limb coordination, complex coordination and eye-hand coordination. The role of the central nervous system (stimulus identification and response selection) is emphasised in fast reaction time tasks, while the role of the peripheral neuromuscular components and the intrinsic and the extrinsic feedback systems is important during longer tasks.

The motor performance and motor skills are essential and important in various daily activities, constituting a substantial part of human life, and their meaning is especially great in traffic, sports and unexpected situations. A driver can brake and stop the car before it hits a suddenly appearing object, while another collides in an identical situation. A young person can maintain his balance after a slip, while an older person may fall down and break his hip. A sprinter takes a second step soon after the starting shot, while another is still on the start line. These incidents are good examples of situations where good motor performance functions are needed and also illustrate the individual differences seen in these functions.

Many physiotherapy programmes and treatments are expected to improve coordination and motor performance at the central or peripheral levels, and people working in physiotherapy have certainly read this statement on some occasion: This physiotherapy treatment improves coordination and motor performance. What does this actually mean? If one goal of the treatment is to improve coordination and motor performance and this aim is achieved during the treatment period, what has actually happened and which components or systems (central/peripheral) of performance have changed ? The previous literature contains little information on these issues, and the present study was done in an attempt to answer some of these questions.

Even the simplest movements require not only the contraction of the prime moving muscle, but also control of the antagonist, fixator and postural muscles. It has been hypothesised that inadequate motor performance causes poorly coordinated movements and adds to the work load when tasks are performed with unergonomic movements. This tendency to work with uneconomical movements may lead to musculoskeletal disorders and cumulative microtraumas or, at least, increase the risk of these problems. There is evidence that physically active subjects have better performance in some motor tasks (e.g. reaction time) than less active ones, and a few longitudinal intervention studies have shown that training improves some aspects of motor performance. However, there are also contradictory results. In addition, many factors, such as aging and different diseases, especially neurological and musculoskeletal ones, impair motor performance. Does physiotherapy have enough resources to respond to this challenge by improving motor performance?

This study examines the human motor performance in normal healthy volunteers and the effects of four commonly used physiotherapy treatments (strapping, hot pack treatment, cold pack treatment and muscle strength training) on it. In addition, reliability of these measurements is presented.

2. Review of the literature

2.1. Motor performance terminology

The terminology used in human motor performance research varies between studies, depending on the speciality of the research group, which complicates the comparison of the results of different studies. The term “motor performance” (Schmidt 1991) has been used more or less synonymously with such terms as “motor speed” (Ruff & Parker 1993), “psychomotor performance” (Panton *et al.* 1990), “psychomotor functions” (Era 1987), “psychomotor capacity” (Viikari-Juntura *et al.* 1994) and “psychomotor speed” (Simonen 1997).

Panton *et al.* (1990) defined psychomotor performance as the ability of an individual to process and react to specific external information, and Simonen (1997) defined psychomotor speed as a subject’s ability to perform a rapid motor response to a sudden signal. These definitions are adequate and pertinent when the studies deal with motor performance components such as simple reaction time, choice reaction time or speed of movement. In addition to the above components, however, there are several other motor performance components, such as movement speed/movement accuracy, tapping speed, multi-limb coordination, complex coordination and eye-hand coordination (Schmidt 1991). In these tasks or tests, the performance time and the duration of the task are longer and the tasks are more complex than in the reaction time tasks, which are performed with one rapid movement. In addition, the role of intrinsic and extrinsic feedback during the tasks has been emphasised in these cases compared to reaction time tests. In this study, the term “motor performance” has been used to refer to the following four aspects: reaction time, speed of movement, tapping speed and coordination (=speed of movement/accuracy). In addition, this term has been used because the study deals with many different human motor performance components, not only reaction times.

The term motor performance has also been used synonymously with such terms as “skilled motor performance” or “motor behaviour”. However, these terms include two components: motor learning and motor performance, because a person has to learn a movement or a movement pattern before he is able to perform it (Schmidt 1991). After many successful repetitions, one can call this movement pattern a skill. The terms “ability”, i.e. a general, innate psychomotor trait (Morrow *et al.* 1995), and “skill”, i.e. a specific, learned psychomotor capacity (Morrow *et al.* 1995) have sometimes been used synonymously, but these terms have been distinguished by Fleishman (1964): Skills are learned traits based on the abilities that the person possesses, whereas abilities are more general and innate in nature than skills. Gutherie (1952) defined skill as follows: Skills consist of their ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy.

2.2. Motor performance

Human motor performance is a part and a subfield of human performance, and the human motor system can be seen as a processor of information, with signals received from the environment via the sensory systems, processed at the central level and output as movements at the peripheral level. Information processing at the central level consists of three stages: 1) the stimulus identification stage, 2) the response selection stage, and 3) the response programming stage. The central level also participates in the follow-up and correction of movements via intrinsic and extrinsic feedback systems. The conceptual model of human performance (Fig. 1.) has been presented by Schmidt (1991). This model explains the movements as responses to an unanticipated stimulus or event. However, the model is largely based on feedback systems (intrinsic and extrinsic), and it does not explain all movements and locomotion of human. For instance, the model is insufficient to explain voluntary movements, which contain anticipation aspects and feed-forward components.

The capacity of this information processing model depends on some higher-level factors, such as arousal, attention and memory (Schmidt 1991, Taimela 1991). Increased arousal increases performance up to a certain point, after which a further increase arousal decreases the performance. The optimal level of arousal is relatively low for demanding decision-making and fine motor control tasks and relatively high for minimal decision-making and gross motor tasks (Weinberg & Hunt 1976).

Attention, i.e. the capacity to process information elicited from the environment, occasionally restricts performance. At the response-programming stage, the motor system can organize and initiate only one action at a time, and the maximum rate is about three actions during one second. In addition, two-handed movements are difficult to perform if the temporal structures are different for the hands (Schmidt 1991). The memory system, which stores the information of movements, is divided into three parts: short-term sensory store (duration about 250 msec), short-term memory (duration about 30 sec) and long-term memory (very long duration) (Schmidt 1991). In addition, there are many other factors, such as age (Wilkinson & Allison 1989) and gender (Ruff & Parker 1993), which affect different aspects of motor performance, but these factors will explained in more detail in the later sections.

The peripheral neuromuscular component executes the programmed commands and produces movements. All movements require not only the contraction of the prime moving muscle, but also control by the antagonist, fixator and postural muscles (Rothwell 1994). When a person has learnt a movement or a movement pattern and has repeated it successfully many times, this movement pattern can be called a skill. There are three skill classification

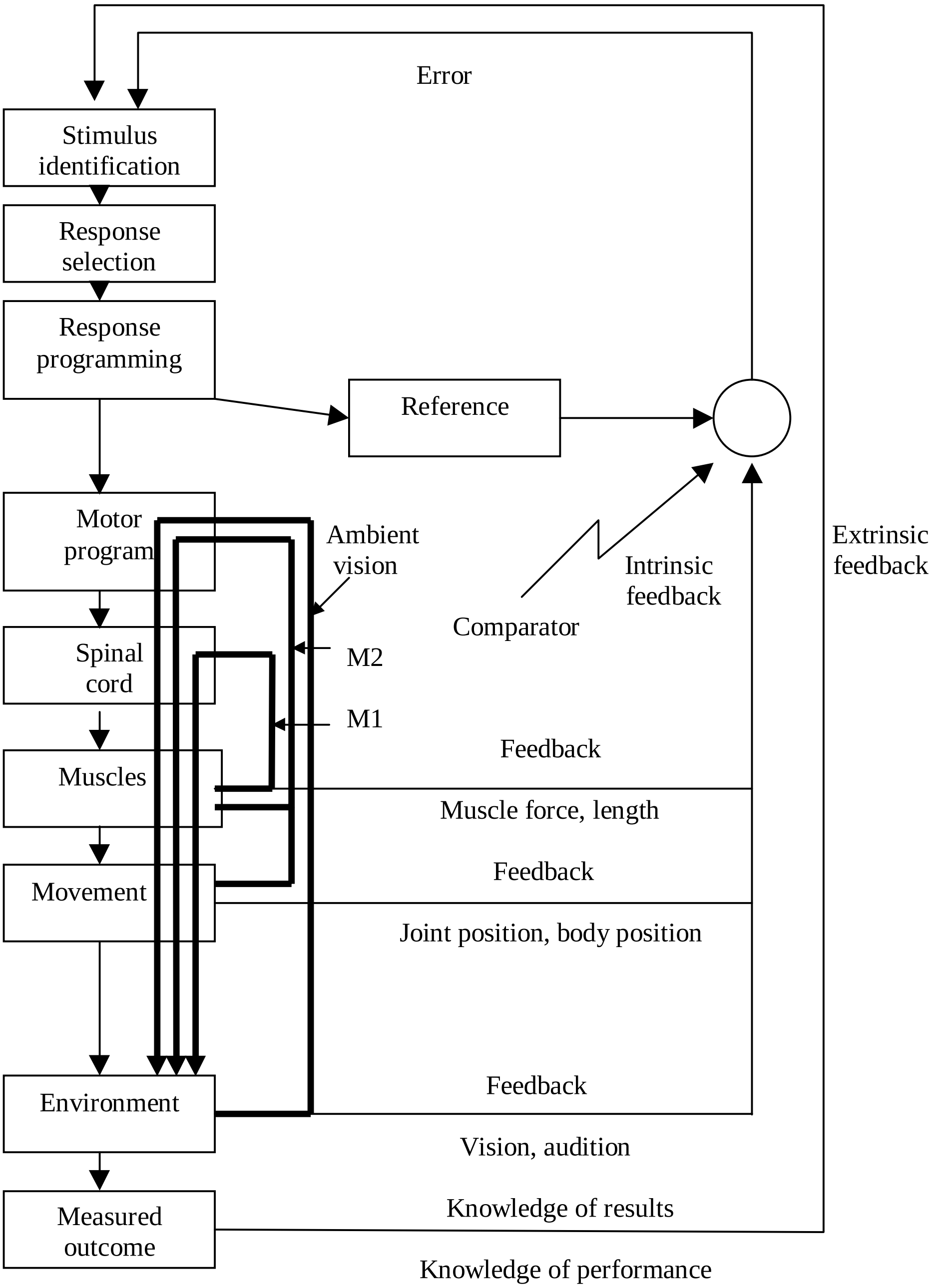


Fig. 1. Conceptual model of human motor performance presented by Schmidt (1991). M1 and M2 refer to electromyographic (EMG) responses to the stretch of muscle after a suddenly applied load.

systems: 1) Open and closed skills, where an open skill is one for which the environment is variable and unpredictable during the action, and a closed skill is one for which the environment is stable and predictable. 2) Discrete, continuous and serial skills, where a discrete skill has a clearly defined beginning and end with a brief duration of movement, a continuous skill has no clear beginning or end and its duration is several minutes, and a serial skill is a group of discrete skills which results in new, more complicated actions. 3) Motor and cognitive skills, where the most important item of a motor skill is the quality of the movement itself, while for a cognitive skill the decisions about which movement to make are essential. (Schmidt 1991)

The general motor performance skill consists of separate motor abilities. These abilities, as identified by the researches, are variable and number about 20-30, or even 50 (Schmidt 1991). Fleishman (1957) presented the following abridged list of abilities: multi-limb coordination, spatial orientation, finger dexterity, arm-hand steadiness, visual acuity, reaction time, movement speed, manual dexterity, mechanical aptitude and kinesthetic sensitivity. These are the factors and components of motor abilities, and the abilities result in general motor skills. The previous studies have shown that the relationships and correlations between skills are low, assuming that there are many abilities which are highly specific to certain tasks (Lotter 1960, Fleishman & Parker 1962, Drowatzky & Zuccato 1967).

2.3. Motor performance in musculoskeletal disorders

There is some evidence to suggest that motor performance has effects on the etiology of musculoskeletal disorders (Kuorinka *et al.* 1981, Owen & Damron 1984, Taimela *et al.* 1993, Luoto *et al.* 1995, Pienimäki *et al.* 1997). It has been hypothesised that poor motor performance causes poorly coordinated movements in daily activities and adds to the work load when tasks are performed with unergonomic movements. Work done with uneconomical movements may exceed the load threshold of the musculoskeletal components, and this overuse may lead to diseases of these structures or, at least, increase the risk of such problems.

Pienimäki *et al.* (1997) demonstrated bilaterally decreased reaction times and speed of movement in a population of chronic unilateral tennis elbow syndrome patients. They suggested that the decreased motor performance may be of primary origin and may imply an increased risk to develop the tennis elbow syndrome, or else it may be a result of chronicity.

However, there are also contradictory results. Viikari-Juntura *et al.* (1994), who studied 26 patients with tenosynovitis and 26 controls, did not find differences between the cases and controls in motor performance and concluded that motor performance tests (reaction and movement time, Purdue Pegboard Test, finger dexterity and block design test) are poor predictors of wrist tenosynovitis.

A longitudinal follow-up study in a group of 99 chronic low back pain patients (Luoto *et al.* 1996) showed that the association between a poor motor performance and musculoskeletal diseases is not as simple as presented above. In this study, the deterioration of low back pain patients' reaction times was reversible after rehabilitation if the patients' condition improved during follow-up, but no reversibility was observed if the disability deteriorated. On the basis of these results, the authors suggested that the decrease of reaction times is rather a consequence than a cause of the disease. Thus, the study gave evidence that successful rehabilitation may improve certain aspects of motor performance, at least in a situation where motor performance has minimised the consequences of the disease. Recently, Kuukkanen & Mälkiä (1998) demonstrated in a controlled nine-month follow-up of 90 low back pain patients (the intervention was a three-month active rehabilitation program) that back pain intensity was associated with the psychomotor performance of the foot ($r = 0.24$ for choice reaction time, 0.24 for movement time and 0.25 for total response time). In addition, there were no changes in foot reaction time, but the movement time and the total response time improved statistically significantly during the study period. However, similar improvement was also observed in the control group.

In addition, many other diseases impair different aspects of motor performance. This phenomenon has been demonstrated in, for instance, coronary disease patients (Hertzog *et al.* 1978) and many neurological patient groups (Behbehani *et al.* 1990, Haaland *et al.* 1994, Baumann *et al.* 1995).

2.4. Motor performance measurements

2.4.1. Reaction time

Reaction time, defined as the interval from the presentation of an unanticipated or anticipated stimulus until the beginning of the response, is probably the most common method used to study a person’s central information processing speed and fast coordinated peripheral movement response. Reaction time tasks load and involve both the central and peripheral components and functions. The role of the central nervous system (stimulus identification and response selection) is emphasised in reaction time tasks, while the significance of the peripheral neuromuscular components and the intrinsic and extrinsic feedback systems is not so essential.

The simple reaction time test contains only one type of signal and a previously known movement response to it. The choice reaction time test contains several different signals and variable movement responses to them (Taimela 1991). The motor response to a constant signal may be only the lift of the finger(s) from the start plate or button, or the movement of the hand to the target plate or button. The response can also be performed in many other ways, e.g. with the feet (Simonen 1997, Kuukkanen & Mälkiä 1998) or vocally (Baron & Journey 1989).

In choice reaction time tasks, the choice reaction time is linearly related to the amount of information that must be processed to resolve the uncertainty about the various possible stimulus-response alternatives, and it increases at a constant rate each time the number of stimulus-response alternatives is doubled (Hick 1952, Schmidt 1991). This relation has been called Hick’s law, and it implies that the choice reaction time is linearly related to the log of the number of possible stimulus alternatives (Hick 1952).

Hick’s law is more explicitly expressed as follows:

$$\text{Choice reaction time} \quad t = a + b \log_2 N$$

a = empirical constant (= minimum movement time)
b = empirical constant (= reciprocal of the channel capacities of the systems making choices)
N = number of choices

(Hick 1952)

In addition, such factors as stimulus type (auditive/visual/proprioceptive) (Kamen & Morris 1988), movement response (Baumann *et al.* 1995, Pienimäki *et al.* 1997), foreperiod time (Wilkinson & Allison 1989, Schmidt 1991) and the character of response (e.g. manual/vocal) (Baron & Journey 1989) have an effect on the reaction time. Because the differences between the apparatus and the movement responses vary so widely, it is quite impossible to compare the absolute reaction time values obtained in different studies.

The total motor response is divided into decision time and movement time. The decision time is the time from the initiation of the stimulus to the time when the movement response begins. This time interval has sometimes been called initiation time (Houx & Jolles 1993) or reaction time (Henry 1961) too. The decision time is usually expressed in milliseconds. The decision time also includes the premotor time, i.e. the time when there is already activation in the muscles, but the movement has not yet begun (in fig. 2. located in the latter part of the decision time component). Movement time is the interval from the initiation of the movement response to the end of the movement. This part of the response has been called speed of movement (Panton *et al.* 1990, Kondraske 1991) too. Movement time is expressed in milliseconds or centimetre/second. The total motor response (decision time + movement time) has been called total reaction time (Finkel *et al.* 1995), reaction time (Taimela 1991) or total response time (Smith & Carew 1987). Taimela (1991) presented the following model of the components of reaction time (Fig. 2.):

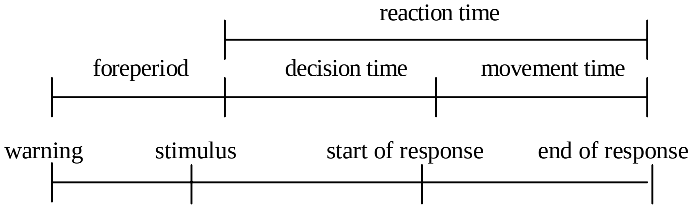


Fig. 2. Components of reaction time (Taimela 1991).

Reaction times are related to the person’s age. In a cross-sectional study of a large sample (5325 subjects), Wilkinson & Allison (1989) showed that the average reaction time (the mean of the last eight of ten trials) slowed from the 20s up to age 60, and with the teens and under 10s. The fastest reaction time indicated similar decline to the average reaction time, but varied much less within age groups. In addition, the intra-subject variability of reaction time only increased at ages under 10 and over 60. However, the sample was collected during an exhibition (Medicines for Man), and the age distribution was heavily biased toward the ages most likely to be found at such an exhibition, which means that the age groups were not equal in this respect.

In a longitudinal study (where the total follow-up time was eight years and the repeated tests were performed at two-year intervals) on 264 subjects aged 17 yrs to 96 yrs, Fozard *et al.* (1994) pointed out that the simple auditory reaction time increased by approximately 0.5 msec/yr and the choice auditory reaction time by 1.6 msec/yr, beginning at about age 20. Houx & Jolles (1993) showed that the effect of age was especially obvious in the difficult tasks.

The results concerning the effect of gender on reaction times are contradictory. Some studies have shown that males are faster than females across the age groups, and this phenomenon has been seen in both simple and choice reaction time tasks (Houx & Jolles 1993, Fozard *et al*. 1994, Era *et al*. 1995). On the other hand, Landauer *et al*. (1980) and Landauer (1981) showed that there are no sex differences in visual reaction time, and noticed that women perform faster on the decision part of the task, while men perform faster on its motor aspects. However, the sample sizes were quite small in these studies.

Reaction time is usually measured with the dominant hand (Simonen 1997), and there is no consensus about which side has faster reaction times. Kerr *et al*. (1963) studied ten strongly left-handed and ten strongly right-handed subjects, and noticed that the dominant hand was faster than the non-dominant hand. In contrast, Annett & Annett (1979) presented results contradictory to those reported by Kerr *et al*. (1963). It is a well documented fact that the motor cortex of each hemisphere controls movements primarily on the contralateral side of the body (Rothwell 1994). Marzi *et al*. (1991) used a meta-analytic procedure (16 studies) to study reaction time and interhemispheric transfer time in normal right-handed subjects. They noticed that reaction times were faster in the right hand, and explained the asymmetries by the superiority of the right hemisphere in detecting simple visual stimuli and by the corresponding superiority of the left hemisphere in executing the manual response. Another explanation may be the asymmetry of the interhemispheric transmission of visuomotor information, with is transferred from the right hemisphere (side of stimulus entry) to the left (side of response generation) faster than in the reverse direction. There is some evidence that left-handed women react faster to an auditory stimulus with their left hand than their right-handed counterpart with their right hand (Sathiamoorthy *et al.* 1994).

The definition of foot dominance is more complex than that of hand dominance, because foot dominance and hand dominance are not logically ipsilateral. It has been recommended that foot dominance should be defined operationally in light of the behavioural context (stability, mobility, bilateral) and the demands (level of complexity) of the particular tasks to be performed (Gabbard & Hart 1996). In previous studies, foot dominance has been defined using bilateral tasks, including stabilization and mobilization functions, such as kicking a ball (Chapman *et al.* 1987) and picking up a pebble with the toes (Peters 1988). Friberg and Kvist (1988) noticed in a sample of 892 young healthy subjects that the correlation between the laterality of the take-off leg and handedness was poor, but a majority (81.4 % of jumpers, 65.1 % of other athletes and 76.8 % of conscripts) invariably used the longer leg for take-off. All in all, however, there are inconsistencies between the foot dominance studies, and it is impossible to make exact conclusions about foot dominance until more research is conducted. However, there is some evidence that right-handed subjects have faster reaction times in the right foot than in the left foot (Lotter 1960).

There are also several other factors which have been proved to have an effect on reaction times, such as learning (Fishman & Lim 1991), high physical activity (Simonen 1997), favourable functioning of certain senses, high isometric muscular force and cognitive performance, longer education and good perceived health (Era *et al*. 1986) have association to better reaction times. On the contrary, tiredness (Corfitsen 1995), use of alcohol (Glenn & Parsons 1992), smoking, car-driving (Simonen 1997) and some drugs (Hart *et al*. 1976) have association to slowed reaction times. Genetics (Simonen 1997), and the time of day (Payne 1989) also have effect on reaction times.

In addition, many diseases and symptoms, such as myotonia congenita (Baumann *et al.* 1995), diabetes (Deary 1992), chronic unilateral tennis elbow syndrome (Pienimäki *et al.* 1997), Parkinson's disease (Nakashima *et al.* 1993) and low back pain (Taimela *et al.* 1993) slow down reaction times.

Previous studies have reported acceptable reliability values for reaction time tests, but the methods used to calculate these values vary greatly between the studies. Neubauer (1990) studied 81 university students (age range 19-38 yrs) and calculated correlations (=r) for median parameters. The values varied within 0.88-0.94, depending on the response. Simonen (1997) studied 34 healthy men aged 25-61 yrs and calculated the inter-session (time between sessions was two weeks) repeatability value for the means of the five fastest values (calculated from a total of twelve values), and the correlations (=ICC) were 0.49-0.68.

2.4.2. Speed of movement

One essential part of motor performance is the speed of movement, which indicates the subject's ability to perform fast movements, which are important in different balance and protection movements and reflexes. The term "movement time" is used in many studies to indicate the speed of movement of the extremities (Beh 1989, Bjorklund 1991). Movement time is the interval from the initiation of the movement response to the end of the movement expressed in milliseconds. This part of the response has also been called speed of movement (Panton *et al.* 1990, Kondraske 1991) and is expressed as centimetres/second. In this summary and substudies, the unit cm/sec has been used, which may be a physically more relevant unit for speed of movement.

