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Contents

Preface

The problems and main results of the following published investigations are reviewed in this report:

A. Kirjonen, J. (1970) Eräät fyysisen toimintakykyisyyden osatekijät istumasta korokkeelle nousu -liikesuorituksen ja lihastyön siinä aiheuttamien muutosten selittäjinä (Some components of physical fitness in relation to the movement pattern in stepping from a sitting position up to a platform and to its alterations after muscular exercise). *Reports from the Institute for Educational Research 56. University of Jyväskylä, Jyväskylä.*

B. Kirjonen, J. (1970) The relationship between some components of physical fitness and the modification by muscular exercise of the movement pattern in rising from a sitting position and stepping up to a platform. *Reports from the Department of Psychology 101. University of Jyväskylä, Jyväskylä.*

C. Kirjonen, J. & Rusko, H. (1971) Liikkeen kinemaattisista ominaispiirteistä, niiden psykofyysisistä selitysyhteyksistä ja näiden muutoksista psykomotorisen kuormituksen ja kestävyysharjoittelun vaikutuksesta (On the kinematic characteristics and psychophysical correlates of a human movement and their changes during psychomotor loading and endurance conditioning) *Studies in Sport, Physical Education and Health, 2. University of Jyväskylä, Jyväskylä.*

The purpose of the present paper is to survey these studies and to discuss certain aspects of their theoretical background. The studies were carried out at the Department of Psychology, the Institute for Educational Research and the Department of Public Health, University of Jyväskylä.

The project was initiated by Martti Takala, Head of the Department of Psychology, and followed subsequently by Pentti Pitkänen and Isto Ruoppila, for whose encouragement I am particularly grateful. The discussions I have had with Veikko Heinonen have been very inspiring and beneficial and I am grateful for the interest he has taken in my work.

I also owe a dept of gratitude to a number of my colleagues and friends; I wish to thank Jeddi Hasan for his advice and valuable criticism, and my thanks are due to Pekka Kiviaho, Raimo Konttinen, Risto Telama ja Rauno Velling for their advice and for discussions with them, which have contributed directly or indirectly to the realization of these studies.

The entire project has profited greatly from Heikki Rusko's contributions, in Study C, to the solutions of certain methodological problems. He has also read the manuscript (C) and offered valuable criticisms. Pekka Sarviharju, Erkki Mattila and Risto Nieminen have given me assistance in carrying out the experiments of Study C. I wish to express my warm thanks for technical assistance to Anneli Kautto (drawings), Anja Niskanen (typing), Annikki Poutiainen (programming) and Aaro Sorsa (recording and test apparatus).

The paper was translated by Jaakko Railo and the translation was checked by Andrew Chesterman.

These studies were supported financially by the Ministry of Education, grants from the Finnish Research Council for Physical Education and Sports. In 1969 I was awarded a grant for young scholars by the Rector of the University of Jyväskylä. I thank the University of Jyväskylä for the acceptance of this report for its series of Studies in Sport, Physical Education and Health.

Jyväskylä, April 1971

Juhani Kirjonen

1. INTRODUCTION

1. 1 General

This project largely arose from a desire to analyse individual differences in human gross motor behaviour, and variations in these differences concomitant either with variations in other psychological and physical variables or with changes in certain external factors such as loading.[1] The loads a human being may be exposed to, either permanently or temporarily, include both abnormal and normal states. Examples of the former are provided by chronic illnesses and by sudden injuries, while the latter may be exemplified by a variety of factors associated with work (exertion, postures and positions, working conditions) or with other activies such as recreation and sports, household duties, studies and the like.

In addition, one of the objects in this project was to experiment with the use of statistical multivariate methods in the study of motion, a field where they have previously been applied to a comparatively limited extent, partly because sufficiently simple measurement and analysis methods have not been available. Methodological problems therefore played an important part in the execution of the project.

1. 2 Analysis of movement

One of the principal fields of application of the kinematic methods of motion study (Contini & Drillis 1966) has been muscular work defined as any overt performance. Investigators have been interested mainly in the economy and effectiveness of the human machine (Barnes 1963, Blum 1956, Crossman 1959, Hasselqvist, Söderström & Wiklund 1965, McGormick 1965 and Tiffin & McGormick 1965). Speed, accuracy, the force applied, and the energy cost of activity are typical variables of such studies. Minimizing the time, errors and excess variability of movements would increase the work output. Neither description of psychophysical characteristics of motor activities, nor analysis of gross and fine motor coordination, have been primary objects of the kinematic research into movement. This

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[1] Analysis means both the recording and measurement of movement in terms of several kinematic variables, and the application of statistical multivariate methods.

project has some points of contact with investigations of psychmotor and expressive movements. Like the latter, the present project tries to identify the most significant relationships between the characteristics of movement and certain organismic and environmental variables (Brengelmann 1957, Allport & Vernon 1933, Luria 1932, 1966, Takala 1962). Within this frame of reference, the coordination and timing of movements occupy a pivotal position. How can we describe co-operation between several perceptual-motor units of an organism? The dimensions of expressive moments, such as tempo, tension, intensity, etc. might be neither sufficient nor universal enough for a description of any movement whatsoever, regardless of its complexity or topology (Bernstein 1967).