There are two different ways to calculate speed of movement: The average speed (=velocity) of movement is defined as the rate of change in position with respect to time, and can be stated more explicitly as:

$$\text{Average velocity} = \frac{\Delta\ \text{position}}{\Delta\ \text{time}} = v_a = \frac{\Delta\ s}{\Delta\ t}$$

(Ohanian 1989)

The instantaneous velocity at a certain point of time is calculated and expressed with the following formula:

$$\text{Instantaneous velocity} = v(\Delta t) = \lim_{\Delta t \to 0} \Delta s/\Delta\ t$$

(Ohanian 1989)

In motor performance studies, especially those concerning speed of movement measures with reaction times, speed of movement has usually been calculated using average velocity. This method is partly inadequate to express the maximal speed of movement, because the method is clearly dependent on the acceleration and deceleration components of movement. These components take time, and the speed of movement is rarely constant (especially in reciprocal tapping tasks).

Houx & Jolles (1993) demonstrated an age-dependent decrease in movement time, indicating that motor execution took a longer time for older persons, and this tendency was especially obvious when the response requirements were more complex. However, this age-related decline of speed of movement has been reported by using a cross-sectional study design, and a study of the real effect of aging on motor performance would require a longitudinal study design. Children have slower speed of movement than adults. Haywood (1979) studied age differences in arm movement time over distances proportional to size and noticed that children (7-9 yrs) were slower than adults even when moving over a proportionally shorter distance. They hence suggested that the age differences in arm movement speed are not solely attributable to the size differences between the subjects.

Previous studies have shown that there is a clear gender difference in the speed of movement of the hand. Houx & Jolles (1993) noticed that women's movement times were slower by as much as 34 % than men's, and that the gender difference was independent of age. Landauer *et al*. (1980) and Landauer (1981) in their decision and movement time studies showed, that women performed faster on the decision part of the task, while men performed faster on its motor aspects (= movement time).

The author did not find any studies dealing with the differences between the dominant and nondominant hands in the speed of movement, but there is some evidence that the ipsilateral foot has shorter movement times than the contralateral foot in simple and choice reaction time tasks (Simonen *et al*. 1995).

Some researchers have studied the effects of muscle state on movement time. Ward (1978) studied the effect of muscle state on reaction and movement times in elbow extension in a group of eleven subjects. Total reaction time was divided into a premotor reaction time, a motor reaction time and an elbow movement time, and these were measured from an agonist muscle in normal, pretensed and relaxed conditions (quantified by electromyography). Differences were observed in the total reaction time and premotor time, but not in the motor reaction time or movement time.

It has been suggested that the speed of arm movement has some effects on spinal disorders. Lauren *et al.* (1997) demonstrated recently with a sample of 123 council workers that people with either very slow or very fast hand movement speed may have an increased risk of neck pain. They suggested that the etiology of neck pain is different in these two cases.

Rapid movements always contain an intense and a high-acceleration component, and these high accelerations strain the body. This effect has been noticed with two different types of acceleration, those of external origin (Hämäläinen & Vanharanta 1992, Hämäläinen 1993) and those of internal origin (Lauren *et al.* 1997), and these studies seem to suggest that the subject's ability to perform fast movements is not necessarily only a good characteristic, but could actually even increase the risk of musculoskeletal diseases.

Previous studies have reported quite high reliability values for movement time tests. Neubauer (1990) reported correlation values (r) varying within 0.98-0.99 for the median parameters, depending on the response.

2.4.3. Tapping speed

Finger tapping indicates the subject's fine motor speed ability, and it is measured by a finger tapping test. The test was originally called the Finger Oscillation Test (Halstead 1947), and it is a standard test component of the Halstead-Reitan battery (Reitan & Wolfson 1985). It is also used to assess motor performance in contrast to motor preference (Provins *et al.* 1982). The test is performed with the index finger, and the result is expressed as a number of taps within a certain period of time (Ruff & Parker 1993) or Herz (Shimoyama *et al.* 1990).

In a group of 358 volunteers aged 16-70 years, Ruff & Parker (1993) showed that tapping speed is related to age, but a decrease in tapping speed with increasing age was only noticed in the group of women. The tapping performance was 49.5 taps (dominant hand) and 45.6 taps (nondominant hand) for women in the age range of 16-24 yrs, while the corresponding values for women in the age range of 55-70 yrs were 45.7 taps and 40.4 taps. No such decrease was seen among men, for whom the corresponding values were 52.9 and 48.2 taps (age 16-24), and 53.5 and 48.3 taps (age 55-70). It is noteworthy that education (number of years of education) had no effect on the results. However, Era *et al.* (1986) demonstrated that the tapping rate was also lower among older men (the age groups were 31-35 yr, 51-55 yr and 71-75 yr). Shimoyama *et al.* (1990) similarly noticed in their quantitative analysis of the finger tapping tests of 111 normal subjects that tapping frequency decreased with advancing age (r= -0.52 for both hands), but age did not affect the SD of tapping frequency (r= 0.13 for the right hand and 0.09 for the left hand). However, it should be borne in mind, that all these studies concerning the age-related decline of tapping speed have been made using a cross-sectional study design, and longitudinal study designs are needed to study the real effect of aging on the tapping speed.

Ruff & Parker (1993) noticed a clear gender difference between men and women in tapping speed, since women were substantially slower, particularly in the older age groups (values above). The same phenomenon was also shown in some previous studies (King *et al.* 1978, Dodrill 1979, Shimoyama *et al.* 1990).

Finger tapping is a fine motor task, and a difference between the dominant and nondominant hands is expected, the values of the dominant side being higher than the values of the nondominant side (Gill *et al.* 1986, Ruff & Parker 1993). Shimoyama *et al.* (1990) showed in their study that the mean tapping frequency was 5.62 ± 0.95 Hz for the dominant (=right) hand and 5.24 ± 0.91 Hz for the nondominant (=left) hand.

McManus *et al.* (1986) studied tapping speed between the five fingers and noticed that the first (thumb) and second (index) fingers were the best and the fourth (ring) finger was the weakest in the task. They suggested the main reason for this phenomenon to be the difference in musculature between the fingers. Independent extensor muscles, such as extensor indicis and extensor digiti minimi, and the completely independent musculature of the thumb play an important role in the tapping performance. On the basis of their results, they concluded that the differences between the fingers are a function of differential peripheral motor control, whereas the difference between the dominant and nondominant hand is a consequence of the cerebral dominance of control mechanisms.

Several motor dysfunctions of cerebellar, basal ganglia and cerebral origins decrease tapping speed, and this phenomenon has been seen in at least dysmetric patients with cerebellar diseases, parkinsonian patients and hemiparetic patients (Shimoyama *et al.* 1990).

Test-retest studies have shown the reliability of tapping speed to be quite high. Ruff & Parker (1993) retested 30 % of their sample (the total sample was 358) six months later and analysed it with correlation analyses. The test-retest correlation (r) was 0.71 ($p<.001$) for the dominant hand and 0.76 ($p<.001$) for the nondominant hand. In another study, Gill *et al.* (1986) studied the effects of trials and sessions on finger tapping in a group of 18 subjects. The subjects performed 10 sessions (consecutive weeks), and each session included 10 trials. They did not notice an improvement in performance over the sessions, but there was an increase over the trials among men for both hands. The average test-retest reliability (r) was 0.94 for men and 0.86 for women. The differences in the results of these two studies are probably a consequence of the different sample sizes between the studies.

2.4.4. Accuracy/speed of movement (Fitts' task)

Speed of movement has been shown to be inversely related to target difficulty when rapid and small-amplitude movements of the hand are used in a reciprocal tapping task (Fitts 1954). Fitts found that the average movement time used in the task increased as the amplitude of the movement increased and as the width of the target decreased. He described a mathematical principle of movement speed used in the task and accuracy, which is known as Fitts' Law:

$$\text{Movement time } t = a + b\,[\text{Log}_2(2A/W)]$$

a = empirical constant (= minimum movement time)
b = empirical constant (= reciprocal of the channel capacities of the systems making choices)
A = movement amplitude
W = width of targets

(Fitts 1954, Schmidt 1991)

The last part of the formula, $[\text{Log}_2(2A/W)]$ has been called as the Index of Movement Difficulty (I_d), which defines the difficulty of the various combinations of movement amplitude (A) and width of target (W). Movement time is linearly related to the Index of Movement Difficulty $[\text{Log}_2\,(2A/W)]$, and is constant when the ratio of movement amplitude (A) to target width (W) is constant (= a long movement to a wide target is as rapid as a short movement to a narrow target) (Fitts 1954, Schmidt 1991).

From the abovementioned formulas, it is possible to derive the Binary Index of Performance (I_p), which expresses the results as a performance rate. In a task where movement amplitude (A) and target width (W) are fixed for a series of movements, the Binary Index of Performance (I_p) is defined as:

$$\text{Binary Index of Performance } (I_p) = 1/t\,[\text{Log}_2(2A/W)] \text{ bits/sec}$$

t = average time in seconds per movement
A = movement amplitude
W = width of targets

(Fitts 1954)

The results are expressed as bits/second, which represents the “capacity” of the neurologic communication channels involved in the task (Kondraske 1991). Fitts (1954) used the term “information capacity of the motor system” and defined it by the ability to produce consistently one class of movement from among several alternative movement classes. The greater the number of alternative classes, the greater is the information capacity of a particular type of response.

Fitts’ task involves a type of visually guided motor response, which is an essential component of a wide variety of skills needed for daily work and recreation (Wickens 1984). In addition, the task has been used to demonstrate the age-related decrease in motor performance (Welford *et al.* 1969), and even to measure biological age (Hochschild 1989). Because the task has been used in studies which deal with aging and motor performance, it is clear that the performance of the task is age-related. York & Biederman (1990) studied sex-related decrements in Fitts’ task over the life span in a group including 62 men and 84 women aged 20-89 years. They noticed that men and women aged 20-39 performed similarly, but after the age of 40 movement times clearly increased and continued to increase through 89 years of age. In addition, the results showed that older men slowed down relatively more than older women. The mean movement time for women at age 80-89 yr was 132 % of the values recorded for women aged 20-29. The corresponding value for men was 149 %. There was also a gender difference between men and women in the manner in which they performed the task, and women made 40 % fewer errors than men.

Surprisingly, the author did not find any studies dealing with the differences between the dominant and nondominant hands on Fitts’ task, or with the reliability of the task.

2.4.5. Other common motor performance tests

There are also many other motor performance tests, and it is impossible present a complete list in this context, but some commonly used examples can be given. The tests can be classified broadly in terms of what they appear to measure, e.g. sensory function, central processing, motor function or perceptual-motor function, but this grouping is ambiguous, because almost all tests include some elements of all functions. In addition, motor performance tests usually do not give reference values with which the results could be compared, and the comparison of absolute values between studies is impossible, because the tests used in different laboratories vary in several ways, including the complexity of stimulus, the size of measurement equipment and the type of response required (Wetherell 1996).

One of the most commonly used tests is the Purdue Pegboard Test developed by Joseph Tiffin in 1948. This test measures gross movement of hands and finger tip dexterity and includes five subtests: 1) right hand, 2) left hand, 3) both hands, 4) right+left+both hands and 5) assembly. The Purdue Pegboard contains pins, collars and washers, which are located in four cups at the top of the board, and the test subjects have to pick up pins and collars and to insert them into the holes. The big advantage of this test is that it has reference values (Tiffin & Asher 1948).

One method is to measure the general activities of daily life, such as putting on a shirt, tying a shoelace and threading a needle. A timer measures how long it takes to perform the task, and the results are expressed in seconds (Kondraske 1991).

Different driving simulators have been used to estimate driving ability before granting a driver's licence and the effects of drugs on driving ability (Milner & Landauer 1973).

The development of microcomputers has added to the menu of motor performance tests, and different video game tasks (e.g. air combat and slalom driving) and reaction time tests have been developed to measure motor performance (Kennedy *et al*. 1982).

Some investigators have used different test batteries (e.g. Halstead-Reitan Battery and STRES Battery) to study motor performance, and these batteries have included series of well-known individual tests, such as reaction time and tapping speed (Reitan & Wolfson 1985, Wetherell 1990).

2.5. Effects of exercise on motor performance

Effects of exercise on motor performance can occur at the central nervous system level and the peripheral level (Sale 1988). At the central level, neural adaptations may cause changes in the activation of muscles, which improve skill and coordination (Rutherford & Jones 1986). At the peripheral level, nerve conduction velocity (Halar *et al*. 1985) and the cross-sectional area of muscles (Garfinkel & Cafarelli 1992) increase.

There is some evidence that subjects who have been physically active throughout their lives have better motor capacity than inactive subjects of the same age (Clarkson 1978, Baylor & Spirduso 1988, Era *et al*. 1991). The value of these studies has been questioned because of the selection bias due to genotype, and the results of cross-sectional studies may therefore be insufficient to show how exercise affects the age-related decline in motor performance (Panton *et al*. 1990, Simonen 1997).

However, this relationship between exercise and motor performance has led to the assumption that subjects, especially older ones, may be able to increase their motor performance through exercise training. It has been postulated that training which increases aerobic capacity may also improve cerebral circulation and contribute to the transport of oxygen to brain cells. This increase in cerebral oxygenation could also have trophical effects on the neurons that supply the muscle fibers, and this enhancement of brain function may also improve motor performance aspects (Spirduso 1980, Dustman *et al*. 1984). In addition, rats studies have demonstrated that endurance training is associated with improved neurotransmitter functioning (brain dopamine level) (DeCastro & Duncan 1985) and the preservation of dopaminenergic cells (MacRae *et al*. 1987). The above changes are assumed to improve and accelerate mainly the response-selection and response-programming stages at the central nervous system level, and hence to improve e.g. reaction times.

Obviously the abovementioned assumption is one reason why many investigators have tried to use aerobic exercise training (walking, running) to improve motor performance. However, the results are inconclusive. Dustman *et al*. (1984) showed that subjects aged 55-70 years improved their simple reaction time by carrying out a four-month aerobic exercise training program. Rikli & Edwards (1991) noticed that the exercise program improved the simple and choice reaction times of women aged 57-85 years, and they assumed exercise to be effective in reversing or at least slowing down certain age-related declines in motor performance. In contrast, Paas *et al.* (1994) investigated the effects of a 10-month running program on simple and choice reaction times. They did not see changes in these aspects, and concluded that the improvement of physical fitness did not necessarily involve an improvement of motor performance. Panton *et al.* (1990) found that a six-month aerobic training program did not change reaction time and movement time in 49 untrained men and women 70-79 years of age, and they hence did not support the theory that motor performance is related to aerobic capacity. They did not believe that endurance training could increase oxygen delivery to brain cells at rest, but presumed that it could be a threshold for aerobic capacity, which is necessary to maintain motor performance. In addition, they suggested that an aerobic training effect could be noticed in a more complex choice reaction time task, which requires more central processing.

Panton *et al.* (1990) studied the effects of muscle strength training on reaction time and speed of movement, and the results indicated that a six-month strength training program with three 30-minute sessions weekly did not affect either reaction time or speed of movement in a group of 20 subjects (mean age 72.2 years). They assumed one reason for this finding to be that the measured task did not require enough muscle force for strength to play a major role. Moritani & Mimasa (1990) noticed in their study, which dealt with the adjustment of muscle strength in isometric contractions (the goal was 20 % and 60 % of maximal voluntary contraction) after 15000 practice contractions, that force variability decreased and the goal force was achieved faster.

Prolonged task-specific training has been known to increase performance in motor tasks. DeJong (1957) and Crossman (1959) showed that extended training produces a logarithmic reduction in the cycle time of several repetitive industrial operations. Rabbitt & Banerji (1989) showed with an easy four-choice reaction time task (practice consisting of ten sessions of 200 signals on five days = 10000 responses) that this decrease in mean time was not necessarily a consequence of the fact that the fastest cycle times recorded after the practice would be faster than the fastest cycle times before the training. They noticed that the improvement of performance with practice was mainly due to a marked reduction of the skewing of reaction time distributions.

2.6. Muscle strength training and its effects on the neuromuscular system

Muscle strength training in various forms is one of the most common therapy methods in physical therapy, and it is commonly used to improve muscle performance and strength. Because strength training causes both neural and muscular changes and adaptation of the neuromuscular system, it may also change the movement patterns performed with the trained muscles and effect changes in coordination. Three main principles of training have been presented: 1) overload principle (DeLorme 1946), 2) specificity principle (McCafferty & Hovath 1977) and 3) reversibility principle (Enoka 1994).

According to the overload principle, “to increase their size or functional ability, muscle fibers must be taxed toward their present capacity to respond”, which means that there is a threshold point that must be exceeded before an adaptive response will occur (DeLorme 1946). According to the specificity principle “training adaptations are specific to the cells and their structural and functional elements that are overloaded”, which means that the induced change is specific to the exercise stress, and that strength training, for example, increases strength rather than endurance (McCafferty & Hovath 1977). The reversibility principle points out that “training-induced adaptations are transient”, which means that when the training is discontinued, the system adapts to the new and lower requirements (Enoka 1994).

There are several training and loading techniques which increase muscle strength. The most commonly used training techniques are isometric training, dynamic training, training with accommodation devices, plyometric training and neuromuscular electrical stimulation. The main principles of these techniques are that the muscle length is constant in isometric training and varies in dynamic training. Training with accommodation devices provides an accommodating resistance, and one special type of this training is isokinetic training, i.e. movement in which the angular velocity is constant. Plyometric exercises train a specific movement pattern, the eccentric-concentric sequence of muscle activity, and in neuromuscular electrical stimulation muscles are activated by external electric shocks. (Enoka 1994)

The quantity of load used during training depends on the subject’s initial strength level and the main goal of training (i.e. whether the main goal is to increase maximal strength, endurance strength or speed strength), and the exact numerical load values must be defined individually.

2.6.1. Acute changes

One characteristic of the motor system is its adaptability to different levels of usage. The increase in core temperature achieved by a warm-up or muscular work improves the biomechanical performance of the motor system by increasing the dissociation of oxygen from hemoglobin and myoglobin, increasing metabolic reactions and muscle blood flow and enhancing the conduction velocity of action potentials (Shellock & Prentice 1985). In addition, an increase in muscle temperature causes changes in muscle stiffness, defined as the slope of a force-length relationship. Muscular work disturbs the actin-myosin bonds that have developed and thereby reduces the passive stiffness of the muscles by moving the muscle groups through a complete range of motion (Wiktorsson-Möller *et al*. 1983).

On the other hand, muscular work and strength training cause neuromuscular fatigue, which impairs some aspects of performance. Heavy muscular work performed with continuous isometric (Häkkinen & Komi 1986), intense intermittent isometric (Viitasalo & Komi 1980) or dynamic (Komi & Tesch 1979) resistance decreases muscle strength temporarily in trained muscles. In addition, one strength training session decreases electromyographic (EMG) activity and shifts the shape of the force-time curve of trained muscles (Häkkinen 1994). Previous findings have suggested that these changes may be consequences of neuromuscular fatigue (Häkkinen 1993, 1994 & 1995).

Neuromuscular fatigue is not caused by impairment of a single process, and fatigue varies from one condition to another, depending on the amount of force, the muscles involved and the duration of activity. This phenomenon is called the task dependency of muscle fatigue (Enoka & Stuart 1992). Neuromuscular fatigue has been classified as central or peripheral (Fitts & Balog 1996), and Bigland-Ritchie (1984) defined the potential sites of neuromuscular fatigue as: 1) excitatory input to higher motor centres, 2) excitatory drive to lower motor neurons, 3) motor neuron excitability, 4) neuromuscular transmission, 5) sarcolemma excitability, 6) excitation-contraction coupling, 7) contractile mechanisms, and 8) metabolic energy supply and metabolite accumulation.

The neural drive to the muscles at the central level has been tested by comparing the force of fatigued muscles during a maximum voluntary contraction to the force which has been added via external electrical stimulation. These tests indicate that the neural drive to the muscle provided by the central nervous system is not always maximal, and that the decrease in central drive can be a factor which decreases the force output (Belanger & McComas 1981).

There is some evidence that physical activity has some influence on nerve conduction velocity. Halar *et al.* (1985) showed in 20 subjects that the nerve conduction velocity of the sural nerve increased from 36.1±3.1 m/sec to 39.0±3.2 m/sec during 30 minutes of walking. However, they pointed out that this influence is not the same for all types of exercise and that not all nerves may be affected in the same way. There are some studies which suggest that impairment of neuromuscular propagation (conversion of an axonal action potential into a sarcolemmal action potential) is one mechanism that may contribute to the decline in force during different tasks (Fuglevand *et al.* 1993)

At the muscle level, fatigue may take place at the conversion of the action potential into a muscle fiber force (excitation-contraction coupling). Changes in the intracellular state decrease the amount of Ca^{2+} released (essential factor in muscle contraction) and the amount of Ca^{2+} returned to the sarcoplasmic reticulum (Westerblad & Lännergren 1990).

In addition, products of energy metabolism and blood flow may decrease muscle force during muscle work. For example, intramuscular pressure during muscle work can compress blood vessels and occlude blood flow (Sjøgaard *et al.* 1988).

Intensive muscle work, especially with eccentric contractions, may cause muscle soreness, most commonly 24-48 hrs after the exercise (Dick & Cavanagh 1987). There is no full consensus as to the mechanism that causes muscle soreness, but several potential explanations have been presented. Morgan (1990) assumed it to be result from the process where the acto-myosin bond is broken mechanically. Clarkson *et al.* (1986) presumed the main reason to be the loss of cellular calcium homeostasis, while Stauber (1989) assumed muscle soreness to be a consequence of an inflammatory response.

Morris (1977) showed that neuromuscular fatigue did not affect unresisted fractionated reaction time components (premotor time + motor time = total reaction time), but increased all resisted total reaction times. Because the changes were manifested in the motor time component, he suggested that neuromuscular fatigue takes place in the peripheral muscular component.

Jaric *et al.* (1997) investigated the effects of agonist and antagonist muscle fatigue on the performance of rapid, self-terminating arm movements. They found agonist muscle fatigue to be associated with a decrease in peak velocity and peak deceleration and antagonist muscle fatigue to be associated with a decrease in peak deceleration. They suggested that agonist muscle fatigue affects movement velocity more than antagonist muscle fatigue.

2.6.2. Long-term changes

It is well known that prolonged muscle strength training increases muscle strength in trained muscles. This effect has been perceived in children (Sewall & Michelli 1986), middle-aged subjects (MacDougall *et al.* 1980) and elderly people (Sipilä *et al.* 1996). However, the increase of muscle strength is greatly training-specific and depends on the type, intensity and duration of muscle work, and the changes in measured muscle strength are greatest in the tasks and exercises that have been used during the exercise period (Thorstensson *et al.* 1976).

Strength training causes both neural and muscular changes and adaptation of the neuromuscular system. Neural adaptation predominates in the early phase of training (Moritani & DeVries 1979). It is presumed that the neural adaptation of muscles in the early phase of training is due to a more active recruitment of motor units and an increase of their firing rates upon maximum voluntary contraction. The recruitments of slow- (type I) and fast-twitch (type IIa,b) muscle fibers are in relation to the intensity of effort. For rapid, powerful movements, the fast-twitch fibers are activated (Edgerton 1978). The authors assumed the improvement of strength performance to be due to the fact that the subjects can recruit more of type IIa, and especially type IIb, motor units during maximum contraction of the measured muscles, and that they can express their true strength capacity by increasing their capacity to recruit more type II motor units during rapid, powerful movements. This means that strength-trained subjects can more fully activate their prime moving muscles in maximal voluntary contractions. However, there is intersubject variability in this ability, and some muscles are more difficult to activate than others. Untrained subjects may have difficulty both in recruiting all motor units and in gaining optimal firing rates of the activated units in certain muscles (Sale 1988).

Apart from the increased activation of the agonist muscle (prime movers in a task), neural adaptation may cause changes in the activation of synergist and antagonist muscles, which can be manifested as improved skill and coordination (Rutherford & Jones 1986). The co-contraction of antagonist muscles may provide a stabilization factor during rapid contractions of agonist muscles. On the other hand, co-contractions of antagonist muscles may be a limit factor for full motor unit activation of agonist muscles. Muscle training may decrease the amount of co-contraction, offering a greater force in the direction of agonist muscle movement (Basmajian 1978, Sale 1988)

The greater motor unit activation achieved by muscle training may also increase the rate of force development, but this may be require explosive type of training (Häkkinen *et al.* 1985).

A good example of neural factor adaptations are the strength training studies of unilateral extremities. These studies have shown that strength also increases in the untrained extremity, but changes only take place in EMG values, not in muscle size. This indicates that the “cross-training” effect is a result of neural adaptation (Moritani & DeVries 1979).

These findings lead to the conclusion that it is possible to increase strength without adaptation in the muscle, but not without adaptation in the nervous system (Enoka 1994).

When muscle strength training continues for over three or four weeks, the increase in strength is caused notably by the mechanisms that increase muscle size. The contribution of neural factors decreases over time, but they continue to play some role for at least eight weeks (Moritani & DeVries 1979). The increase in muscle cross-sectional area and size is a consequence of hypertrophy, and implies an increase in the cross-sectional area of a single muscle fiber. It has been suggested that hypertrophy of muscle fibers is a consequence of a change in the ratio of protein synthesis to reduction, but this has not been clearly defined. It has been assumed, that this ratio depends on hormonal (testosterone, growth hormone, insulin), metabolic and mechanical (stretch, contraction) factors (Jones *et al.* 1989, Enoka 1994).

However, the increase in cross-sectional area depends greatly on the subject's initial strength level. With novice subjects, 6 weeks of isometric strength training increased the cross-sectional area of biceps brachii and brachioradialis by 5 % (Davies *et al.* 1988), and 8 weeks' training increased the cross-section of quadriceps femoris by 15 % (Garfinkel & Cafarelli 1992), but not even 24 weeks' strength training increased the cross-sectional area of the muscle fibers of biceps brachii in a group of experienced body builders (Alway *et al.* 1992).

After all, most studies on muscle strength training have addressed the effect of training on muscle force and EMG changes (Moritani & DeVries 1979, Häkkinen & Komi 1983). The authors of previous studies have given very little attention to the effects of strength training on the other motor components of the trained extremities, such as reaction time, speed of movements and coordination.

2.7. Strapping

There has been an increase in the use of joint strapping over the last few years, and some American football teams spend up to $ 50,000 per year on athletic tapes (Beynnon & Renström 1991). Strapping is also often used as a therapy method in physical therapy, especially with athletes and sports teams. Strapping has been used both prophylactically and to prevent and recover new and further ligament sprains after ligament injury. Strapping may play a significant role in the prevention of joint injuries, especially in the ankle (Garrick & Requa 1973).

The theoretical goal of strapping is to externally stabilize the ligamentous structures of the joint, without altering the normal joint kinematics and mechanics (Garrick & Requa 1973). Strapping has a restrictive effect on the range of joint movement immediately after its application. Greene & Hillman (1990) showed, in a group of seven subjects, that strapping restricted the ankle inversion-eversion range of motion by approximately 40 % right after the application. However, strapping quickly loses its restrictive effect on the range of motion following exercise. Fumich *et al.* (1981) showed that strapping may lose as much as 40 % of its range restrictiveness during ten minutes of exercise. Andreasson & Edberg (1983) found that the support decreased by 1/3 after 200 running steps and by another 1/3 after 400 steps, and Myburgh *et al.* (1984) noticed that no significant restriction effect may exist following a one-hour squash match.

Because strapping decreases the range of motion in the taped joint (which is naturally one of the theoretical aims of strapping), it may also have an effect on the other components of the motor performance of the strapped joint.

Wilkerson (1991) showed that strapping of the ankle joint decreased the range of motion in the ankle joints of 30 college football players and suggested that this may impede performance in certain athletic skills. Both Mayhew (1972) and Juvenal (1972) showed that ankle strapping decreased the subjects' vertical jumping abilities and other movements performed with strong plantar flexion. Burks *et al.* (1991) showed in a group of 30 athletes, that strapping of the ankle joint decreased the performance in vertical jump (4 %), shuttle run (1.6 %) and sprint (3.5 %). In contrast, Verbrugge (1996) presented results contradictory to those of Burks *et al.* (1991). Verbrugge found strapping to have no effect on the results of 26 male athletes in tests of agility run, 40-yard sprint and vertical jump. There are also some other researchers who have reported strapping to have no effect on the performance of the strapped foot. Greene & Hillman (1990) showed that ankle strapping did not affect subjects' vertical jumping ability. Abdenour *et al.* (1979) reported no differences between strapped and unstrapped ankles in the dynamic strength of inversion and eversion when measured by an isokinetic resistance device. Hamer *et al.* (1992) showed that ankle strapping had no effect on wobbleboard performance, and Tropp *et al.* (1984) noticed, in a group of 38 soccer players, that taping had no effect on stabilometric values. Thomas & Cotton (1971) reported that strapping of the ankle joint had no significant effect on the time to complete an agility run. Because the effects of strapping on motor performance are still so contradictory, further studies are needed before relevant conclusions can be made.

Many investigations have shown the restrictive effect of strapping on the range of single-joint movement (Fumich *et al.* 1981, Vaes *et al.* 1985, Gross *et al.* 1987), but in all studies dealing with the effect of strapping on the performance, the measurements and tests have been performed with whole-body movements (e.g. jumping, running). Little attention has been given to the movements and other components of the performance of the strapped joint only. In addition, almost all strapping studies deal with the ankle joint. The author did not find any studies dealing with the effects of strapping on the performance of the hand.

2.8. Hot and cold pack treatments

Local cold and hot pack treatments are among the most common methods used in physical therapy. These treatments are often used as pretreatment immediately before active or passive movement therapy (Kottke *et al.* 1982, DeLisa & Gans 1993). However, little information is available in the literature concerning the effects of these treatments on motor performance and the movements of the treated area, in spite of the fact that the usual goal of these treatments is to improve motor performance before movement therapy. This knowledge would be useful when designing and implementing movement therapy after cold or hot pack treatments.

2.8.1. Hot pack treatment

Hydrocollator packs contain silicate gel in a cotton bag. The gel absorbs and holds a large amount of water with its high heat-carrying capacity. The packs are immersed in a tank filled with water (temperature 70-80°C). Treatment is done drip-dry over layers of terry cloth for 20 to 30 minutes, and the main transfer of heat from the pack to the patient takes place by conduction (Lehmann 1982, DeLisa & Gans 1993).

It has been suggested that hot pack treatment increases the extensibility of collagen tissues, decreases joint stiffness, produces pain relief, relieves muscle spasms, increases blood flow and assists in the resolution of inflammatory infiltrates, edema and exudates

(Lehmann 1982, DeLisa & Gans 1993). It has been shown, that joint temperature has an effect on the resistance of movement and the movement speed of the joint. Higher temperatures decrease the resistance and increase the speed of movement, while lower temperatures produce an opposite effect (Hunter *et al.* 1952). Lehmann *et al.* (1970) showed that heat application produces greater extensibility of fibrous collagen tissues. However, heat alone, without stretching, did not increase the length, and the optimal result was achieved by a combination of heat and stretch application.

The previous literature on the effects of heat application on isometric muscle strength has reported contradictory results. Barnes (1983) showed that isometric strength decreased when muscle temperature increased. In contrast, King *et al.* (1970) suggested that isometric grip strength increased during heat application, and Davies & Young (1983) did not notice any change in the strength of triceps surae after heat application. Cornwall (1994) noticed in a group of 18 subjects that heat application in a 40°C water bath did not alter the wrist extensor muscle's ability to quickly develop isometric tension, but immersion in a 10°C water bath decreased it. Nor did he find any significant decrease in maximal voluntary contraction following heat application, which has been reported in previous studies, and he assumed the main reason for this to be the difference in muscle temperature between the studies.

One important aim of hot pack treatment is to improve the motor performance of the treated area and joints before movement therapy, but little information exists in the literature concerning these effects. Bhattacharya *et al.* (1991) found that the interaction of noise and heat entailed superior performance in two-hand coordination and reaction time at levels of moderate difficulty in a group of 24 volunteers, but the results of this study were based on an interaction between noise and heat, not only heat. In addition, the heat application was not local.

2.8.2. Cold pack treatment

Cold packs are plastic bags that contain silicate gel, which has a high cold-carrying capacity. The packs are cooled in a freezer (temperature -15 to -20°C), and a towel is placed around the pack before application to skin. The treatment time is 10-30 minutes.

The cold pack treatment reduces muscle tone in cases of muscle spasms, decreases metabolic activity and blood flow (Taber *et al.* 1992), inhibits spasticity (Hartviksen 1962, Knutsson & Mattsson 1969), slows down nerve conduction (Abramson *et al.* 1966) and decreases pain, edema and swelling in acute musculoskeletal trauma (DeLisa & Gans 1993).

Local cold treatment also has effects on factors of motor performance. Abramson *et al.* (1966) showed that nerve conduction decreases with cooling. De Jong *et al.* (1966) showed that nerve conduction velocity decreases linearly at a rate of 1.84 m/s/°C between 36°C and 23°C. Goodgold & Eberstein (1977) presented values of 2 to 2.4 m/s for the same phenomenon. Li (1958) and Li & Gouras (1958) showed in their animal studies that cooling has effects at the neuromuscular junction level. Blockade of the neuromuscular junction occurred at a temperature of 5°C and prevented nerve conduction. They also noticed that as the temperature decreased, the duration of endplate potentials increased and their frequency decreased.

At the muscle level, the cooling of muscles affects muscle strength and endurance. Walker showed as early as 1949, by using electrical nerve stimulation in an animal study, that the duration of the rise of contraction and the one-half relaxation time increased with decreasing temperatures ranging from 37 °C to 24.5 °C. Coppin *et al.* (1978) and Cornwall (1994) showed that the maximal muscle strength of a cooled arm decreased compared with the contralateral arm, which was not cooled. Clarke *et al.* (1958) studied the effect of cooling on the endurance of muscle strength. They showed that a maximal duration of sustained contraction is achieved at 27 °C, while at a lower temperature the contraction was shortened, but this shortening also took place at higher temperatures than 27 °C. They postulated that the rate of metabolism increases at higher temperatures and causes early accumulation of metabolites and earlier fatigue.

The cooling of whole body also has an effect on motor performance. Oksa *et al.* (1993, 1995) found that cooling causes a decrement in muscular performance. Giesbrecht and Bristow (1992) showed a decrement in manual arm performance during whole body cooling, when the core temperature decreased 0.5 °C. In contrast, in a study dealing with working in cold environment, Tochihara *et al.* (1995) did not find significant differences in manual performance between the test and control groups.

After all, many studies that deal with the effects of cooling on performance are quite old, and new studies performed with modern technology are needed to clarify these questions. Moreover, most of these studies on local cooling concern the effect of temperature on muscle force. The investigators have given very little attention to the effects of temperature on the other components of the performance of extremities, such as coordination. Fox (1961) studied typing speed with a standardized test after both hands had been cooled in water at 10 °C to 42 °C temperature and noticed that the time needed for the task increased when hand temperatures decreased, and this decrease was manifested before grip strength decreased. Parry (1982) studied braking with a hand-operated lever braking system at a normal hand temperature (mean: 27.8 °C) and with cooled hands and fingers (6 °C) and showed a significant decrement in the performance of the measured aspects after cooling. This phenomenon may take place when riding a motorcycle with cold hands, especially in the northern climate.

3. Purpose of the study

Some physiotherapy programmes and treatments are assumed to improve coordination and motor performance before movement therapy (e.g. hot and cold pack treatments) during a competition (strapping) or rehabilitation program (muscle strength training). In spite of this, little information is available in the literature concerning the effects of these treatments on the motor performance and movements of the treated area. The purpose of the present study was hence to gain further knowledge about the effects of these four commonly used physical therapy methods, including strapping, hot pack treatment, cold pack treatment and muscle strength training, on the motor performance (reaction time, speed of movement, tapping speed and accuracy/speed of movement) of healthy persons (studies II-V).

In addition, the association between age, gender and preferred handedness and the motor performance of hand and foot in a healthy population were studied, and the reliabilities of the measurements were determined (study I).

In detail, the specific aims of this study were:

1. To determine and evaluate the test-retest repeatability of the motor performance measurements used in the present study for the hand and foot between two test sessions performed on consecutive days (I).
2. To study the associations between age, gender and preferred handedness and the different aspects of the motor performance (reaction time, speed of movement, tapping speed and accuracy/speed of movement) of the hand and foot in a healthy population (I).
3. To examine the effects of four commonly used physical therapy methods, including strapping, hot pack treatment, cold pack treatment and muscle strength training exercise (acute fatigue effect and long-term effect of exercise) on the motor performance of healthy persons (II-V).

4. Subjects and methods

4.1. Subjects

Reliability studies. In the reliability study of the motor performance tests the 40 participants were healthy voluntary female staff (physiotherapist) members (the mean age 33.8 years, SD 6.6, range 23-53) at the Oulu University Hospital, who did not have diseases which may have influence the motor function needed to perform the tests.

In the reliability study of wrist muscle strength and EMG tests, the 16 participants were healthy voluntary female staff (physiotherapist) members (the mean age 40.1 years, SD 4.6, range 32-49) at the Oulu University Hospital.

Study I. The aim was to recruit 200 healthy subjects. To achieve this target, 500 subjects (50 in each age group mentioned below) were randomly selected (an age- and gender-specified sample was ordered from the Bureau of the Census in February 1992) from among the population of Oulu (population on Jan.1. 1992 was 102,280 inhabitants). After that, 343 letters were sent in the order of the name lists to recruit 200 healthy volunteers of the needed age and gender (response rate 58.3 %). The main criterion for inclusion was normal motor function and an ability to perform the tests. The subjects had various socioeconomic and educational backgrounds. The sample consisted of 100 women and 100 men.

The subjects were categorized into ten groups as follows: men aged 21-30 yr, women aged 21-30 yr, men aged 31-40 yr, women aged 31-40 yr, men aged 41-50 yr, women aged 41-50 yr, men aged 51-60 yr, women aged 51-60 yr, men aged 61-70 yr and women aged 61-70 yr. Each group consisted of 20 subjects.

The preferred handedness was self-reported by the subjects (the interview question was: Are you right-handed or left-handed?). There were 186 right-handed and 14 left-handed subjects, and the presented values were calculated from the values of right-handed subjects, which means that the final sample size was 186 subjects. The characteristics of the study subjects are shown in more detail in Table 1.

Studies II-V. The participants in the studies II-V were healthy voluntary staff members (physiotherapists) at the Oulu University Hospital, who were recruited to the studies by personal invitation. To be included in the studies, the subjects had to have no history of hand or foot injuries, no heart disease, no hypertension or neurological diseases, which might have a influence the motor function needed to perform the tests. All subjects were tested for their right hand, because it was the dominant side of all subjects according to the criterion of the preferred hand for writing. In study II, all subjects were also right-leg dominant on the criteria of the preferred foot for kicking a ball and making a vertical jump. The characteristics of the subjects of these studies are shown in more detail in Table 1.

Table 1. Characteristics of the subjects in the population study and in the intervention studies.

Characteristic		Study I			Study II	Study III	Study IV	Study V
		All	Male	Female				
Number of subjects		186	93	93	14	20	30	16
Gender: male/female		186	93	93	2/12	-/20	-/30	-/16
Age:	Mean (yr)	45.4	45.5	45.3	28.1	35.4	38.5	36.1
	SD	14.4	14.4	14.5	4.1	5.4	5.2	5.5
	Range	21-70	21-69	21-70	21-33	25-45	29-47	25-45
Height:	Mean (cm)	169.5	176.3	162.9	172.1	165.0	164.3	164.3
	SD	9.5	7.2	6.3	4.5	4.9	4.7	4.7
Weight:	Mean (kg)	72.3	80.1	64.7	68.3	63.9	60.6	62.9
	SD	13.1	12.0	9.1	3.4	8.1	6.6	7.9

4.2. Study designs

In the reliability studies of motor performance, wrist muscle strength and EMG tests, all subjects were measured twice on consecutive days and they performed the tests at the same time of the day. The results were then compared.

Study I was a cross-sectional study of the population of Oulu, which has been stratified into the abovementioned ten groups. The studies II, III and V were non-controlled intervention studies, and the interventions between the measurements were strapping of the ankle and wrist joints (study II), hot and cold pack treatments of the forearm (study III), and a ten-week strength training program of the hands (study V). Study IV was a cross-over intervention study, and the intervention was a one-hour strength training session of hands.

In study I, all subjects were measured once (the measurement time was between 15.00-19.00 o'clock) The same therapist measured all subjects, and standardized instructions and explanations of the testing procedure were given to the subjects. The tests were demonstrated, and each subject was allowed to perform three training trials of each test before the measured trials. The results were then compared between the different age and gender groups and between the right and left extremities.

In study II, the subjects were measured twice on consecutive days and they performed the same tests on both days. The subjects performed the tests at the same time of the day. First (on day one) they performed all tests without strapping, and on the following day (on day two) they repeated the tests with strapped right wrist and ankle joints. The results were then compared.

In study III, all subjects were first measured three times on consecutive days, and they performed the same tests every day (=3 baseline measurements). On the fourth or fifth day the subjects underwent a twenty-minute hot pack treatment of the right hand. The forearm was kept between two hot packs from the elbow to the fingers. Three consecutive measurements were made: 1) immediately, 2) fifteen minutes and 3) thirty minutes after the treatment. Each measurement session lasted for about five minutes. A week later all subjects underwent a fifteen-minute cold pack treatment of the right hand. The treatment area was the same as in the heat pack treatment. Again, measurements were made 1) immediately, 2) fifteen minutes and 3) thirty minutes after the treatment.

In study IV, the 30 participants were randomly divided into two groups (Group A (n= 15) and Group B (n=15)). At first, both groups carried out a motor performance tests of the right hand on three consecutive days (= 3 baseline measurements). The subjects performed the same tests at the same times of the day on each day. On the fourth day, the subjects in group A carried out a one-hour muscle strength training session of the hands. The isometric muscle strengths of wrist flexion/extension were measured immediately before the training session, and EMG data were recorded during the isometric tests. During the following hour, the subjects of group A carried out a one-hour muscle strength training session, and muscle strength, EMG and motor performance were measured immediately after it. Group B did only the motor performance tests as a control group. One week later the programs of the groups were exchanged, and each group performed the tests that the other group had done previously. Thus, group B carried out the one-hour muscle strength training session with muscle strength, EMG and motor performance measurements, and group A did only the motor performance tests as a control group.

In study V, before the ten-week upper extremity strength training period, the motor performance of the right hand was measured three times on consecutive days and the subjects performed the same tests each day. The isometric muscle strengths of wrist flexion/extension and elbow flexion/extension were measured once and the EMG data were recorded during elbow flexion/extension isometric tests. During the following months, the subjects carried out a ten-week strength training program of the hands. After the training period, the same measurements were made as before the training.

4.3. Methods

4.3.1. Motor performance measurements

The Human Performance Measurement/Basic Elements of Performance (=HPM/BEP) system (Human Performance Measurement, Inc. Arlington, TX 76004-1996) was used for the collection of motor performance data. In these studies, the modules for hands (studies I-V) and feet (studies I-II) were used. The module for hands (=BEP 1) (Fig. 3.) is a multifunctional system designed to measure different aspects of the hand, including reaction time, movement speed, tapping speed and coordination. BEP 1 consists of eight red lights used as visual stimuli and fifteen touch-sensitive plates that are divided into four regions on top of the module. Different tests are performed on the four regions of the module. The module for feet (=BEP 2) (Fig. 4.) is a multifunctional system designed to measure the same aspects of foot performance. BEP 2 consists of two red lights for visual stimuli and seven touch-sensitive plates that are divided into three regions on top of the module. The same therapist measured all subjects, and standardized instructions and explanations of the testing procedures were supplied to the subjects. All procedures were as described in the manual (Kondraske 1991). The tests were demonstrated, and each subject was allowed to perform three training trials on each test before the measured trials. The trials with anticipation errors or the most obvious delays were failed and repeated. The number of trials and the measurement times were set as by the Human Performance Measurement software.

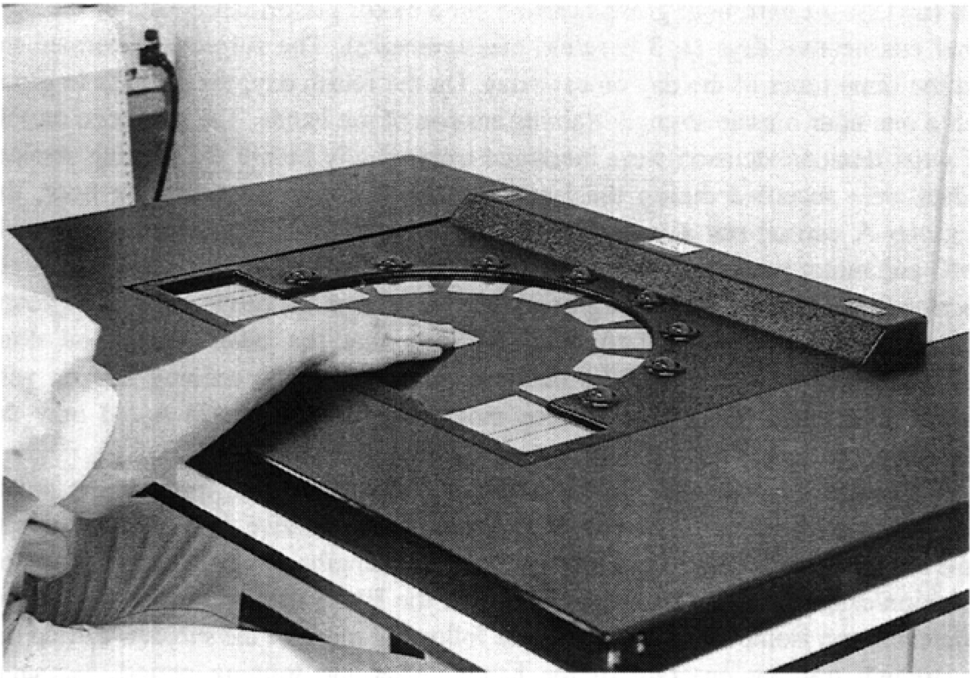


Fig. 3. The HPM/BEP 1 device and the measurement of the reaction time of the hand.