The first studies concerning the relationships between the kinematic characteristics of movement and physical proficiency were conducted several decades ago. Oeser (1936) investigated the movement paths of good and poor javelin throwers for coordination, changes in acceleration and timing. Several tasks of apparatus gymnastics have been analysed thoroughly (Borrmann 1960/61, Reiter 1960/61). In later investigations attempts have been made to explain the characteristics represented by certain movement variables in terms of a few general indices of physical fitness (Jones & Hanson 1961). These investigations have been concerned with performances based on instructions emphasizing speed. I considered it necessary, however, to devote particular attention to spontaneous movement, which can be supposed to have connections with variables of psychological interest: those representing personality traits (Eysenck 1968, Castaneda 1956, Takala et al. 1964), expressive movements (Rimoldi 1951, Takala 1962, 1963, Takala & Partanen 1964), psychomotor functions and spatial visualization (French 1951, Smith 1964). For a more detailed account of the selection of variables, the reader is referrer to Study C. The dimensions of motor activities, apart from being highly specific (Cumbee 1954, Howell & Alderman 1967, Seashore, H. G. 1942, Seashore, R. H. 1963), have relationships with spatial-visualization abilities (Fleishman 1967, Fleishman & Hempel 1956, Vernon 1964). The variables describing these might be of great significance in explaining the kinematic structure of movement characteristics and their correlates.

The measurement technique employed was virtually identical with the one described by Jones et al. (1958 a, 1958 b). This technique is superior to previous stroboscopic methods in that the colour coding of successive flashes makes possible a higher degree of accuracy.

1. 3 Effect of loading

In recent decades psychological research has devoted much attention to the influences impinging upon man in his environments, and the nature and effects of such phenomena as fatigue, arousal and stress have been investigated (e.g. Bartley & Chute 1947, Duffy 1957, Hebb 1955, Lazarus 1966, Selye 1956). The attempts where the reactions of an individual have been chosen as the sole point of departure have not led to conceptual clarity. Nevertheless, they have yielded certain hypothetical models of the interrelations between man's performance and the influences mentioned. Among the models concering the effects of arousal, for example, the best known is likely to be the so-called "inverted U" (Corcoran 1965, Duffy 1962, Hebb 1955, Yerkes-Dodson 1908). Grandjean (1968) suggested that the arousal and fatigue dimensions are overlapping. The state of arousal is regulated by a labile system of inhibitory and activating mechanisms. The level of arousal-fatigue is influenced by two inhibitory systems, an active and a passive one. The former term refers to the increased activity in the inhibitory system in the brain stem, and the latter to the lowered sensory input. If the inhibitory system (either one) dominates, a state of fatigue (sleepiness) will develop. Because all the afferent pathways have collaterals to the ascending reticular activating system (ARAS), the amount or rate of afferent impulses increases general arousal.

Another model that has provided stimuli for research is Deese's (1962, Lazarus et al. 1952) analysis of the concept of stress and the impact of stress upon skilled motor performance. Deese emphasizes, in particular, that a continued increase in arousal during a loading situation moves along a dimension of gradually intensifying subjective feeling of discomfort. Attempts have been made to alter arousal experimentally by means of muscular activity, in such a way, for example, that the tension in another muscle group has been increased simultaneously with the criterion task performance (Stennet 1957). A drawback in the definitions of stress advanced in these contexts has been a tendency toward a rigid dichotomization of a clearly continuous dimension, i.e., an inclination to consider stress and non-stress as mutually exclusive conditions. No definition sufficiently clear to make the term useful in empirical study has so far been given for stress in psychology (Howard & Scott 1965, Teichner 1968). The term *loading*, having reference to the stimulus, is more suitable for the purpose (Welford 1968).

Despite the difficulties in the definition of concepts, Deese's model is helpful in formulating hypotheses for the present studies. According to this model, the effect of motor loading (stress) manifests itself principally as an increased variability in the velocity and paths of movements. Up to a certain point, the increase in velocity can also be regarded thereby as an improvement in the coordination of performance.

Deese's hypotheses have found support in generel neurophysiological observations (Duffy 1962, Gellhorn 1967) concerning the so-called ergotropic symptoms, associated with a general rise in the organism's sensitivity and with facilitated reactions. These symptoms are characterized by, e.g., sympathoadrenal excitation, heightened muscle tension, EEG-desynchronization and a speeding up of reactions and movements. The symptoms need not necessarily be concomitants of motor tasks or exertions; similar symptoms occur when the loading is mental (Germana 1968, 1969).

No hard and fast line can be drawn between the physical and psychological loading effects. The stimuli always have both physical and symbolic characteristics (Teichner 1968). The responses of an organism are not only signs of disorganization but also partly activities compensatory to the loading stimulus. The quality of these compensatory activities also depends on the physiological and psychological state of the organism. Such activities seem to be more liable to exeed the the normal limits of variation as the effectors are more peripheral, the stimulus-reaction systems are more complex, and the individual becomes less adapted to the situation. There is some evidence suggesting that the most sensitive measures of loading are those of intra-individual variability in several psychomotor tests (Ross, Hussman & Andrews 1954, Weckroth & Häkkinen 1957).