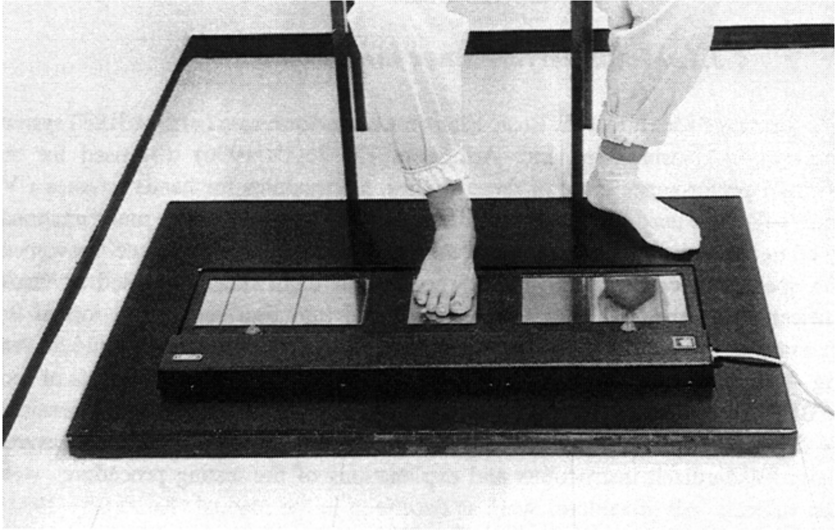


Fig. 4. The HPM/BEP 2 device and the measurement of the reaction time of the foot.

Hand tests: Simple reaction time test (studies I-IV): The subject was instructed to place her/his hand on the plate, in the middle of the BEP 1 apparatus (Fig. 3.). The subject heard a beep signal, which was the sign to be ready to respond. From two to six seconds after this, all the eight lights were activated simultaneously and the subject lifted her/his hand as quickly as possible from the plate by dorsiflexion of her/his wrist joint. Reaction time was expressed in milliseconds and was the time from the initiation of the light stimulus to the time when the subject lifted her/his hand from the plate. The subjects performed 5 trials.

One-choice reaction time and speed of movement test (study I): The subject heard a beep signal, which was the indication for her/him to be ready for response. Two to six seconds after the acoustic signal, a light stimulus appeared and the subject was instructed to lift her/his hand immediately after the predefined light stimulus appeared and to move it as quickly as possible to the plate immediately in front of the activated light (the measurement system presented stimuli in the pseudo-random order). Two different measures were obtained from each trial: 1) One-choice reaction time, expressed in msec, is the time between the appearance of a light stimulus and the hand lifting from the center plate. 2) Movement speed, expressed in cm/sec, is determined as the distance between the center plate and the target plate (distance 10 cm) divided by the time needed for the performance of the movement. The subjects performed 5 trials.

Two-choice reaction time and speed of movement test (studies I-V): The subject performed the test with the same method as in the one-choice reaction time and the speed of movement test, but there were two possible activated lights. The subjects performed 6 trials.

Four-choice reaction time and speed of movement test (study I): The subject performed the test with the same method as in the one-choice reaction time and the speed of movement test, but there were four possible activated lights. The subjects performed 12 trials.

Index finger tapping test (studies I, III-V): The subject tapped the touch plate with the maximal rate of her/his index finger for a period of ten seconds. The results were expressed in taps/sec. The subjects performed 2 trials.

Wrist tapping test (study II): The subject tapped the touch plate with the maximal rate of flexion/extension movement of her/his wrist joint for a period of ten seconds. The results were expressed in taps/sec. The subjects performed 2 trials.

Coordination test (studies I-V): The subject was instructed to tap two narrow plates alternately (the width of the plates was 17 mm and the distance between them 40 cm, and hence I_d is 5.56) as rapidly as possible and to avoid errors for a period of ten seconds. Two different measures were obtained from a given trial. There was one measure of accuracy in units of percentage of correct hits, and one measure of average movement speed during the task in units of cm/sec. The final measure was obtained by combining speed and accuracy, and the result was expressed in bits/sec (Fitts 1954). The subjects performed 2 trials.

Foot tests: Simple reaction time test (studies I, II): All foot tests were performed sitting (except the coordination test in the anterior-posterior direction, which was performed standing). In the simple reaction time test, the subject was instructed to place her/his foot on the plate in the middle of the BEP 2 apparatus (Fig. 4.). The subject heard a beep signal, which was the sign to be ready to respond. Two to six seconds after this, both lights were activated simultaneously and the subject lifted her/his foot as quickly as possible from the plate by dorsiflexion of her ankle joint. Reaction time was expressed in milliseconds and was the time from the initiation of the light stimulus to the time when the subject lifted her foot from plate. The subjects performed 5 trials.

One-choice reaction time and speed of movement test (study I): The subject heard a beep signal, which was the indication to be ready for response. Two to six seconds after the acoustic signal, a light stimulus appeared, and the subject was instructed to lift her/his foot immediately after the predefined light stimulus appeared and to move it as quickly as possible to the plate immediately in front of the activated light (to the right in right foot test and to the left in left foot test). Two different measures were obtained from each trial: 1) One-choice reaction time, expressed in msec, is the time between the appearance of the light stimulus and the foot lifting from the center plate. 2) Movement speed, expressed in cm/sec, is determined by dividing the distance between the center plate and the target plate (10 cm) by the time needed for the performance of movement. The subjects performed 5 trials.

Two-choice reaction time and speed of movement test (studies I, II): The subject performed the test with the same method as in the one-choice reaction time and speed of movement tests, but there were two possible activated lights. The subjects performed 6 trials.

Foot tapping test (studies I, II): The subject tapped the touch plate with the maximal rate of plantar/dorsiflexion movement of the ankle joint for a period of ten seconds. The heel was kept on the floor the whole time. The results were expressed in taps/sec. The subjects performed 2 trials.

Coordination test in the lateral direction (studies I, II): The subject was instructed to tap two narrow plates alternately in lateral direction (the width of the plates was 10 cm and the distance between them 45 cm, and hence I_d is 3.17) as rapidly as possible and to avoid errors for a period of ten seconds. Two different measures were obtained from a given trial. There was one measure of accuracy in units of percentage of correct hits, and one measure of the average movement speed during the task in units of cm/sec. The final measure was obtained by combining speed and accuracy, and the result was expressed in bits/sec (Fitts 1954). The subjects performed 2 trials.

Coordination test in the anterior-posterior direction (study I): The subject performed the test with same procedure as in the lateral direction test, but the test was performed standing, and the subject was allowed to lean on a support. The subjects performed 2 trials.

4.3.2. Muscle strength measurements

The isokinetic/isometric Lido Active Multi-joint System (Loredan Biomedical, Inc. Davis, California. Distributed by Kuntoväline Oy FIN-00620 Helsinki) (Fig. 5.) was used to measure isokinetic (study II) and isometric (studies IV and V) muscle strength. In all isokinetic tests, the subjects performed five repetitions. The average peak torque was calculated (by the software) and expressed in Newton x Meter (=Nm). In all isometric tests, the subject performed three maximum efforts and each effort lasted for five seconds. The rest period between the trials was 30 seconds. The average peak torque was calculated and expressed in Newton x Meter (=Nm). The manufacturer's recommendations for stabilization and joint axis alignment were followed. In the elbow muscle strength measurement, the lever arm was calculated with a sliding cuff system, and the lever arm used in the ankle and wrist muscle strength measurements was constant and it was set individually.

Muscle strength of the wrist (studies II, IV, V): In the isometric muscle strength test (studies IV and V) of the wrist joint, the subject performed three maximum efforts of flexion/extension of the wrist joint. The subject was sitting on the Lido table with her right forearm in a pronated position (in the extension test) or in a supinated position (in the flexion test) on the armrest. The subject was stabilized with forearm straps.

In the isokinetic muscle strength tests (study II), the subjects performed five repetitions, and the forearm was in a pronated position in the flexion/extension test and in a neutral position in the ulnar/radial deviation test. The subject was stabilized with forearm straps.

Muscle strength of the elbow (study V): In the muscle strength test of the elbow joint, the subject performed three maximum efforts of flexion/extension of the elbow joint. The flexion/extension of the elbow joint was measured with the subject sitting on the Lido table with her right forearm in a supinated position (elbow flexion was 60^o from the neutral position) and placed on the elbow rest. The subject was stabilized with an elbow strap and also with a strap across the chest.

Muscle strength of the ankle (study II): In the isokinetic strength test of the ankle, plantar and dorsiflexion were measured with the subject seated on the Lido table with the right foot placed on the plantar/dorsiflexion footplate. The right knee was in a flexed position and the foot was stabilized with two tight foot straps (across the arch), with a tight strap across the hips and a side stabilization bar/thigh cuff placed against the lateral distal thigh. The subjects performed five repetitions.

Eversion/inversion of the ankle was measured with the subject lying on his/her side on the Lido table and with the right foot placed on the eversion/ inversion footplate. The right knee was placed in full extension and stabilized with a strap, and a side stabilizing bar/thigh cuff was placed against the lateral distal thigh. The subjects performed five repetitions.

4.3.3. Electromyographic measurements

A microcomputer and an eight-channel telemetric Noraxon Telemyo System (Noraxon U.S.A., Inc. Scottsdale, Arizona. Distributed by Noraxon Finland FIN-90220 Oulu) (Fig. 5.) were used to collect EMG data during isometric muscle contractions (studies IV, V). Skin preparation at the electrode sites included shaving the hair, skin abrasion and cleaning the skin with alcohol. Two pairs of pregelled surface disk electrodes (Nikomed, type 4535: silver chloride, radius 7.5 mm, interelectrode distance between centres 25 mm) were placed parallel to the muscle. The preamplifier electrodes were located over the greatest muscle bulk of the muscles (the electrodes were positioned along a line representing the greatest circumference of the muscles) and a ground electrode was placed on the breast bone (study IV) or the scapula (study V). The signals were transmitted using a battery-operated transmitter pack (type M16-TTFB-0024) and a receiver (type M16-RTFB-0024) to the amplifier (type: differential, input impedance: 16 Mohm, common mode rejection ratio: 85 dB, input noise: $<1\mu V$ RMS, gain: 1000, bandwidth 16-500 Hz, type 6-pol. Butterworth) and from the amplifier to the computer with an interface cable and an A/D card (DT2801) and analysed with software version 1.0. After amplification, the raw bipolar EMG signals were recorded and processed by using smoothing (smoothing factor 30) and full-wave rectification. Three efforts, each lasting for five seconds, were recorded, but the EMG data values were analysed and calculated during two seconds (from two to four seconds), and the final result was the mean value of three efforts. The measured muscles were biceps brachii and triceps brachii (study V) and the flexor and extensor muscle groups of the wrist joint (study IV).

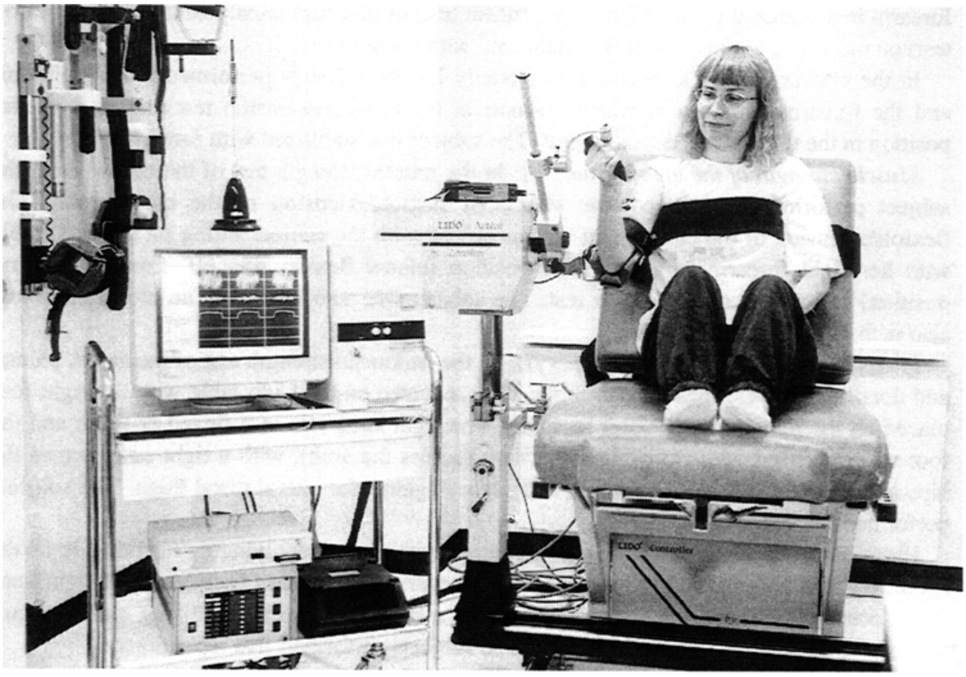


Fig 5. Lido Active Multi-joint and Noraxon Telemyo System, and the measurement of isometric muscle strength and EMG of the hand.

The recordings were unilateral, and the right hand was used. The mean EMG (MEMG) and the integrated EMG (IEMG) of the muscles were calculated, because these are the two central parameters used for amplitude quantification. MEMG represents the mean level of excitation over the observation period, expressed in volts. IEMG is the area under the amplitude curve for a defined time period, expressed in volts x sec.

4.3.4. Training programs

In study IV, the subjects carried out a one-hour muscle strength training session of the hands. The aim of the training was to fatigue the muscles of the hands. The subjects trained using free weights as resistance, and the training was applied to the muscles of the hands. The training consisted of circuit strength training with 12 exercises, and the subjects performed three sets with 15 repetitions at each training point with a pause of 30 s between the sets. The speed of performance was 6 repetitions/10 sec. The rest between the training points was one minute (after three training points the rest was two minutes). The intensity of training (=weight of resistance) was chosen individually, to allow the subjects to perform 15 repetitions at each training point but no more. The exercises of one-hour muscle strength training session are described in detail in the fourth original paper (Study IV, table 2).

In study V, the subjects participated in a ten-week progressive strength training program of the hands. It consisted of two supervised one-hour sessions a week and at least two 40-minute home training sessions a week. The group trained using free weights as resistance, and the training was designed to increase the strength of the hand muscles. Supervised training consisted of circuit strength training (16 exercises including two rest points), and the subjects performed three 30 s sets at each training point with a pause of 30 s between the sets. The rest between the training points was one minute. The intensity of training was increased three times during the ten-week period and it was about 50 % of the one repetition maximum (1 RM). This was individually calculated and adjusted for each subject from the 1 RM tests performed with hand weights in the exercises including supervised training program. The 1 RM tests were performed at the beginning of the training and after 2, 4 and 8 weeks of training.

The home training program consisted of ten exercises for the hands performed with hand weights. It was designed to increase the strength of the flexor and extensor muscles of the elbow and wrist joints. The subjects kept a diary of their home training. The exercises are presented in detail in the fifth original paper (Study V, tables 2 and 3).

4.3.5. Statistical methods

In study I, the reliability between the two test sessions was analysed by a variance component model, from which the standard errors of measurement (=SEM) (Fleiss 1986) and the intraclass correlation coefficients (=ICC) (the proportion of the inter-subject variance component out of the total variance of measurements) (Fleiss 1986) were calculated and presented.

Student's paired t-test was used to compare the values between the right and left side and between the hands and feet. For choice reaction time, the influence of different numbers of choices was also tested using this test. In comparing the men and women and the different age groups, a two-tailed t-test for independent samples and a one-way analysis of variance (ANOVA) were used.

In the studies II, IV and V the mean value and standard deviation (SD) in each test were calculated and presented. In addition, the mean values of three baseline measurements were presented (studies IV-V). A nonparametric paired t-test (Wilcoxon test for matched pairs) was used to determine whether there was a statistically significant difference between the mean values obtained before and after the interventions. Non-parametric statistics rather than parametric statistics was used because of the relatively small sample sizes. Parametric statistics require a normal distribution, and as the samples were small this requirement was not fulfilled every time. A separate analysis of each variable was made because the test batteries consisted of many different tests, which reflected different aspects of motor performance, and the aim was to find out the exact positions where the changes were located.

In study III, analysis of variance (ANOVA) for repeated measures was used to determine if there was a statistically significant difference between the measurement times, and Student’s paired t-test was used in *post hoc* analysis to locate these differences in more detail. The statistical analyses were performed using the SOLO® and SPSS® programmes. For all statistical tests, the 0.05 level of probability was accepted as the criterion for statistical significance.

5. Results

5.1. Reliability of tests

5.1.1. Reliability of motor performance tests

In a comparison of the values between the first and second (performed a day later) measurement sessions, Student's paired t-test did not show statistically significant differences between the sessions in any test, which means that the values had not changed systematically in any direction, and that there was no systematic error in the results between the sessions. The intraclass correlation coefficient of the reliability values indicated that reliability was higher for the hand than for the foot in every test. Details of the results are presented in Table 2.

Table 2. The test/retest reliability of the motor performance tests of the right extremities in a sample of 40 female hospital staff members aged 23-53 years.

Measurement	Mean (SD) day 1	Mean (SD) day 2	SEM	ICC
Reaction time (two choices)				
Hand (msec)	292 (33)	284 (32)	17.4	0.75
Foot (cm/sec)	364 (45)	361 (41)	21.7	0.70
Speed of movement (two choices)				
Hand (cm/sec)	107 (26)	102 (27)	8.8	0.91
Foot (cm/sec)	144 (27)	149 (31)	11.2	0.88
Tapping speed				
Hand (taps/sec)	5.6 (0.6)	5.6 (0.6)	0.2	0.91
Foot (taps/sec)	5.1 (0.6)	5.2 (0.5)	0.2	0.86
Accuracy/Speed of movement				
Hand (bits/sec)	10.41 (1.20)	10.44 (1.05)	0.5	0.81
Foot (bits/sec)	6.66 (0.86)	6.79 (0.90)	0.5	0.68

5.1.2. Reliability of wrist muscle strength and EMG tests

In a comparison of the values between the first and second (performed a day later) measurement sessions Student's paired t-test did not show statistically significant differences between the sessions in any test. The intraclass correlation coefficient of reliability values indicated that reliability was higher for the wrist flexion strength measurement than for the extension strength measurement. In addition, the intraclass correlation coefficient of reliability was higher for the EMG measurement of wrist extension than for the EMG measurement of wrist flexion. Details of the results on muscle strength and EMG tests are presented in Table 3.

Table 3. The test/retest reliability of the right wrist muscle strength and EMG tests in a sample of 16 female hospital staff members aged 32-49 years.

Measurement	Mean (SD) day 1	Mean (SD) day 2	SEM	ICC
Wrist flexion (Nm)	10.2 (2.5)	10.0 (2.5)	0.2	0.97
Wrist extension (Nm)	7.1 (1.0)	6.9 (1.2)	0.2	0.91
IEMG flexion (μVsec)	505 (148)	474 (131)	29	0.79
IEMG extension (μVsec)	570 (167)	540 (180)	24	0.84

5.2. Associations between age, gender and preferred handedness and the motor performance of hands and feet (Study I)

Values stratified by age group, gender and preferred handedness are illustrated in Fig. 6., and absolute numerical values are presented in the first original paper (Study I, tables 3-5).

Reaction time. The reaction times of hands were longer in the older age groups in both genders. The differences between the groups were slight at ages 21-50 years, but increased clearly after that. The correlation coefficient (=r) between age (all subjects between 21-70 years) and the right hand simple reaction time was 0.30 (p<.001), and the estimated average delay 0.55 msec/year. The corresponding values for the 4-choice reaction time task were 0.47 (p<.001) and 1.51 msec/year. The reaction times were faster on the left side in each test (p<.001). The differences between the sides were 3 % in simple-, 3 % in one-choice, 4 % in two-choice and 6 % in four-choice reaction time tasks. There were no statistically significant differences in the mean values between men and women. The increasing number of possible choices increased the reaction times. This difference was clear for the simple reaction time between the one-choice and two-choice tests (p<.001), but the difference was smaller between the two-choice and four-choice tests, and the comparisons were not statistically significant.

The reaction times of feet were also longer in the older age groups in both genders, but the difference was small between the age groups of 21-50 years and most distinct at 51-60 years. By 61-70 years the prolongation had disappeared. The correlation coefficient between age (all subjects) and the right foot simple reaction time was 0.10 (p=ns), and the estimated average delay was 0.19 msec/year. The corresponding values for the one-choice reaction time task were 0.12 (p=ns) and 0.35 msec/year and for two-choice task 0.39

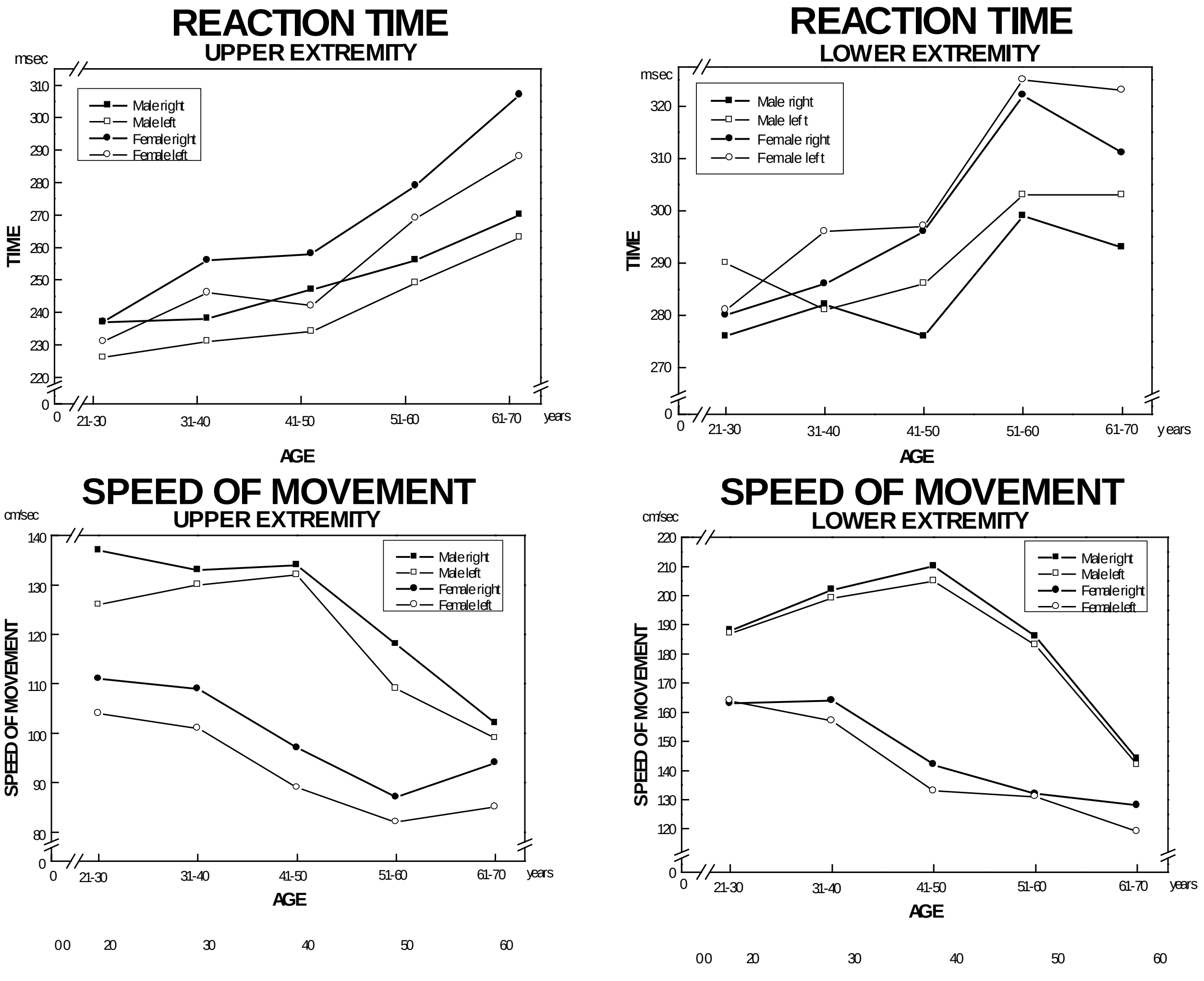
(p<.001) and 1.68 msec/year. The right side showed a faster mean simple reaction time than the left side (p<.001) and the difference was 3 % (all subjects). This was also true of the one-choice test (difference 4 %, p<.001), but not of the two-choice test (difference 0.5%, p=ns). The values for men were faster than the values for women in each age group (p<.001), except in a few cases in the youngest group. Statistically significant differences were found between the simple reaction time and the one-choice and two-choice tests on both sides (p<.001). The reaction times became longer when amount of choices increased.

Speed of movement. The speed of movement of hands was slower in the older age groups in both genders. The slowest values were recorded at ages 51-70 in the group of men, and at 41-60 years in the group of women. The correlation coefficient between age (all subjects) and the right hand speed of movement in the one-choice task was -0.30 (p<.001), and the estimated average decrease 0.69 cm/sec/year. The corresponding values for the two-choice task were –0.26 (p<.001) and 0.56 cm/sec/year, and these for the four-choice task –0.42 (p<.001) and 0.82 cm/sec/year. The right side was faster in the two-choice (difference between sides 10 %, p<.001) and four-choice tests (difference 6%, p<.001). The average speed of movement was faster for men than women in each age group (p<.001), and the difference varied within 27-32 %, depending on the test. Statistically significant differences were seen between the one, two and four-choice tests for speed of movement (p<.001). Speed of movement decreased when the number of choices increased.

The speed of movement values for feet were slowest after 50 years of age for men and after 40 years for women. The correlation coefficient between age (all subjects) and the right foot speed of movement in the one-choice task was –0.31 (p<.001), and the estimated average decrease 1.08 cm/sec/year. The corresponding values for the two-choice task were –0.28 (p<.001) and 1.05 cm/sec/year. The right side was significantly faster in the two-choice test (difference 3 %, p<.01), but not in the one-choice test (difference 2 %, p=ns). Men were faster than women in each age group (p<.001), and the difference varied within 26-31 %, depending on the test. The speed of movement of the left side was higher in the one-choice test than on the two-choice test (p<.01), but no significant difference was seen on the right side.

Tapping speed. The tapping speed values of hands were slower after 50 years of age in both genders. The correlation coefficient between age (all subjects) and right index finger tapping speed was –0.31 (p<.001), and the estimated average decrease 0.02 taps/sec/year. The corresponding values for the left index finger were –0.36 (p<.001) and 0.02 taps/sec/year. Tapping speed was higher for the right side (difference 8 %, p<.001). Tapping rate was also higher for men than women (p<.001) in each age group, and the difference was 6 % for both hands (all subjects).

The tapping speed of feet was lower in the older age groups in both genders, except in the oldest age group of women. The correlation coefficient between age (all subjects) and right foot tapping speed was –0.33 (p<.001), and the estimated average decrease 0.02 taps/sec/year. The corresponding values for the left foot were – 0.29 (p<.001) and 0.02 taps/sec/year. For feet, tapping speed was higher on the right side (p<.001), and the difference was 4 % (all subjects). Men had higher rates than women in each age group (p<.001), and the differences were 14 % for the right foot and 15 % for the left foot.


REACTION TIME
UPPER EXTREMITY
msec
TIME
310
300
290
280
270
260
250
240
230
220
0
Male right
Male left
Female right
Female left
0
21-30
31-40
41-50
51-60
61-70
years
AGE
REACTION TIME
LOWER EXTREMITY
msec
TIME
320
310
300
290
280
270
0
Male right
Male left
Female right
Female left
0
21-30
31-40
41-50
51-60
61-70
years
AGE
SPEED OF MOVEMENT
UPPER EXTREMITY
cm/sec
SPEED OF MOVEMENT
140
130
120
110
100
90
80
0
Male right
Male left
Female right
Female left
0
21-30
31-40
41-50
51-60
61-70
years
AGE
00
20
30
40
50
60
SPEED OF MOVEMENT
LOWER EXTREMITY
cm/sec
SPEED OF MOVEMENT
220
210
200
190
180
170
160
150
140
130
120
0
Male right
Male left
Female right
Female left
0
21-30
31-40
41-50
51-60
61-70
years
AGE
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20
30
40
50
60

Fig. 6
]

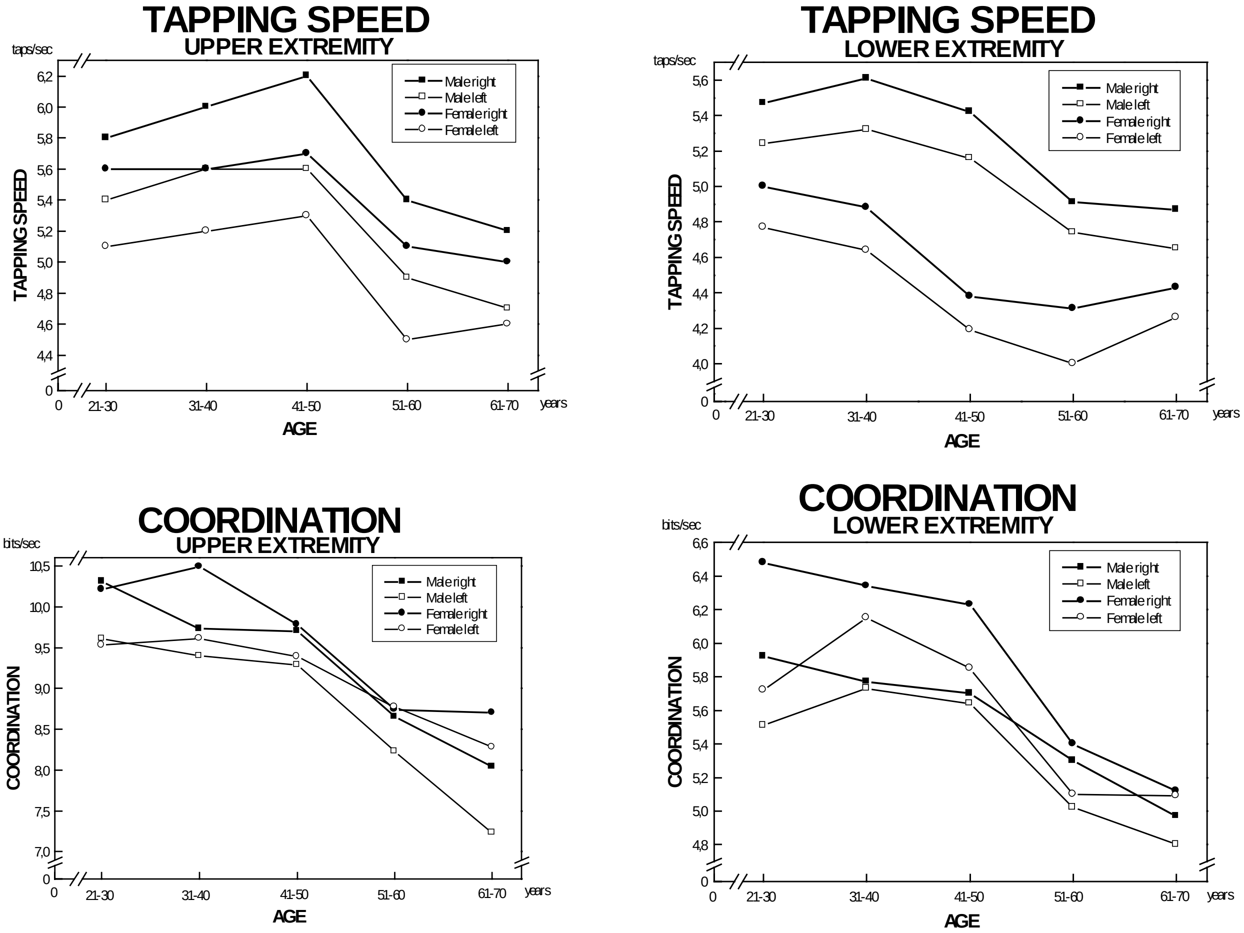
TAPPING SPEED
UPPER EXTREMITY
taps/sec
TAPPING SPEED
6,2
6,0
5,8
5,6
5,4
5,2
5,0
4,8
4,6
4,4
0
0
21-30
31-40
41-50
51-60
61-70
years
AGE
Male right
Male left
Female right
Female left
TAPPING SPEED
LOWER EXTREMITY
taps/sec
TAPPING SPEED
5,6
5,4
5,2
5,0
4,8
4,6
4,4
4,2
4,0
0
0
21-30
31-40
41-50
51-60
61-70
years
AGE
Male right
Male left
Female right
Female left
COORDINATION
UPPER EXTREMITY
bits/sec
COORDINATION
10,5
10,0
9,5
9,0
8,5
8,0
7,5
7,0
0
0
21-30
31-40
41-50
51-60
61-70
years
AGE
Male right
Male left
Female right
Female left
COORDINATION
LOWER EXTREMITY
bits/sec
COORDINATION
6,6
6,4
6,2
6,0
5,8
5,6
5,4
5,2
5,0
4,8
0
0
21-30
31-40
41-50
51-60
61-70
years
AGE
Male right
Male left
Female right
Female left

Fig. 6

Fig. 6. The components of motor performance that depended on age, gender and preferred handedness. In Fig. 6, some single test values are combined as follows: Reaction time of upper extremity (right) = [simple reaction time (right) + one-choice reaction time (right) + two-choice reaction time (right) + four-choice reaction time (right)]/4. Reaction time of upper extremity (left) = [simple reaction time (left) + one-choice reaction time (left) + two-choice reaction time (left) + four-choice reaction time (left)]/4 . Speed of movement of upper extremity (right) = [one-choice speed of movement (right) + two-choice speed of movement (right) + four-choice speed of movement (right)]/3. Speed of movement of upper extremity (left) = [one-choice speed of movement (left) + two-choice speed of movement (left) + four-choice speed of movement (left)]/3. Reaction time of lower extremity (right) = [simple reaction time (right) + one-choice reaction time (right) + two-choice reaction time (right)]/3. Reaction time of lower extremity (left) = [simple reaction time (left) + one-choice reaction time (left) + two-choice reaction time (left)]/3. Speed of movement of lower extremity (right) = [one-choice speed of movement (right) + two-choice speed of movement (right)]/2. Speed of movement of lower extremity (left) = [one-choice speed of movement (left) + two-choice speed of movement (left)]/2.

Coordination (accuracy/speed of movement). The coordination values of hands were lower in the older age groups in both genders. The correlation coefficient between age (all subjects) and right hand coordination was –0.51 (p<.001), and the estimated average decrease 0.05 bits/sec/year. The corresponding values for the left hand were –0.52 (p<.001) and 0.05 bits/sec/year. In the coordination test the values were higher for the right side (p<.001, and the difference was 6 % for all subjects). There were no significant differences between men and women, but the mean value for the group of women was usually higher. Men had a higher speed of movement on the task, but women avoided errors better.

The coordination of feet was measured in two different ways: in the lateral direction (with the subject sitting) and in the anterior-posterior direction (with the subject standing). The coordination values of feet were lower in the older age groups in both genders in both tests. The correlation coefficient between age (all subjects) and right foot coordination in the lateral direction was –0.41 (p<.001), and the estimated average decrease 0.03 bits/sec/year. The corresponding values for the left foot were –0.29 (p<.001) and 0.02 bits/sec/year. In the anterior-posterior direction the values were – 0.30 (p<.001) and 0.02 bits /sec/year for both feet. In coordination, the values were higher for the right side in both tests, while the difference in the lateral direction was 5 % (p<.001) and that in the anterior-posterior direction 3 % (p<.05). No significant difference was seen in the values between the lateral and anterior-posterior directions. This was also true of men and women. Men had a higher mean speed of movement than women, but women made fewer errors (target misses).

5.3. Effect of strapping on the motor performance of the ankle and wrist joints (Study II)

Strapping of wrist joint. Strapping of the right wrist joint prolonged the simple reaction time by 9 % (p<.01) (performed with a dorsiflexion movement of the wrist joint) and the choice reaction time by 9 % (p<.05), and decreased the wrist tapping speed by 21 % (p<.01). Speed of movement and hand coordination showed no statistically significant changes.

Wrist strength (average peak torque) decreased in flexion 180 deg/sec by 14 % (p<.05) and in ulnar deviation 180 deg/sec by 8 % (p<.05). Average peak torque at 60 deg/sec in these directions showed no statistically significant changes. There were no statistically significant changes in extension and radial deviation at either speed. Detailed results of the hand tests are presented in Table 4.

Table 4. Effect of strapping on the motor performance and the muscle strength of the wrist joint (mean (SD)).

Measurement	Unit	Unstrapped	Strapped	Change (%)	p
Simple reaction time	(msec)	189 (37)	206 (32)	+ 9	<.01
Choice reaction time	(msec)	267 (41)	290 (50)	+ 9	<.05
Speed of movement	(cm/sec)	107 (38)	102 (38)	–5	ns
Wrist tapping	(taps/sec)	5.9 (1.2)	4.7 (1.1)	–21	<.01
Coordination	(bits/sec)	10.1 (1.1)	9.8 (1.1)	–3	ns
Wrist flexion 60 deg/sec	(Nm)	12.9 (4.1)	11.4 (3.4)	–12	ns
Wrist flexion 180 deg/sec	(Nm)	11.0 (3.4)	9.5 (2.1)	-14	<.05
Wrist extension 60 deg/sec	(Nm)	5.9 (2.2)	5.6 (1.7)	–5	ns
Wrist extension 180 deg/sec	(Nm)	4.8 (2.1)	4.6 (1.4)	–4	ns
Ulnar deviation 60 deg/sec	(Nm)	12.2 (3.2)	11.4 (2.5)	–7	ns
Ulnar deviation 180 deg/sec	(Nm)	11.2 (2.4)	10.3 (1.5)	–8	<.05
Radial deviation 60 deg/sec	(Nm)	9.1 (2.7)	8.8 (2.4)	–3	ns
Radial deviation 180 deg/sec	(Nm)	8.5 (2.2)	8.3 (1.9)	–2	ns

ns = not significant (p>.05).

Strapping of ankle joint. Strapping of the right ankle joint prolonged the simple reaction time by 12 % (p<.01) and the choice reaction time by 9 % (p<.05), and decreased the foot tapping speed by 14 % (p<.01). Speed of movement and foot coordination showed no statistically significant changes.

Ankle strength decreased in plantar flexion 60 deg/sec by 22 % (p<.01) and 180 deg/sec by 14 % (p<.01), and in inversion 60 deg/sec by 28 % (p<.05) and 180 deg/sec by 15 % (p<.05). Dorsiflexion and eversion showed no statistically significant changes. Detailed results of the lower extremity tests are presented in Table 5.

Table 5. Effect of strapping on the motor performance and the muscle strength of the ankle joint (mean (SD)).

Measurement	Unit	Unstrapped	Strapped	Change (%)	p
Simple reaction time	(msec)	229 (41)	257 (40)	+ 12	<.01
Choice reaction time	(msec)	340 (69)	371 (63)	+ 9	<.05
Speed of movement	(cm/sec)	144 (24)	134 (23)	–5	ns
Ankle tapping	(taps/sec)	5.0 (0.6)	4.3 (0.8)	–14	<.01
Coordination	(bits/sec)	7.0 (0.6)	6.4 (1.0)	–8	Ns
Plantar flexion 60 deg/sec	(Nm)	82.2 (20.8)	64.1 (21.6)	–22	<.01
Plantar flexion 180 deg/sec	(Nm)	53.6 (10.0)	46.0 (11.4)	–14	<.01
Dorsiflexion 60 deg/sec	(Nm)	18.8 (3.9)	19.0 (4.2)	+1	ns
Dorsiflexion 180 deg/sec	(Nm)	15.1 (2.9)	16.4 (2.2)	+9	ns
Inversion 60 deg/sec	(Nm)	23.3 (6.6)	16.9 (5.9)	–28	<.05
Inversion 180 deg/sec	(Nm)	18.9 (4.1)	16.1 (4.3)	–15	<.05
Eversion 60 deg/sec	(Nm)	13.0 (4.7)	10.4 (2.8)	–20	ns
Eversion 180 deg/sec	(Nm)	10.8 (4.5)	8.9 (2.2)	–18	ns

ns = not significant (p>.05).

5.4. Effect of hot and cold pack treatments on the motor performance of the hand (Study III)

Reproducibility test (1-3 baseline measurements) indicated that there were no statistically significant changes in the results of the right hand between the two consecutive measurement sessions. In the choice reaction time test, however, the results improved between the first and third measurement sessions in a statistically significant way (p<.05).

Hot pack treatment. The ANOVA results of hot pack treatment indicated that there were statistically significant changes in the simple reaction time (p<.05) and tapping speed tests (p<.01), but no statistically significant changes in the choice reaction time (p=.24), speed of movement (p=.87) and coordination tests (p=.36).

More detailed *post hoc* analysis with Student's paired t-test showed that the hot pack treatment prolonged the simple reaction time measured immediately after the treatment (p<.05) and increased tapping speed, which change could still be observed thirty minutes after the treatment (p<.05). Detailed results of the tests are presented in Table 6.

Cold pack treatment. The ANOVA results of cold pack treatment showed that there were statistically significant changes in the simple reaction time (p<.05) and tapping speed tests (p<.001), but no statistically significant changes in the choice reaction time (p=.39), speed of movement (p=.08) and coordination tests (p=.41). *Post hoc* analysis indicated that the simple reaction time was prolonged in the measurements performed immediately (p<.05) and fifteen minutes after the treatment (p<.05). Although the ANOVA results did not indicate statistically significant changes in the speed of movement, an *a priori* analysis with Student's paired t-test showed that the cold pack treatment decreased the speed immediately after the treatment (p<.05). This change was normalised fifteen minutes after the treatment. The cold pack treatment clearly decreased tapping speed, and this change was not normalised by thirty minutes after the treatment (p<.001). Detailed results of the tests are presented in Table 6.

Table 6. Effect of hot and cold pack treatments on the motor performance of the hand (mean (SD)).

Measurement	X_1	X_2	X_3	X_{1-3}	Treatment	0 min	15 min	30 min
Simple reaction time (msec)	176 (22)	173 (21)	175 (17)	174 (19)	Hot pack	183 (17)*	180 (16)	180 (16)
					Cold pack	182 (21)*	183 (19)*	180 (17)
Choice reaction time (msec)	269 (38)	261 (38)	254 (36)	261 (35)	Hot pack	252 (27)	252 (35)	257 (30)
					Cold pack	251 (30)	253 (37)	253 (31)
Speed of movement (cm/sec)	101 (19)	97 (20)	98 (21)	99 (19)	Hot pack	100 (26)	100 (27)	102 (29)
					Cold pack	92 (21)*	96 (23)	98 (22)
Tapping speed (taps/sec)	5.8 (0.6)	5.8 (0.6)	5.8 (0.6)	5.8 (0.6)	Hot pack	5.9 (0.5)*	6.0 (0.6)*	5.9 (0.5)*
					Cold pack	4.8 (0.5)**	5.2 (0.6)**	5.4 (0.6)**
Coordination (bits/sec)	10.79 (1.37)	10.73 (1.32)	11.09 (1.37)	10.87 (1.30)	Hot pack	11.08 (1.40)	11.16 (1.38)	11.27 (1.53)
					Cold pack	11.17 (1.31)	11.19 (1.38)	11.16 (1.51)

X_1= 1. Baseline measurement
X_2= 2. Baseline measurement
X_3= 3. Baseline measurement
X_{1-3}= Mean of baseline measurements
0 min= immediately after the treatment
15 min = 15 minutes after the treatment
30 min = 30 minutes after the treatment
Paired t-test compared to X_{1-3}
* = p<.05
** = p<.001

5.5. Effect of a one-hour strength training session on the motor performance of the hand (Study IV)

The results of the muscle strength tests did not indicate statistically significant differences between the groups A and B, and the groups were equal in this respect. The results of the 3 baseline measurements indicated that there were no statistically significant changes in the results on the right hand motor performance during these consecutive measurement sessions (=days) in either group. The results on the mean values showed that there were no statistically significant differences between the groups A and B, and the groups were also equal in this respect.

Isometric wrist flexion and extension strength were lower after the training session in both groups. In group A, strength training of the hand decreased wrist flexion strength by 18 % (p<.001), and wrist extension strength decreased by 18 % (p<.001). In group B, flexion strength decreased by 19 % (p<.001), and extension strength decreased by 17 % (p<.001). Detailed results of the muscle strength tests are presented in Table 7.

Table 7. Results of isometric muscle strength tests before and after the muscle strength training period.

	Group A		p	Group B		p
	Before Mean (SD)	After Mean (SD)		Before Mean (SD)	After Mean (SD)	
Wrist extension (Nm)	8.00 (1.61)	6.58 (1.46)	<.001	8.58 (1.38)	7.11 (1.20)	<.001
Wrist flexion (Nm)	11.58 (1.92)	9.44 (1.38)	<.001	12.40 (2.14)	10.04 (1.61)	<.001

The results of the EMG tests showed that both MEMG and IEMG decreased in the measured muscles during maximum isometric contraction. In group A, the mean amplitude of the flexor group decreased by 18 % (p<.001) and that of the extensor group by 15 % (p<.001). The IEMG of the flexor group decreased by 18 % (p<.001) and that of the extensor group by 14 % (p<.001).

In group B, the MEMG of the flexion group decreased by 26 % (p<.001) and that of the extension group by 22 % (p<.001). The IEMG of the flexor group decreased by 26 % (p<.001) and that of the extensor group by 21 % (p<.001). Detailed results of the EMG tests are presented in Table 8.

Table 8. Results of EMG tests before and after the strength training period.

	Group A		p	Group B		p
	Before (SD Mean)	After Mean (SD)		Before Mean (SD)	After Mean (SD)	
Flexors of the wrist (MEMG)(μV)	299 (100)	245 (92)	<.001	245 (78)	182 (60)	<.001
Flexors of the wrist (IEMG)(μVsec)	597 (200)	489 (184)	<.001	490 (159)	364 (120)	<.001
Extensors of the wrist (MEMG)(μV)	292 (60)	249 (44)	<.001	278 (126)	218 (87)	<.001
Extensors of the wrist (IEMG)(μVsec)	579 (124)	499 (88)	<.001	552 (243)	435 (172)	<.001

The results of the motor performance tests showed that there were no statistically significant changes in the results between the mean values of the three baseline measurements and the values obtained after the training session. However, the simple reaction time tended to become longer (p=.07 for group A and .06 for group B). Detailed results of the motor control tests are presented in Table 9.

Table 9. Motor performance of the hand before and after the muscle strength training period (mean, SD).

Measurement	X_1	X_2	X_3	X_4	X_5	p
Simple reaction time (msec)						
Group A	170 (24)	167 (22)	167 (19)	177 (20)	169 (17)	.07
Group B	173 (16)	172 (17)	172 (22)	171 (20)	187 (22)	.06
Choice reaction time (msec)						
Group A	256 (32)	249 (29)	252 (30)	249 (31)	245 (31)	.44
Group B	261 (47)	256 (37)	256 (38)	256 (34)	252 (30)	.91
Speed of movement (cm/sec)						
Group A	101 (22)	99 (22)	103 (26)	105 (29)	103 (25)	.42
Group B	102 (17)	98 (16)	100 (20)	98 (22)	96 (20)	.23
Tapping speed (taps/sec)						
Group A	5.93 (0.61)	5.91 (0.60)	5.93 (0.59)	6.03 (0.49)	5.88 (0.45)	.27
Group B	5.70 (0.56)	5.68 (0.61)	5.69 (0.57)	5.71 (0.54)	5.74 (0.54)	.62
Coordination (bits/sec)						
Group A	10.47(1.07)	10.47(0.91)	10.36(0.90)	10.34(1.28)	10.49(0.97)	.69
Group B	10.50 (0.78)	10.58 (0.89)	10.52 (0.87)	10.53 (1.07)	10.52 (1.24)	.95

X_1 = 1. Baseline measurement
X_2 = 2. Baseline measurement
X_3 = 3. Baseline measurement
X_4 = Group A: Measurement after training. Group B: 4. Baseline measurement.
X_5 = Group A: 4. Baseline measurement. Group B: Measurement after training.
Paired t-test compared between the mean of X_{1-3} and the measurement after training (Group A=X_4, Group B=X_5)

5.6. Effect of a ten-week strength training program on the motor performance of the hand (Study V)

There were no statistically significant changes in the subject characteristics between the beginning and the end of the 10-week strength training period. Reliability testing (1-3 baseline measurements) indicated that there were no statistically significant changes in the results of the right upper extremity between the two consecutive measurement sessions (=days), while the results of the choice reaction time test decreased between the first and the third measurement session in a statistically significant way (p<.05).

The results of the muscle strength tests indicated that all measured isometric muscle strengths (flexion/extension of the right wrist joint and flexion/extension of the right elbow joint) had increased during the training period. Strength training of the hand increased wrist joint flexion strength by 21 %, wrist joint extension strength by 15 %, elbow joint flexion strength by 16 % and elbow joint extension strength by 7 %. Detailed results of the muscle strength tests are presented in Table 10.

Table 10. Results of isometric muscle strength tests before and after a ten-week muscle strength training period.

	Before training Mean (SD)	After training Mean (SD)	p
Wrist extension (Nm)	6.79 (1.42)	7.83 (1.28)	<.001
Wrist flexion (Nm)	12.69 (2.72)	15.33 (4.16)	<.01
Elbow extension (Nm)	33.12 (4.95)	35.44 (4.83)	<.05
Elbow flexion (Nm)	31.63 (5.29)	36.77 (4.85)	<.001

The results of the EMG tests showed that both IEMG and MEMG increased in the measured muscles during maximum isometric contraction. The mean amplitude of m. biceps brachii increased by 19 % and that of m. triceps brachii by 29 %. The IEMG of m. biceps brachii increased by 19 % and that of m. triceps brachii by 30 %. Detailed results of the EMG tests are presented in Table 11.

Table 11. Results of EMG tests before and after a ten-week muscle strength training period.

	Before training Mean (SD)	After training Mean (SD)	p
Biceps brachii (MEMG)(μV)	446 (194)	530 (167)	<.05
Biceps brachii (IEMG)(μVsec)	889 (393)	1061 (334)	<.05
Triceps brachii (MEMG)(μV)	173 (67)	223 (86)	<.01
Triceps brachii (IEMG)(μVsec)	346 (135)	447 (171)	<.01

The results of the motor control tests indicated that there were no statistically significant changes in the results between the beginning and the end of the training period in speed of movement (p=.31). Choice reaction time improved by 6 % (p<.01), tapping speed increased by 3 % (p<.01), and coordination increased by 5 % (p<.05). Detailed results of the motor control tests are presented in Table 12.

Table 12. Motor performance of the upper extremity before and after a ten-week muscle strength training period (mean, SD).

Measurement	X_1	X_2	X_3	Before training X_{1-3}	After training X_{4-6}	p
Choice reaction time (msec)	271 (43)	267 (39)	255 (36)	264 (37)	248 (39)	<.01
Speed of movement (cm/sec)	101 (21)	94 (21)	96 (23)	97 (21)	102 (23)	ns
Tapping speed (taps/sec)	5.8 (0.7)	5.9 (0.7)	5.8 (0.7)	5.8 (0.6)	6.0 (0.6)	<.01
Coordination (bits/sec)	10.45(1.05)	10.46(1.08)	10.69(1.01)	10.54(0.99)	11.04(1.35)	<.05

X_1 = 1. Baseline measurement
X_2 = 2. Baseline measurement
X_3 = 3. Baseline measurement
X_{1-3} = Mean of three baseline measurements (before training period)
X_{4-6} = Mean of three baseline measurements (after training period)
Paired t-test compared between X_{1-3} and X_{4-6}
ns = not significant ($p>.05$).

6. Discussion

The purpose of the present study was to gain further knowledge about the effects of four commonly used physical therapy methods, i.e. strapping, hot pack treatment, cold pack treatment and muscle strength training, on motor performance. The measured motor performance parameters were reaction times, speed of movement, tapping speed and accuracy/speed of movement, and the measurements were done on healthy persons (studies II-V). In addition, the associations between age, gender and preferred handedness and the motor performance of the hand and the foot in a healthy population were studied, and the reliability of the measurements was confirmed (study I).

6.1. Subjects

In study I, healthy subjects from various socioeconomic and educational categories were randomly selected from the population of Oulu. This helps somewhat to generalize the results, and the composition of the sample can be presumed to represent a normal population of this area. However, there were some factors which may bias the results. The subjects were invited by mail for the measurements, and this may have caused some selection. 343 letters had to be sent randomly to recruit 200 healthy volunteers of the targeted age and gender, and the response rate (58.3 %) was quite low. However, the response rate varied a lot between the age groups, and the main reason for the low mean response rate was the age group of 21-30 yrs. In the older age groups the response rate was almost 100 %, while about 120 letters had to be sent before 40 volunteers aged 21-30 yrs were found, which means that the subjects in this age group were obviously a selected sample. This impairs the generalisation of the results in this age group. The precise reason for the low response rate in this age group is not known, but studying or working in other cities, shift work and lack of time could be potential explanations.

Generalisation of the results is limited to the age range of 21-70 yrs. The sample represents the age range where the impairment of motor performance (e.g. reaction time) is quite even and linear (Wilkinson & Allison 1989), while some previous studies have shown that the results could be quite different among teens and under the age of ten (Wilkinson & Allison 1989).

Preferred handedness was self-reported by the subjects, and there were 22 subjects who reported themselves to be mixed-handed (in these cases the criterion for the preferred hand was writing). A previous study suggested that as many as about 33 % of the population is mixed-handed (Annett 1972). These subjects might cause some biases concerning the left/right side differences in the results. However, these subjects were divided evenly between the ten age groups, and their share was quite small in each group.

The total number of subjects was quite large, but because the sample was divided by age and gender, each age group consisted of only 17-20 test subjects. Therefore, small differences in the mean values between the age groups (e.g. the younger groups) did not appear clearly in the small sample. In the older age groups, however, the decrease in performance was clear and significant despite the small sample size.

The subjects in the studies II-V were mainly healthy female (two men in study II) staff members at the Oulu University Hospital, which restricts the generalisation of the results. The results are limited to females. The reasons why only females were studied were mainly practical. Because the selection criteria for the studies were quite loose (the subjects were to have no diseases which may influence motor function or the ability to perform the tests), it was easiest to select the subjects from the staff, and the staff of a hospital are mainly female. This arrangement also helped the timing and increased the subjects' adherence to the training programs. Another reason for this choice was the need to keep the samples homogeneous, because there are some sex differences in the test results of these studies (e.g. muscle strength). In addition, the participants in the previous reliability study (study I) were also female, and the samples were hence comparable with regard to age and gender to the sample in which reliability had been established.

The mean age and the age range were about same in all studies, being characteristic of the working female population. But because a large proportion of the subjects were physiotherapists, who might engage in more physical activities and have a better physical condition than females in general, generalisation of the results to the whole working female population might be perilous.

The subjects in many original studies were partly the same, which may mean that there was some learning effect during the studies. However, the intervals between the studies were quite long, and the mean baseline values in the studies were approximately the same. On the basis of this, it seems that there was no learning effect between the studies.

The number of subjects in the studies was quite small, and the results might have been more conclusive if larger samples and control groups had been used. The main reason for these deficiencies was the capacity problem. To increase the trust of the results, we performed three tests before and three after the training.

After all, the studies were done with healthy volunteers, and the results might have been different in a population with musculoskeletal disorders. With them, for example, the changes in pain after the treatments and strength training may alter the motor performance differently from healthy subjects. Further research is necessary to clarify this problem.

6.2. Methods

6.2.1. Muscle strength measurements

All muscle strength measurements were performed with the Lido Active Multi-joint System, which has been demonstrated to be both valid and reliable strength measurement device (Patterson & Spivey 1992). The same therapist, with an experience of about 3000 measurement sessions, measured all subjects. A special reliability test was made for wrist strength measurement, because it was the most frequently measured joint in our studies. The test-retest (intratester) reliability of the isometric wrist flexion and extension muscle strength measurements was acceptable and quite high (ICC was 0.97 for flexion and 0.91 for extension). A previous study demonstrated the isokinetic Lido Active Multi-joint System to be a reliable system for measuring the ankle dorsal and plantar flexors in a healthy population (Andersen 1996). The percentage differences were 5.6 % and 8.0 % for dorsal flexion and 3.8 % and 8.7 % for plantar flexion at 60 ^{o}/sec and 180 ^{o}/sec, respectively (Andersen 1996). The author did not find any studies dealing with the reliability of the Lido system in elbow flexion and extension tests.

Average peak torque was calculated from three efforts by the software, and it was reported instead of the best of three efforts, because we tried to increase the trust of the results with this method, and the EMG values recorded during the muscle strength tests were also calculated from these three efforts.

The subjects performed altogether 120 tests (= 30 subjects x 2 muscles x 2 tests) in study IV and 128 tests (= 16 subjects x 4 muscles x 2 tests) in study V. There were no cases where the subject would have demonstrated increased torque on each of trial, but twice (2 %) in study IV and 12 times (9 %) in study V the maximum effort was achieved during the last trial. Based on this result, the author cannot be completely sure that ”maximal” effort was fulfilled in these cases, but since the percentages of such cases were quite small, it seems that ”maximal” effort was achieved quite well by the subjects. In future studies, this uncertainty could be avoided by allowing additional efforts or by using electrical stimulation when the muscles are activated during effort.

6.2.2. Electromyographic measurements

Surface EMG measures the mass action of muscles, and some cross-talk may occur, especially when many narrow muscles are tightly gathered, and during dynamic muscle work. In addition, the reliability of EMG measurements decreases when the electrodes are disconnected between two measurements. Despite these limitations of surface EMG measurement, acceptable reliability results have been shown. Komi & Buskirk (1970) studied elbow flexors with both surface and inserted wire electrodes. They reported acceptable test-retest reliability coefficients for both short-term (10-minute interval) (mean r=0.88) and long-term (three days) measurements (r=0.69) performed with surface electrodes. Our own reliability test was made for the wrist flexor and extensor muscle groups (the interval between the measurements was 24 hours, and the electrodes were disconnected between the two measurements), and the test-retest (intratester) reliability was acceptable (ICC was 0.79 for the flexor muscle group and 0.84 for the extensor muscle group).

In study V, the interval between the two measurement sessions was 10 weeks, and there was obviously some variation in the placement of electrodes between the baseline measurements and the tests performed after the training period. This might mean that the numbers of motor units between the electrodes were different in the two sets of measurements. In addition, we only measured EMG values from m. biceps and triceps brachii. On the forearm, where many narrow muscles are tightly gathered the measurements would have required needle electrodes, but we did not have the necessary equipment. However, it seems that the strength training period had a true increasing effect on motor unit activation, because the changes in EMG values were so systematic.

In study IV, however, the EMG measurements were recorded from the flexor and extensor muscle groups of the wrist, because there was no variation in the placement of the electrodes between the measurements (the electrodes were kept on the skin during the training session and the places were the same before and after the training session), and the numbers of motor units between the electrodes were mainly the same in the two sets of measurements. However, it was quite impossible to define exactly the muscles under the electrodes, and the terms ”flexor and extensor muscle groups” of the wrist joint were used in the study. The author believes that the EMG values were comparable, although the particular muscles were not identified exactly, because there were no systematic changes in the reliability study, although the electrodes were disconnected between the measurements.

6.2.3. Motor performance measurements

The same person, with an experience of about 4000 measurement sessions, measured all subjects, and the HPM manual was used as a reference for all tests and the number of trials and calculation methods of results were determined by the Human Performance Measurement software. The test-retest (intratester) reliability of the measurements was established in study I. The moderate reliability of some tests may be explained by the low variability between the subjects and the fairly large sample size. The intraclass correlation coefficient is a ratio resulting from a comparison of the adjusted inter-subject variability combined with appropriate error terms (Shrout & Fleiss, 1979). Because the test sample for the reliability test was quite homogeneous (female staff members (physiotherapists) with an age range of 23-53 years), the results were quite similar and the variability between the subjects was quite small.

The learning effect may bias the results of motor performance tests of this kind. However, no such effect was observed in the reliability study. In addition, three baseline measurements were done in the studies III-V, and they indicated that there were no statistically significant changes in any results between two consecutive measurement sessions. But twice in the choice reaction time test (studies III and V) the results decreased between the first and the third measurement sessions in a statistically significant way ($p<.05$).

On the basis of these results, it seems that learning was only slight, and that this effect did not bias the results or the conclusions of the study.

Regarding age and gender in the intervention studies II-V, the samples were similar to the sample in which reliability had been established earlier (study I), and the sample of the reliability study was quite appropriate for assessing the reliability of other studies in this respect. On the other hand, the size of the sample in the reliability study was larger, which may have affected the results, and separate reliability tests (=1-3 baseline measurements) were therefore done in the studies III-V as well.

One problem was the low number of trials used in the tests, which might be insufficient to obtain valid measures and might prevent define conclusions in these tests. In the intervention studies II-V the situation was similar in each measurement session, and this did not bias the results, but in the cross-sectional study I this may have changed the absolute values. However, the number of trials was determined by the Human Performance Measurement software, and the author did not have any opportunity to change these numbers.

In addition, the measurement time in the tapping tests was quite long (10 sec) in view of maximal tapping speed, and fatigue during the tests may have decreased the average tapping speed over the observation period.

6.2.4. Limitations of the study designs

In study I, the subjects were randomly selected from among the population of Oulu (randomisation was made by the Census Bureau), and the composition of the sample can be presumed to represent the normal population of this area. The response rate (58.3 %) was quite low, but varied a lot between the age groups, and the main reason for the low mean response rate was the age group of 21-30 years, which means that the selection of subjects was obviously emphasized in this age group, which impairs the generalisation of the results in this age group. In the studies II-V, the subjects were not randomly selected, and they were voluntary staff members who had been recruited by asking. This naturally restricts notable the generalisation of the results to a larger population. In addition, the results are mainly limited to females aged 20-50 years. In study IV, where two groups were studied, equality of the groups is essential. In this study, the participants were randomly divided into two groups, and the groups were equal in view of the measured aspects.

The lack of a control group is obvious in the studies II, III and V, but the division of the small number of subjects in these studies into test and control groups would have made the groups even smaller. In addition, we wanted to perform several baseline measurements because there was some “rush” in the results between the baseline measurements, which consumed the limited capacity. To increase the trust of the results, we performed three tests before and three tests after the interventions (studies III and V).

The subjects were partly the same in many of the original studies, which may mean that there was somelearning effect during the studies. However, the intervals between the studies were quite long, and the mean baseline values in the studies were at quite the same level. This seems to indicate that there was no learning effect between the studies.

In the studies II, III and V, all subjects performed the tests in the same order, and the authors cannot totally rule out the possibility that a learning effect may have affected the results. The possibility of this effect is especially emphasised in study II, where only one measurement was made before and one after the intervention. In future, this effect can be eliminated by conducting the tests in a random order. However, the reliability study of the measurements did not indicate any learning effect. The author is cautious about making definite conclusions concerning the results of the choice reaction time test, because the results improved twice (studies III and V) between the first and the third baseline measurement sessions in a statistically significant way. This finding limits the reliability of the choice reaction time results.

After all, the studies were done with healthy volunteers. This largely prevents any generalisation of the results to different patient groups, and the results could have been different in a population with musculoskeletal disorders. In such a population, for example, the changes in pain after treatments and strength training may alter the motor performance in different ways compared to healthy subjects. Further studies are necessary to clarify these problems.

6.3. Results

6.3.1. Associations between age, gender and preferred handedness and the motor performance of the hands and feet

Although the results were not always consistent, they indicate that the motor performance of the hands and feet varied by age, gender and preferred handedness.

Age: In general, motor performance was poorer in the older age groups in both genders. This finding was consistent with the previous studies; Wilkinson & Allison (1989) noticed this trend in reaction times, Houx & Jolles (1993) in speed of movement, Shimoyama *et al.* (1990) in tapping speed and Welford *et al.* (1969) in accuracy/speed of movement. The correlation coefficients (r) between age and the tests were 0.10-0.52 (the mean for all tests was 0.33), depending on the test and the level of difficulty of the test. This means that age explains (r^2) about 10 % (range 1-27 %) of the values, which percentage is quite low.Simonen *et al.* (1998) who studied 61 pairs of monozygotic male twins found that familial aggregation (genetic and shared environmental influences) was the greatest single determinant and explained an average of 47 % of decision times, 31 % of movement times, and 37 % of response times. The differences were small between 21 and 50 years, but increased after 50 years for both genders. In earlier studies, Houx & Jolles (1993) reported a similar trend in reaction times for a normal population, but Wilkinson & Allison (1989) found that average reaction times decreased more evenly than in this study between 20 and 69 years of age. In addition, the results suggest that the effect of age is especially obvious in difficult tasks (e.g. simple vs. four-choice reaction time tasks), and age explains more of the decline of the results in complex tasks, where the role of central processing is emphasized.

However, this was a cross-sectional study, where the results of subjects of different ages are compared to each other, and the effects of age on the motor performance were estimations based on the results of different subjects. To study and clarify the real effect of aging on motor performance, one would need a longitudinal study design where the same subjects would be under observation during several years.

Gender: Men had faster average speed of movement and tapping speed than women in each age group. These results are consistent with the previous reports. Houx and Jolles (1993) showed that women had 33.9 % slower speed of movement than men. Landauer (1981) also reported that women had slower movement times. One possible reason for this phenomenon, as suggested by the observations made in the present study is that women appear to be more cautious and to use less aggressive movements while responding, and thus their movements are slower. Dodrill (1979) suggests that the gender difference in the finger tapping rate may be due to gender differences in body and hand size rather than to any neuropsychological mechanism.

There were no significant differences between men and women in the coordination test, but women had higher average values than men for both hands and feet. The main reason is that the women made fewer target errors than the men during tests, a finding consistent with the previous studies (York & Biederman 1990). One reason for this phenomenon may be that the manner of performance in this test differs significantly between men and women. It seems that women try to avoid errors more than men, while men pay less attention to errors and try to perform with a higher speed of movement.

Preferred handedness: As expected, the values were usually higher on the right side than on the left side for both hands and feet. However, the hand reaction times were faster on the left side. One explanation for this finding may be the amount of practice before the trial, which is an important factor in a reaction time test (Rabbitt & Banerji 1989). In this study, the subjects practised three times, which was obviously too little. The hand reaction time tests came the first in the test battery, and these tests were performed initially with the right hand. Assuming that the subjects learned to perform the test during the tests of the right hand, this learning may have transferred to the tests of the left hand. In the tests of foot reaction time, which were performed later in the test battery, there was no such learning effect. In future studies, this error could be avoided by changing randomly the side of beginning.

In the speed of movement tests of the hand, the right side was significantly faster in the two- and four-choice tests, and the right foot was faster in the two-choice test. The effect of preferred handedness on the one-choice test was not statistically significant in either case. In other words, the difference was not significant when the subject knew beforehand the target plate to which the hand or foot was to be moved. When this target plate varied randomly, the preferred side was faster. On the basis of these results, it seems that the effect of the preferred side on speed of movement became significant in more difficult tasks. In addition, in line with this observation, an increase in the number of choices decreased the speed of movement significantly on the left side, but not on the right side.

An increase in the number of choices prolonged reaction times, and the values behaved in congruence with Hick’s law (Hick 1952). The main explanation for this phenomenon is possibly that the subjects doing in choice reaction time tests do not know which light will activate, and they must therefore first process the visual information before responding, which processing takes time. On the basis of the results of two-choice and four-choice tests, it seems that this time does not differ any more significantly between these tasks.

6.3.2. Effect of strapping on the motor performance of the ankle and wrist joints

Strapping may clinically play a significant role in the prevention of joint injuries, especially in the ankle, and prophylactic strapping is usually made on the joint(s) which will be exposed to the hardest strain and will play a major or significant role in the motion. However, based on the results of this and the previous studies (Mayhew 1972, Juvenal 1972, Burks *et al*. 1991), it is important for therapists to realize that strapping of these joints may also have restrictive effects on the motor performance of the joints.

Obviously, the main reason for this is that strapping mechanically prevents the subjects from performing fast movements as quickly as without strapping, and some part of the muscle strength is consumed to break the resistance of the tape.

It is noteworthy that the changes between the strapped and unstrapped values were greatest in the tests which consisted of movements of the strapped joint only (e.g. reaction time and tapping speed). In tests which consisted of movements of several joints together with the strapped joint (e.g. speed of movement and coordination tests), the changes were not so great and did not reach the level of statistical significance. Based on these results, it is hypothesised that the restrictive effect of the strapping of one joint only applies to the strapped joint area, and the subject can compensate for the performance of the strapped joint with the other joints. This could mean that the strapping of one joint does not reduce the total motor performance of the whole extremity very much, and the proximal parts of extremity may compensate for the impaired performance of distal parts of the extremity. This finding can partly explain the contradictory results between this study and some previous studies, e.g. Verbrugge (1996). In these studies, which address with the effect of one strapped joint on performance, the measurements and tests have been made with whole body movements (e.g. jumping, running), where the changes are small, and little attention has been given to the movements of the single strapped joint.

It seems that the extent of restrictive effect of strapping on muscle strength varies between joints, and the average peak torque decreased proportionally more in the ankle joint than in the wrist joint. One potential explanation of this result may be the larger area of strapping and the greater amount of tape applied to the ankle joint than in the wrist joint, and the larger amount of tape might have a more restrictive effect. Another explanation could be the biomechanical differences between these joints.

Although the null hypothesis failed in some cases in this study, it should be noticed that studies evaluating the effectiveness of adhesive strapping on ankle joint support have proved that after a short period of exercise (in most cases 10 minutes), strapping loses its restrictive effect on the range of motion, and the support provided by the adhesive tape is hence substantially reduced (Fumich *et al*. 1981, Andreasson & Edberg 1983, Myburgh *et al*. 1984). Based on this, it is possible that the restrictive effects of strapping also decrease during warm up, exercise or competition, and the effects of strapping can be less restrictive after a short exercise than the results of this study showed. Further research is necessary to elucidate this problem. In addition, the present measurements were performed in laboratory conditions with stabilization and movements mostly of one joint. In real life-tasks and sports activities, however, the movements are performed with several joints, and the subject can compensate for the inadequate performance of the strapped joint with the other joints.

A previous study has shown that the ability to maintain postural equilibrium was reduced among soccer players with functional ankle joint instability (Tropp *et al*. 1985). The results could be different in a sample with previous injuries in these joints and the results of this study hence cannot be generalized. In an injured population, strapping could result in a better performance of the extremities and prevent new injuries.

Despite these limitations, it seems that strapping has some negative effects on the motor performance of a single healthy joint. Therefore, in situations where a subject without previous joint injuries needs maximal performance (as in sports events), it is important to consider carefully and critically whether prophylactic strapping is really necessary and indispensable.

6.3.3. Effect of hot and cold pack treatments on the motor performance of the hand

Based on the results, hot and cold pack treatments of the hand have effects on the performance of the hand expressed as reaction time, speed of movement and tapping speed. However, these changes were quite small after hot pack treatment, whereas cold pack treatment decreased almost all measured aspects.

The tests of reproducibility (1-3 baseline measurements) indicated that the results of the choice reaction time test improved between the first and third measurement sessions in a statistically significant way. The precise reason for this finding is unknown. One possible reason is coincidence (quite improbable), and the most likely explanation is the learning effect. However, there were no statistically significant changes in choice reaction time after the interventions, and the effect of this finding on the overall results of the study is quite slight.

Hot pack treatment increased index finger tapping speed somewhat. The result is partly surprising, because the finger tapping test is a fine motor test with fast back-and-forth movement, and the central level plays an important role in this kind of movement, but it is quite improbable that hot pack treatment could cause changes in the motor control of the central level. Obviously, the potential changes occur mainly at the peripheral level, and the potential reasons for this could be that the treatment improves the extensibility of collagen tissues, decreases joint stiffness and increases blood flow in the treated area (Lehmann 1982, DeLisa & Gans 1993). Higher temperatures decrease the resistance of movements and increase the speed of movement. The conduction of nerve impulses is also faster at a higher body temperature (De Jesus *et al.* 1973, Halar *et al.* 1985).

On the other hand, an opposite effect was seen in the simple reaction time, which was prolonged after the treatment. One potential reason for this result may be the difference in the mental alertness of the subjects between the baseline measurements and the measurement immediately after the hot pack treatment. During the hot pack treatment, all subjects relaxed and some almost fell asleep, which decreased their mental alertness.

Cold pack treatment delayed simple reaction time and decreased speed of movement and tapping speed. Obviously, the main reason for these changes is the decrease of neuromuscular functions. Cold pack treatment decreases metabolic activity, decreases blood flow (Taber *et al.* 1992) slows down nerve conduction (Abramson *et al.* 1966), increases contraction and one-half relaxation time (Walker 1949) and decreases maximal muscle strength (Coppin *et al.* 1978, Cornwall 1994). Faulkner *et al.* (1990) suggested that cooling decreases the power produced by agonist muscles, and increases the power absorbed by antagonist muscles and affects their coordination. This effect could explain the distinct decrease of tapping speed after the treatment. This test is a good example of a fine motor test with fast back-and-forth flexion-extension movement, and such movements require good coordination between the antagonistic muscles. This effect may result in less effective acceleration of the hand at the beginning of the movement after the treatment, as may be seen in the speed of movement results, which were less good after the treatment.

The changes were greatest in the fine motor movements, which were performed with the index finger. One potential reason for this could be that the changes in temperature after the treatments were greatest in the fingers, and the effects of temperature changes were obviously also most distinct in this area.

There were no statistically significant changes after either treatment in the coordination tests, which were not performed only with the treated area of the hand, but with the whole upper extremity. Based on this result, it seems that the effects of the treatments were local, or that the subject can compensate for the impaired performance of the treated area with movements of the whole extremity.

Clinically, these treatments are often used before active or passive movement therapy as pretreatment in a physiotherapy program, and the usual goal of the treatments is to improve motor performance. Based on the results of this study, it seems that the changes attained in healthy persons with hot pack treatment are quite small, and some results are more statistically than clinically significant, but it is more difficult than usual for the subjects to perform fine motor tasks after cold pack treatment of the hand. This knowledge could be useful when designing and implementing movement therapy after cold or hot pack treatments. However, the therapists should bear in mind that the results could be quite different in a population with musculoskeletal disorders. For example, pain may primarily decrease motor performance in them, and the changes may be more significant after these treatments, while the reduction in fine motor hand function after cold pack treatment may be insignificant compared to the need to relieve pain. Further research is necessary to solve these problems.

6.3.4. Effect of a one-hour strength training session on the motor performance of the hand

The procedure used here was to fatigue acutely the muscles of the hands by a one-hour muscle strength training session and to study the effects of neuromuscular fatigue on the motor performance of the hand in five different motor tests.

The expected systematic and definite decrease in muscle strength and EMG activity was achieved. This finding is consistent with the previous studies. Häkkinen *et al.* (1988) showed that intensive maximal muscle strength training of the lower extremities decreased acutely both muscle strength and EMG activity in the vastus lateralis and vastus medialis muscles. In this study, the training session was of hypertrophic type, where the weights were relatively light and the number of repetitions quite high. In such training, fatigue obviously takes place both at the neural level (Bigland-Ritchie *et al.* 1978) and within the muscles (Tesch *et al.* 1986). However, it is assumed that fatigue within the muscles dominates in the hypertrophic type of training (Tesch *et al.* 1986).

The results of this study indicated that a one-hour strength training session of the hands had no effect on the hand motor performance tests. One should be cautious to make any definite conclusions based on the results of a simple reaction time test, because the changes in simple reaction times were quite obvious after the training session, but the results of the other tests were unambiguous.

The findings of the reaction time measurement are consistent with one previous study (Morris 1977), which did not show reaction time changes after muscle fatigue. Morris (1977) proposed some potential explanations for this finding. He suggested that the central nervous system may have a compensatory mechanism which prevents changes in reaction times when working with fatigued muscles. It is also assumed that there may exist different motor systems to control movements, of which one may control the velocity of movements, while another one may control force (Stein 1974). There are also some other studies suggesting that simple reaction time may not be a feasible criterion for measuring muscular fatigue (Kroll 1974, Hayes 1975). In addition, the role of the central nervous system (stimulus identification and response selection) is emphasized in reaction time tasks, and the meaning and manipulation of the peripheral neuromuscular components are not so essential.

There are some factors which should be noted because they may bias the results: 1) The intensity (=weights) of the training session could have been greater, and at a higher intensity of training the fatigue would have been greater. But as the expected systematic and distinct decrease in muscle strength and EMG activity was achieved, it seems that the intensity of training was sufficiently high. It is noteworthy that many of the subjects reported that the motor performance tests were more difficult to perform after the training session (except for the finger tapping test), because of the feeling of muscle fatigue and stiffness. 2) There was an interval of about 6 min. between the end of the training session and the beginning of the motor performance tests, because the muscle strength and EMG measurements were made immediately after the training. It is possible that the muscles recovered somewhat during this time. Obviously, however, this recovery was only slight, because the subjects performed with maximal effort in the muscle strength tests during this time and these tests also fatigued the muscles. 3) The study was done with healthy volunteers, and the results could have been different in a population with musculoskeletal disorders. With them, for example, pain after training may impair the motor performance. Further research is necessary to clarify this.

Based on the results, a one-hour strength training session of the hands appears to decrease acutely muscle strength and EMG activity measured immediately after the training. However, muscle fatigue had no effects on the motor performance functions of the hands expressed as simple reaction time (no definite conclusion), choice reaction time, speed of movement, tapping speed and coordination. It seems that the feeling of incompetence to perform quick and accurate movements with fatigued muscles is mainly a subjective feeling, as no statistically significant objective changes were observed. It may be that the real effect of muscle fatigue on the measured aspects of motor performance of upper extremity is less than generally expected.

Although we did not see changes in the measured aspects of motor performance, the previous studies have demonstrated that muscle fatigue may have some negative effects on human performance including joint position sense (Skinner *et al*. 1986, Carpenter *et al*. 1998), and muscle fatigue may play a role in decreasing total performance.

6.3.5. Effect of a ten-week strength training program on the motor performance of the hand

The aim of the study was to improve the neuromuscular functions of hands and to assess the effect of these changes on the motor performance of the hand in four different motor tests. The improvement of neuromuscular functions was achieved by a ten-week strength training period, which means that the changes at the neural level were obviously more quantitative (non-task-specific) than qualitative (task-specific) concerning measured motor performance tests.

The tests of reproducibility (1-3 baseline measurements) indicated that the results of the choice reaction time test improved between the first and third measurement sessions in a statistically significant way. The precise reason for this finding is unknown, but the most potential explanation is the learning effect. This finding means that although there were statistically significant changes in the choice reaction time after the intervention, one should be cautious about any definite conclusions concerning the results of choice reaction time tests.

The expected systematic and obvious increase in muscle strength and EMG activity was achieved. The increase in EMG activation during maximum isometric contraction together with the observation of minor changes in muscle size suggest that the increases in measured muscle strengths are mainly due to neural adaptation to strength training rather than to muscular adaptation. Previous studies have demonstrated that neural adaptation predominates in the early phase of training, but its role decreases over time, though it continues to play some role for at least eight weeks (Moritani & DeVries 1979).

The recruitments of slow- (type I) and fast-twitch (type IIa,b) muscle fibers are in relation to the intensity of effort. The fast-twitch fibers participate in rapid, powerful movements (Edgerton 1978). Neural inhibition may prevent partly the use of all fast-twitch fibers in the maximal contraction of an untrained muscle (Moritani 1993), and the improvement of strength performance could be due to the fact that the subjects can recruit more of type IIa, and especially type IIb, motor units during maximum contraction of the measured muscles and can thus express their true strength capacity. Another factor that could improve muscle strength is that the firing rate of motor units increases during training (Sale 1988). In addition, previous studies have also shown that ten-week resistance training decreases muscular response latencies and increases the amplitude of the muscular response (MacDougall *et al.* 1980).

These neural changes could explain why strength training of the hand improved the motor performance of the hand, as indicated by the choice reaction time, tapping speed and coordination results. The motor performance tests were performed with fast dynamic movements, which did not require power, but a rapid reaction ability, and it may be that there was a higher number of type II motor units activated during these movements. In other words, the strength training period may decrease their level of neural inhibition and may increase their capacity to recruit more type II motor units during rapid, powerful movements.

There were 20 supervised one-hour training sessions during the training program. The mean value of the subjects' adherence was 14.7 times (74 %) in a supervised program, and 18.7 times (94 %) in home training. The reason for the higher mean value of home training was that some subjects performed more than two training sessions a week during the training program and many performed ”missing” supervised training sessions at home, but there was also more variation in the adherence with home training. The adherence in the programs could have been higher, but the main point, i.e. the increase of muscle strength, was achieved. The main reasons for failure were sickness and lack of time.

Previous studies have shown that the most effective way to enhance motor unit recruitment is to do exercise with almost maximum resistance (Maughan 1984). However, the intensity of training in this study was about 50 % of one repetition maximum, which was obviously too low to reach an optimal result in the recruitment of motor units. In addition, the training was not of the explosive type. With more intense and explosive training, neural adaptation would have been greater. The main reason for the low dose was safety. In addition, the training was performed with dynamic exercise, while the muscle strength measurements were performed with isolated isometric efforts. The increase of muscle strengths was probably greater in dynamic efforts than was shown by the isometric measurements (Thorstensson *et al*. 1976). However, the target measurements, i.e. the motor performance tests, were performed with dynamic movements similar to the muscle exercises made during the training period.

Strength training is clinically one of the most common therapy methods, and it plays a significant role in physical therapy programs. Based on the results, it may be possible to improve the motor performance of the hand in certain motor tasks with strength training of the hand. However, it seems that the specificity of movement patterns plays an important role during a strength training period, and the changes were greatest in the tasks and movements performed with the trained muscles. This knowledge may be useful when planning movement therapy and strength training programs for people working in fine motor tasks or at a conveyor belt. A strength training program planned specifically for the muscles involved in these tasks may help them to perform the tasks faster and more effectively. It is also presumed that the strengthening of the muscles involved in the tasks may prevent overstrain and pain in these muscles (Biering-Sorensen 1984).

The results also suggest that even non-task-specific training may improve the motor performance of the hand, and a quantitative increase of the activation of motor units during muscle contraction may improve motor performance in some motor tasks. In spite of the previous suggestion, qualitative task-specific training may be more effective, because there is evidence to suggest that some motor units in the multifunctional muscles may be task-dependent (Desnedt & Gidaux 1981, Ter Haar Romeny *et al*. 1984).

7. Summary

The reliability of the measurement systems used here was acceptable, and the HPM/BEP system is a potentially useful tool for studying changes in different aspects of human motor performance during rehabilitation.

Although the results were not always consistent, the results indicate that the motor performance of hands and feet varied, depending on age, gender and preferred handedess. It was lower in the older age groups in both genders. The average speed of movement and tapping speed values were higher for men than for women, but there were no gender differences in the coordination tests or the hand reaction time tests. All values (except the reaction times of hands) were better for the dominant side than the nondominant side.

The results demonstrated that strapping has some negative effects on the motor performance and muscle strength of a single healthy joint. Therefore, in situations where a subject without previous joint injuries needs maximal performance (as in sports events), it is important to consider carefully and critically whether prophylactic strapping is really necessary and indispensable. However, the results could be different among subjects with previous injuries in these joints.

It seems that motor performance changes are quite small during hot pack treatment in healthy persons, but it is more difficult than usual for subjects to perform fine motor tasks after cold pack treatment of the hand, which should be noticed when designing and implementing movement therapy after cold pack treatment. However, the hot and cold pack treatments are primarily used to reduce pain, and in patients with musculoskeletal disorders, for example, pain may the primary factor decreasing motor performance, and the changes may be more significant after these treatments. The reduction in fine hand function after cold pack treatment may hence be insignificant when dealing with the need to reduce pain.

The effects of acute and long-term muscle strength training on the muscle strength and EMG activity of the hand were opposite. Acute muscle fatigue had no effect on the motor performance functions of the hand, but the results give some suggestion that even non-task-specific muscle strength training may improve some aspects of the motor performance of the hand. In the case of patients, however, pain may impede the performance in the therapy sessions. This may prevent as high intensity level as in the present studies, and the effects of training on motor performance may hence be slighter.

After all, the interventions used in these studies were quite identical to actual clinical work and the effects of interventions can mainly be generalised in this respect. However, all the studies were done with healthy subjects, and further research is necessary to clarify the effects in different patient populations, where the effects of treatments could be different.

8. Conclusions

The following main findings and conclusions can be summarised:

1. The HPM/BEP system is a potentially useful tool to study motor performance, and the reliability of the system is acceptable.
2. The motor performance of a healthy population, as indicated by reaction time, speed of movement, tapping speed and coordination, was lower in the older age groups in both genders. The average speed of movement and tapping speed values were higher for men than for women, but there were no gender differences in the coordination tests or the hand reaction time tests. All values (except the hand reaction times) were better for the dominant side than the nondominant side.
3. Strapping of the ankle and wrist joints decreased some aspects of motor performance in these joints in healthy subjects.
4. Hot pack treatment of healthy subjects had only minor effects on the motor performance of the treated area. On the contrary, cold pack treatment decreased almost all measured aspects, and these changes were most obvious in fine motor movements.
5. A one-hour strength training session of the hand decreased acutely muscle strength and EMG activity, but muscle fatigue had no effects on the motor performance functions of the hand. It seems that the feeling of incompetence to perform quick and accurate movements with fatigued muscles was mainly a subjective feeling, and that the real effect of muscle fatigue on motor performance was smaller than generally expected.
6. A ten-week strength training period of the hands increased muscle strength and EMG activity in trained muscles. There was also some suggestion that even non-task-specific training, and a quantitative increase of activation of the motor units during muscle contraction might improve motor performance in some motor tasks of the hand.

9. References

Abdenour T, Saville W, White R & Abdenour M (1979) The effect of ankle taping upon torque and range of motion. Athl Train 14: 227-228.

Abramson DI, Chu LWS, Tuck S Jr, Lee SW, Richardson G & Lewin M (1966) Effect of tissue temperature and blood flow on motor nerve conduction velocity. JAMA 198: 1082-1088.

Alway SE, Grumbt WH, Stray-Gundersen J & Gonyea WJ (1992) Effects of resistance training on elbow flexors of highly competitive bodybuilders. J Appl Physiol 72: 1512-1521.

Andersen H (1996) Reliability of isokinetic measurements of ankle dorsal and plantar flexors in normal subjects and in patients with peripheral neuropathy. Arch Phys Med Rehabil 77: 265-268.

Andreasson G & Edberg B (1983) Rheological properties of medical tape used to prevent athletic injuries. Text Res J 53: 225-230.

Annett M (1972) The distribution of manual asymmetry. Br J Psychol 63: 343-358.

Annett M & Annett J (1979) Individual differences in right and left reaction time. Br J Psychol 70: 393-404.

Barnes WS (1983) Effects of heat and cold application on isometric muscular strength. Percept Mot Skills 56: 886.

Baron A & Journey JW (1989) Age differences in manual versus vocal reaction times: further evidence. J Gerontol 44: P157-P159.

Basmajian JV (1978) Muscles alive. Their functions revealed by electromyography. Fourth Edtion. Williams & Wilkins, Baltimore.

Baumann P, Vanharanta H, Kauranen K & Myllylä V (1995) Myotonia congenita: quantitation of different aspects of motor performance. Eur Neurol 35: 206-211.

Baylor AN &Spirduso WW (1988) Systematic aerobic exercise and components of reaction time in older women. J Gerontol 43: P121-P126.

Beh HC (1989) Reaction time and movement time after active and passive smoking. Percept Mot Skills 68: 513-514.

Behbehani K, Kondraske GV, Tintner R, Tindall RA & Imrhan SN (1990) Evaluation of quantitative measures of upper extremity speed and coordination in healthy persons and in three patient populations. Arch Phys Med Rehabil 71: 106-111.

Belanger AY & McComas AJ (1981) Extent of motor unit activation during effort. J Appl Physiol 51: 1131-1135.

Beynnon B & Renström P (1991) The effect of bracing and taping in sports. Ann Chir Gynaecol 80: 230-238.

Bhattacharya SK, Pradhan CK, Tripathi SR & Kashyap S (1991) Human performance capability in psychomotor tasks at variable difficulty levels and physiological reactions under noise and heat conditions. Ind Health 29: 129-138.

Biering-Sorensen F (1984) Physical measurements as risk indicators for low-back trouble over a one-year period. Spine 9: 106-119.

Bigland-Ritchie B (1984) Muscle fatigue and the influence of changing neural drive. Clin Chest Med 5: 21-34.

Bigland-Ritchie B, Jones DA, Hosking GP & Edwards RHT (1978) Central and peripheral fatigue in sustained maximum voluntary contractions of human quadriceps muscle. Clin Sci Mol Med 54: 609-614 .

Bjorklund RA (1991) Reaction time and movement time measured in a key-press and a key-release condition. Percept Mot Skills 72: 663-673.

Burks R, Bean B, Marcus R & Barker H (1991) Analysis of athletic performance with prophylactic ankle devices. Am J Sports Med 19: 104-106.

Carpenter JE, Blasier RB & Pellizzon GG (1998) The effects of muscle fatigue on shoulder joint position sense. Am J Sports Med 26: 262-265.

Chapman JP, Chapman LJ & Allen JJ (1987) The measurement of foot preference. Neuropsychologia 25: 579-584.

Clarke RSJ, Hellon RF & Lind AR (1958) The duration of sustained contractions of the human forearm at different muscle temperatures. J Physiol 143: 454-473.

Clarkson PM (1978) The effect of age and activity level on simple and choice fractioned response time. Eur J Appl Physiol 40: 17-25.

Clarkson PM, Byrnes WC, McCormick KM, Turcotte LP & White JS (1986) Muscle soreness and serum creatine kinase activity following isometric, eccentric, and concentric exercise. Int J Sports Med 7: 152-155.

Coppin EG, Livingstone SD & Kuehn, LA (1978) Effects on handgrip strength due to arm immersion in a 10 degree water bath. Aviat Space Environ Med 49: 1322-1326.

Corfitsen MT (1995) Tiredness and visual reaction time among young male nighttime drivers: a roadside survey. Accid Anal Prev 26: 617-624.

Cornwall MW (1994) Effect of temperature on muscle force and rate of muscle force production in men and women. J Orthop Sports Phys Ther 20: 74-80.

Crossman ERFW (1959) A theory of the acquisition of speed-skill. Ergonomics 2: 153-166.

Davies CTM & Young K (1983) Effect of temperature on the contractile properties and muscle power of triceps surae in humans. J Appl Physiol 55: 191-195.

Davies J, Parker DF, Rutherford OM & Jones DA (1988) Changes in strength and cross sectional area of elbow flexors as a result of isometric strength training. Eur J Appl Physiol 57: 667-670.

DeCastro JM & Duncan G (1985) Operantly conditioned running: effect on brain catecholamine concentrations and receptor densities in the rat. Pharmacol Biochem Behav 23: 495-500.

De Jesus PV, Hausmanowa-Petrusewicz I & Barchi RL (1973) The effect of cold on nerve conduction of human slow and fast nerve fibers. Neurology 23: 1183-1189.

DeJong JR (1957) The effects of increasing skill on cycle time and its consequences for time standards. Ergonomics 1: 51-60.

De Jong PH, Hershey WN & Wagman IH (1966) Nerve conduction velocity during hypothermia in man. Anesthesiology 27: 805-810.

Deary IJ (1992) Diabetes, hypoglycaemia and cognitive performance. In: Smith AP & Jones DM (eds) Handbook of human performance. Academic Press, London. p 243-259.

DeLisa JA & Gans BM (1993) Rehabilitation medicine. Principles and practice. Second Edition. J.B. Lippincott Company, Philadelphia.

DeLorme TL (1946) Heavy resistance exercises. Arch Phys Med 27: 607-630.

Desnedt JE & Gidaux E (1981) Spinal motoneuron recruitment in man: rank deordering with direction but not with speed of voluntary movement. Science 214: 933-936.

Dick RW & Cavanagh PR (1987) An explanation of the upward drift in oxygen uptake during prolonged submaximal downhill running. Med Sci Sports Exerc 19: 310-317.

Dodrill CB (1979) Sex differences on the Halstead-Reitan Neuropsychological Battery and other neuropsychologigal measures. J Clin Psychol 35: 236-241.

Drowatzky JN & Zuccato FC (1967) Interrelationships between selected measures of static and dynamic balance. Res Q Exerc Sports 38: 509-510.

Dustman RE, Ruhling RO, Russell EM, Shearer DE, Bonekat HW, Shigeoka JW, Wood JS & Bradford DC (1984) Aerobic exercise training and improved neuropsychological function of older individuals. Neurobiol Aging 5: 35-42.

Edgerton VR (1978) Mammalian muscle fiber types and their adaptability. Am Zoology 18: 113-125.

Enoka RM (1994) Neuromechanical basis of kinesiology. Second Edition. Human Kinetics, Champaign, IL.

Enoka RM & Stuart DG (1992) Neurobiology of the muscle fatigue. J Appl Physiol 72: 1631-1648.

Era P (1987) Sensory, psychomotor, and motor functions in men of different ages. Scand J Soc Med 15: Suppl 39.

Era P, Berg S & Schroll M (1995) Psychomotor speed and physical activity in 75-year-old residents in three Nordic localities. Aging Clin Exp Res 7: 195-204.

Era P, Jokela J & Heikkinen E (1986) Reaction and movement times in men of different ages: a population study. Pecept Mot Skills 63: 111-130.

Era P, Pärssinen O & Suominen H (1991) Neurophysiological aspects of exercise among the elderly. In: Oja P & Telama R (eds) Sport for all. Elsevier Science Publishers B.V., Amsterdam. p 343-351.

Faulkner JA, Zebra E & Brook SV (1990) Muscle temperature of mammals: cooling impairs most functional properties. Am J Physiol 259: R259-R265.

Finkel D, Whitfield K & McGue M (1995) Genetic and environmental influences on functional age: a twin study. J Gerontol 50: P104-P113.

Fishman MG &Lim C-H (1991) Influence of extended practise on programming time, movement time, and transfer in simple target-striking responses. J Mot Behav 23: 39-50.

Fitts PM (1954) The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol 47: 381-391.

Fitts RH & Balog EM (1996) Effect of intracellular and extracellular ion changes on E-C coupling and skeletal muscle fatigue. Acta Physiol Scand 156: 169-181.

Fleishman EA (1964) The structure and measurement of physical fitness. Englewood Cliffs, NJ: Prentice Hall.

Fleishman EA (1957) A comparative study of aptitude patterns in unskilled and skilled psychomotor performances. J Appl Psychol 41: 263-272.

Fleishman EA & Parker JF (1962) Factors in the retention and relearning of perceptual motor skill. J Exp Psychol 64: 215-226.

Fleiss JL (1986) The design and analysis of clinical experiments. Wiley, New York.

Fox RH (1961) Local cooling in man. Br Med Bull 17: 14-18.

Fozard JL, Vercruyssen M, Reynolds SL, Hancock PA & Reginald EQ (1994) Age differences and changes in reaction time: The Baltimore longitudinal study of aging. J Gerontol 49: P179-P189.

Friberg O & Kvist M (1988) Factors determining the preference of takeoff leg in jumping. Int J Sports Med 9: 349-352.

Fuglevand AJ, Zackowski KM, Huey KA & Enoka RM (1993) Impairment of neuromuscular propagation during human fatiguing contractions at submaximal forces. J Physiol 460: 549-572.

Fumich R, Ellison A, Guerin G & Grace P (1981) The measured effect of taping on combined foot and ankle motion before and after exercise. Am J Sports Med 9: 165-169.

Gabbart C & Hart S (1996) A question of foot dominance. J Gen Psychol 123: 289-296.

Garfinkel S & Cafarelli E (1992) Relative changes in maximal force, EMG, and muscle cross-sectional area after isometric training. Med Sci Sports Exerc 24: 1220-1227.

Garrick JG & Requa RK (1973) Role of external support in the prevention of ankle sprains. Med Sci Sports Exerc 5: 200.

Giesbrecht GG & Bristow GK (1992) Decrement in manual arm performance during whole body cooling. Aviat Space Environ Med 63: 1077-1081.

Gill DM, Reddon JR, Stefanyk WO & Harinder SH (1986) Finger tapping: effects of trials and sessions. Percept Mot Skills 62: 675-678.

Glenn SW & Parsons OA (1992) Neuropsychological efficiency measures in male and female alcoholics. J Stud Alcohol 53: 546-552.

Goodgold J & Eberstein A (1977) Electrodiagnosis of neuromuscular diseases. Second Edition. The Williams and Wilkins Company, Baltimore.

Greene T & Hillman S (1990) Comparison of support provided by a semirigid orthosis and adhesive ankle taping before, during and after exercise. Am J Sports Med 5: 498-506.

Gross M, Bradshaw M, Ventry L & Weller K (1987) Comparison of support provided by ankle taping and semirigid orthosis. J Orthop Sports Phys Ther 9: 33-39.

Gutherie ER (1952) The psychology of learning. Haper & Row, New York.

Haaland KY, Temkin N, Randahl G & Dikmen S (1994) Recovery of simple motor skills after head injury. J Clin Exp Neuropsychol 16: 448-456.

Halar EM, Hammond MC & Dirks S (1985) Physical activity: Its influence on nerve conduction velocity. Arch Phys Med Rehabil 66: 605-609.

Halstead WC (1947) Brain and intelligence. University of Chicago Press, Chicago, IL.

Hamer P, Munt M, Harris C & James N (1992) The influence of ankle strapping on wobbleboard performance, before and after exercise. Aust J Physiother 2: 85-92.

Hart J, Hill HM, Bye CE, Wilkinson RT & Peck AW (1976) The effects of low doses of amylobarbitone sodium and diazepam on human performance. Br J Clin Pharmacol 3: 289-298.

Hartviksen K (1962) Ice therapy in spasticity. Acta Neurol Scand 38: 79-84.

Hayes KC (1975) Effects of fatiguing isometric exercise upon achilles tendon reflex and plantar flexion reaction time components in man. Eur J Appl Physiol 34: 69-79.

Haywood KM (1979) Age differences in movement time over distances proportional to size. Perept Mot Skills 48: 309-310.

Henry FM (1961) Reaction time – movement time correlations. Percept Mot Skills 12: 63-66.

Hertzog C, Schaie KW & Gribbin K (1978) Cardiovascular disease and changes in intellectual functioning from middle to old age. J Gerontol 33: 872-883.

Hick WE (1952) On the rate of gain of information. Q J Exp Psychol 4: 11-26.

Hochschild R (1989) Improving the precision of biological age determinations: Part 2. Automatic human tests, age, norms and variability. Exp Gerontol 24: 301-316.

Houx PJ & Jolles J (1993) Age related decline of psychomotor speed: effects of age, brain health, sex and education. Percept Mot Skills 76: 195-211.

Hunter J, Kerr EH & Whillans MG (1952) The relation between joint stiffness upon exposure to cold and the characteristics of synovial fluid. Canad J Med Sci 30: 367-377.

Häkkinen K (1993) Neuromuscular fatigue and recovery in male and female athletes during heavy resistance loading. Int J Sports Med 14: 53-59.

Häkkinen K (1994) Neuromuscular fatigue in males and females during strenuous heavy resistance loading. Electromyogr Clin Neurophysiol 34: 205-214.

Häkkinen K (1995) Neuromuscular fatigue and recovery in women at different ages during heavy resistance loading. Electromyogr Clin Neurophysiol 35: 403-413.

Häkkinen K & Komi P (1983) Electromyographic changes during strength training and detraining. Med Sci Sports Exerc 15: 455-460.

Häkkinen K, Komi PV & Alén M (1985) Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiol Scand 125: 587-600.

Häkkinen K & Komi P (1986) Effects of fatigue and recovery on electromyographic and isometric force- and relaxation time characteristics of human skeletal muscle. Eur J Appl Physiol 55: 588-596.

Häkkinen K, Pakarinen A, Alén M, Kauhanen H & Komi P (1988) Neuromuscular and hormonal responses in elite athletes to two successive strength training sessions in one day. Eur J Appl Physiol 57: 133-139.

Hämäläinen O (1993) Flight helmet weight, +Gz forces, and neck muscle strain. Aviat Space Environ Med 64: 55-57.

Hämäläinen O & Vanharanta H (1992) Effect of Gz forces and head movements on cervical erector spinae muscle strain. Aviat Space Environ Med 63: 709-716.

Jarić S, Radovanović S, Milanović S, Ljubisavljević M & Anastasijević R (1997) A comparison of effects of agonists and antagonists muscle fatigue on performance of rapid movements. Eur J Appl Physiol 76: 41-47.

Jones DA, Rutherford OM & Parker DF (1989) Physiological changes in skeletal muscle as a result of strength training. Q J Exp Physiol 74: 233-256.

Juvenal J (1972) The effects of ankle taping on vertical jumping ability. Athl Train 7: 146-149.

Kamen G & Morris HH (1988) Differences in sensorimotor processing of visual and proprioceptive stimuli. Res Q Exerc Sports 59: 29-34.

Kennedy RS, Bittner AC Jr, Harbeson M & Jones MB (1982) Television computer games: a new look in performance testing. Aviat Space Environ Med 53: 49-53.

Kerr M, Mingay R & Elithorn A (1963) Cerebral dominance in reaction time responses. Br J Psychol 54: 325-336.

King GD, Hannay HJ, Masek BJ & Burns JW (1978) Effects of anxiety and sex on neuropsychological tests. J Consult Clin Psychol 46: 375-376.

King PG, Mendryk S, Reid DC & Kelly R (1970) The effect of actively increased muscle temperature on grip strength. Med Sci Sports Exerc 2: 172-175.

Knutsson E & Mattsson E (1969) Effects of local cooling on monosynaptic reflexes in man. Scand J Rehabil Med 1: 126-132.

Komi P & Buskirk E (1970) Reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. Electromyogr 4: 357-367.

Komi PV & Tesch P (1979) EMG frequency spectrum, muscle structure and fatigue during dynamic contractions in man. Eur J Appl Physiol 42: 41-52.

Kondraske GV (1991) HPM/BEP manual. (Third Printing). Human Performance Measurement, Inc., Arlington, TX.

Kottke FJ, Stillwell GK & Lehmann JF (1982) Krusen's Handbook of Physical Medicine and Rehabilitation, W.B. Saunders Company, Philadelphia.

Kroll W (1974) Fractionated reaction and reflex time before and after fatiguing isotonic exercise. Med Sci Sports Exerc 6: 260-266.

Kuorinka I, Videman T & Lepistö M (1981) Reliability of a vibration test in screening for predisposition to tenosynovitis. Eur J Appl Physiol 47: 365-376.

Kuukkanen T & Mälkiä E (1998) Effects of three-month active rehabilitation program on psychomotor performance of lower limbs in subjects with low back pain: a controlled study with a nine-month follow-up. Percept Mot Skills 87: 739-753.

Landauer AA (1981) Sex differences in decision and movement time. Percept Mot Skills 52: 90.

Landauer AA, Armstrong S & Digwood J (1980) Sex differences in choice reaction time. Br J Psychol 71: 551-555.

Lauren H, Luoto S, Alaranta H, Taimela S, Hurri H & Heliövaara M (1997) Arm motion speed and risk of neck pain. A preliminary communication. Spine 22: 2094-2099.

Lehmann JF (1982) Therapeutic heat and cold. Third Edition. Williams & Wilkins, Baltimore.

Lehmann JF, Masock AJ, Warren CG & Koblanski JN (1970) Effect of therapeutic temperatures on tendon extensibility. Arch Phys Med Rehabil 51: 481-487.

Li CL (1958) Effect of cooling on neuromuscular transmission in the rat. Am J Physiol 194: 200-206.

Li CL & Gouras P (1958) Effect of cooling on neuromuscular transmission in the frog. Am J Physiol 192: 464-470.

Lotter WS (1960) Interrelationships among reaction times and speed of movement in different limbs. Res Q Exerc Sports 31: 147-155.

Luoto S, Hurri H & Alaranta H (1995) Reaction time in patients with chronic low-back pain. Eur J Phys Med Rehab 5: 47-50.

Luoto S, Taimela S, Hurri H, Aalto H, Pyykkö I & Alaranta H (1996) Psychomotor speed and postural control in chronic low-back pain patients: A controlled follow-up study. Spine 21: 2621-2627.

MacDougall JD, Elder GC, Sale DG, Moroz JR & Sutton JR (1980) Effects of strength training and immobilization on human muscle fibres. Eur J Appl Physiol 43: 25-34.

MacRae PG, Spirduso WW, Walters TJ, Farrar RP & Wilcox RE (1987) Endurance training effects on striatal D2 dopamine receptor binding and striatal dopamine metabolites in presenescent older rats. Psychopharmacol 92: 236-240.

Marzi CA, Bisiacchi P & Nicoletti R (1991) Is interhemispheric transfer of visuomotor information asymmetric ? Evidence from a meta-analysis. Neuropsychologia 29: 1163-1177.

Maughan R (1984) Relationship between muscle strength and muscle cross-sectional area; implications of training. Sports Med 1: 263-269.

Mayhew J (1972) Effects of ankle taping on motor performance. Athl Train 7: 10-11.

McCafferty WB & Hovath SM (1977) Specificity of exercise and specificity of training: A subcellular review. Res Q Exerc Sports 48: 358-371.

McManus IC, Kemp RI & Grant J (1986) Differences between fingers and hands in tapping ability: Dissociation between speed and regularity. Cortex 22: 461-473.

Milner G & Landauer AA (1973) Haloperidol and diatzepam alone and together with alcohol in relation to driving safety. Blutalkohol 10: 247-254.

Morgan DL (1990) New insights into the behavior of muscle during active lengthening. Biophys J 57: 209-221.

Moritani T (1993) Neuromuscular adaptations during the acquisition of muscle strength, power and motor task. J Biomech 26: Suppl. 1: 95-107.

Moritani T & DeVries H (1979) Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phys Med 58: 115-130.

Moritani T & Mimasa F (1990) An electromyographic analysis of neuromuscular control during the acquisition of a motor task. J Sports Med Sci (Japan) 4: 35-43.

Morris AF (1977) Effects of fatiguing isometric and isotonic exercise on resisted and unresisted reaction time components. Eur J Appl Physiol 37: 1-11.

Morrow JR (Jr), Jackson AW, Disch JG & Mood DP (1995) Measurement and evalution in human performance. Human Kinetics, Champaign, IL.

Myburgh K, Vaughan C & Isaacs S (1984) The effects of ankle guards and taping on joint motion before, during and after a squash match. Am J Sports Med 6: 441-446.

Nakashima K, Shimoyama R & Takahashi K (1993) Paired choice reaction tasks in patients with Parkinson's disease. Acta Neurol Scand 87: 178-183.

Neubauer AC (1990) Selective reaction times and intelligence. Intelligence 14: 79-96.

Ohanian HC (1989) Physics. Second edition, expanded. Rensselear Polytechnic Institute. WW Norton & Company Inc., New York.

Oksa J, Rintamäki H, Hassi J & Rissanen S (1993) Gross efficiency of muscular work during step exercise at -15^{o}C and 21^{o}C. Acta Physiol Scand 147: 235-240.

Oksa J, Rintamäki H, Mäkinen T, Hassi J & Rusko H (1995) Cooling-induced changes in muscular performance and EMG activity of agonist and antagonist muscles. Aviat Space Environ Med 66: 26-31.

Owen BD & Damron CF (1984) Personal characteristics and back injury among hospital nursing personel. Res Nurs Health 7: 305-313.

Paas FG, Adam JJ, Janssen GM, Vrenken JG & Bovens AM (1994) Effect of a 10-month endurance-training program on performance of speeded perceptual-motor tasks. Percept Mot Skills 78: 1267-1273.

Panton LB, Graves JE, Pollock ML, Hagberg JM & Chen W (1990) Effect of aerobic and resistance training on fractionated reaction time and speed of movement. J Gerontol 45: 26-31.

Parry M (1982) Skin temperature and motorcyclists' braking performance. Percept Mot Skills 54: 1291-1296.

Patterson LA & Spivey WE (1992) Validity and reliability of the LIDO Active Isokinetic System. J Orthop Sports Phys Ther 15: 32-36.

Payne RB (1989) Psychomotor performance as a function of time of day. Pecept Mot Skills 68: 455-461.

Peters M (1988) Footedness. Asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychol Bull 103: 179-192.

Pienimäki T, Kauranen K & Vanharanta H (1997) Bilaterally decreased motor performance of arms in chronic unilateral tennis elbow syndrome. Arch Phys Med Rehabil 78: 1092-1095.

Provins KA, Milner AD & Kerr P (1982) Asymmetry of manual preference and performance. Percept Mot Skills 54: 179-194.

Rabbitt P & Banerji N (1989) How does very prolonged practice improve decision speed ? J Exp Psychol 188: 338-345.

Reitan RM & Wolfson D (1985) Halstead-Reitan neuropsychological test battery: theory and clinical application. Neuropsychology Press, Tucson, AZ.

Rikli RE & Edwards DJ (1991) Effects of a three-year exercise program on motor function and cognitive processing in older women. Res Q Exerc Sport 62: 61-67.

Rothwell J (1994) Control of human voluntary movement. Chapman & Hall, London.

Ruff RM & Parker SB (1993) Gender and age-specific changes in motor speed and eye-hand coordination in adults: normative values for the Finger Tapping and Grooved Pegboard Tests. Percept Mot Skills 76: 1219-1230.

Rutherford OM & Jones DA (1986) The role of learning and co-ordination in strength training. Eur J Appl Physiol 55: 100-105.

Sale DG (1988) Neural adaptation to resistance training. Med Sci Sports Exerc 20: Suppl 5: 135-345.

Sathiamoorthy A, Sathiamoorthy SS, Bhat SK, Hiremath S & Shenoy N (1994) Influence of handedness on the visual and auditory reaction time. Indian J Physiol Pharmacol 38: 297-299.

Schmidt RA (1991) Motor learning and performance. Human Kinetics, Champaign, IL.

Sewall L & Michelli LJ (1986) Strength training for children. J Pediatr Orthop 6: 143-146.

Shellock FG & Prentice WE (1985) Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med 2: 267-278.

Shimoyama I, Ninchoji T & Uemura K (1990) The finger-tapping test. A quantitative analysis. Arch Neurol 47: 681-684.

Shrout PE & Fleiss JL (1979) Intraclass correlations: uses in assessing rater reliability. Psychol Bull 86: 420-428.

Simonen R (1997) Determinants of adult psychomotor speed. A study of monozygotic twins. Studies in sport, physical education and health 47. University of Jyväskylä, Finland.

Simonen R, Videman T, Battie M & Gibbons L (1995) Comparison of foot and hand reaction times among men: a methodologic study using simple and multiple-choice repeated measurements. Percept Mot Skills 80: 1243-1243.

Simonen R, Videman T, Battie M & Gibbons L (1998) Determinants of psychomotor speed among 61 pairs of adult male monozygotic twins. J Gerontol 53: M228-M234.

Sipilä S, Multanen J, Kallinen M, Era P & Suominen H (1996) Effects of strength and endurance training on isometric muscle strength and walking speed in elderly women. Acta Physiol Scand 156: 457-464.

Sjøgaard G, Savard G & Juel C (1988) Muscle blood flow during isometric activity and its relation to muscle fatigue. Eur J Appl Physiol 57: 327-335.

Skinner HB, Wyatt MP, Hodgdon JA, Conard DW & Barrack RL (1986) Effect of fatigue on joint position sense of the knee. J Orthop Res 4: 112-118.

Smith GA & Carew M (1987) Decision time unmasked: individuals adopt different strategies. Aust J Psychol 39: 339-351.

Spirduso WW (1980) Physical fitness, aging, and psychomotor speed: A review. J Gerontol 35: 850-865.

Stauber WT (1989) Eccentric actions of muscles: Physiology, injury, and adaptation. In Pandolf KB (Ed.) Exercise and sports sciences reviews. Williams & Wilkins, Baltimore.

Stein RB (1974) Peripheral control of movement. Physiol Rev 54: 215-243.

Taber C, Contryman K, Fahrenbruch J, Lacount K & Cornwall MW (1992) Measurement of reactive vasodilatation during cold gel pack application to nontraumatized ankles. Phys Ther 72: 294-299.

Taimela S (1991) Individual-related characteristics and musculoskeletal injuries with special reference to reaction time, mental ability and psychological factors. Annal Univ Tur. D 85. University of Turku, Finland.

Taimela S, Österman K, Alaranta H, Soukka A & Kujala UM (1993) Long psychomotor reaction time in patients with chronic low-back pain: preliminary report. Arch Phys Med Rehabil 74: 1161-1164.

Ter Haar Romeny BM, Denier Van Der Gon JJ & Gielen CAM (1984) Relation between location of a motor unit in the human biceps brachii and its critical firing levels for different tasks. Exp Neurol 85: 631-650.

Tesch P, Colliander E & Kaiser P (1986) Muscle metabolism during intense, heavy-resistance exercise. J Appl Physiol 55: 362-366.

Thomas J & Cotten D (1971) Does ankle taping slow down athletes ? Coach Athl 34: 20-27.

Thorstensson A, Hulten B, Von Domlem W & Karlsson J (1976) Effect of strength training on enzyme activities and fibre characteristics in human skeletal muscle. Acta Physiol Scand 96: 392-398.

Tiffin J & Asher EJ (1948) "The Purdue Pegboard": Norms and studies of reliability and validity. J Appl Psychol 32: 234-247.

Tochihara Y, Ohkubo C, Uchiyama I & Komine H (1995) Physiological reaction and manual performance during work in cold storages. AADE Ed J 14: 73-77.

Tropp H, Ekstrand J & Gillquist J (1984) Factors affecting stabilometry recordings of single limb stance. Am J Sports Med 12: 185-188.

Tropp H, Odenrick P & Gillquist J (1985) Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med 6: 180-182.

Vaes P, De Boeck H, Handelberg F & Opdecam P (1985) Comparative radiologic study of ankle joint bandages on ankle stability. Am J Sports Med 13: 46-50.

Verbrugge JD (1996) The effects of semirigid Air-Stirrup bracing vs. adhesive taping on motor performance. J Orthop Sports Phys Ther 23: 320-325.

Viikari-Juntura E, Hietanen M, Kurppa K, Huuskonen M, Kuosma E & Mutanen P (1994) Psychomotor capacity and occurence of wrist tenosynovitis. J Occup Med 36: 57-60.

Viitasalo JT & Komi PV (1980) EMG, reflex and reaction time components, muscle structure and fatigue during intermittent isometric contractions in man. Int J Sports Med 1: 185-190.

Walker SM (1949) Potentiation of twitch tension and prolongation of action potential induced by reduction of temperature in rat and frog muscle. Am J Physiol 157: 429-435.

Ward T (1978) Muscle state: reaction and movement time in elbow extension. Arch Phys Med Rehabil 59: 377-383.

Weinberg RS & Hunt VV (1976) The interrelationships between anxiety, motor performance, and electromyography. J Mot Behav 8: 219-224.

Welford AT, Norris AH & Schock NW (1969) Speed and accuracy of movement and their changes with age. Acta Psychol 30: 3-15.

Westerblad H & Lännergren J (1990) Recovery of fatigued xenopus muscle fibers is markedly affected by the extracellular tonicity. J Muscle Res Cell Motil 11: 147-153.

Wetherell A (1990) The STRES Battery: standardised tests for research into environmental stress. In: Lovesey EJ (ed) Contemporary Ergonomics. Taylor & Francis, London. p 270-275.

Wetherell A (1996) Performance tests. Environ Health Perspect 104: Suppl. 2: 247-273.

Wickens CS (1984) Engineering psychology and human performance. Merrill, Columbus, OH.

Wiktorsson-Möller M, Öberg B, Ekstrand J & Gillquist J (1983) Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. Am J Sports Med 11: 249-252.

Wilkerson G (1991) Comparative biomechanical effects of the standard method of ankle taping and a taping method designed to enhance subtalar stability. Am J Sports Med 6: 588-595.

Wilkinson RT & Allison S (1989) Age and simple reaction time: decade differences for 5,325 subjects. J Gerontol 44: 29-35.

York JL & Biederman I (1990) Effects of age and sex on reciprocal tapping performance. Percept Mot Skills 71: 675-684.

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