Preliminary investigations (Kirjonen 1968) had made it plain that components of physical fitness have a bearing on the changes caused by physical loading. Thus, an attempt was made here to map out such effect in detail,both qualitatively and quantitatively. Moreover, an effort was made to explore whether and to what extent comparable effects occur following other kinds of loading, such as psychomotor ones. As far as the general effects of arousal are concerned, this is presumably the case. Provided that physical endurance is related also to feelings of discomfort or to pain tolerance (French 1951, Gellhorn & Thompson 1944, Ryan & Kovacic 1966, Ryan 1969), endurance training could be of significance in reducing the disorganization effect of loading (Hammerton & Tickner 1968).

2. THE PRESENT STUDY

The following main groups of problems were studied:

1. Is it possible to develop a system for the description of movement on the basis of reliable kinematic measurements, and expressible as a factor structure of the characteristics of gross motor functions, i.e., as a kind of kinematic taxonomy?

2. What correlative associations can be found between the characteristics of a gross-body movement and certain components of physical fitness, psychomotor, spatial-visual and personality variables?

3. What changes in the characteristics of a movement can be observed as a result of physical or psychomotor loading?

4. Is the possible effect of loading on the characteristics of the movement different in individuals who differ as regards physical fitness, and certain components of psychomotor functions, spatial-visualization and personality?

5. What is the impact of regular endurance conditioning on the characteristics of the movement and on the changes which may occur in these under loading?

3. EXECUTION OF THE STUDY

3. 1 First part of the project (A & B)

The subjects, numbering 84, were male students of the University of Jyväskylä (age range 254—429 months). Tests of physical fitness were administered to the subjects before the day of the experiment. In the individual experiment the subjects had to repeat the movement of rising from a sitting position and stepping up to a platform at a free tempo both before and after a six-minute bicycle-ergometer working test. The movements were recorded with a stroboscopic photography technique. The analysis was based on three recorded trials, of which two preceded the task and one followed it. The movement was described in terms of kinematic variables based on motion and time study findings, on psychomotor findings and on findings concerning expressive movements. Factor analyses were computed from the intercorrelations of the dependent variables and those of the independent variables. Several analyses of variance were also computed by using a two-factor model with repeated measurements.

3. 2 Second part of the project (C)

The subjects, numbering 30, were young conscripts (aged 19—22 years) who had volunteered for the study. Perceptual ability tests and a general personality questionnaire were administered to the subjects prior to the experiment. Both the movement pattern analysed and the recording technique employed were the same as in the first part of the project. A greater number of kinematic variables were, however, used and measured on this occasion. In each individual experiment the loading consisted in an audiovisual multiple-choise reaction task that lasted about an hour (in two phases of equal length) and was to be performed in a highly motivated laboratory situation. The analysis was based on four recorded trials; two of these preceded the loading task, one took place between its two phases, and one followed it. The experiment was repeated after a ten-week period of muscular endurance conditioning with four exercise periods per week. There were three experimental groups, and the exercise load was different for each group. Factor analyses, regression analyses and analyses of variance (two and three-factor models with repeated measurements) were carried out.

4. RESULTS

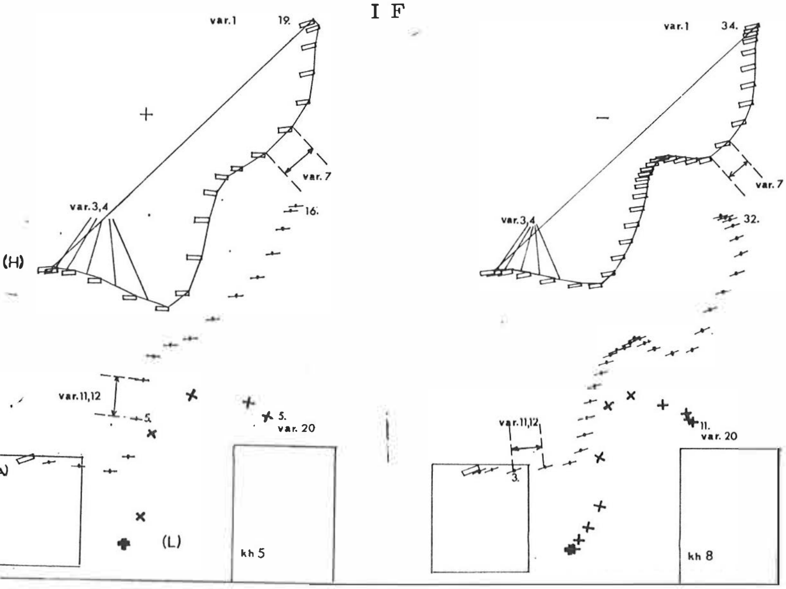
4. 1 The description of movement

The results of the factor analyses (A and C) revealed that two different principles governed the groupings of the variables. First, the most crucial factors, such as *TEMPO*, *WIDTH* and *TIMING*, were constituted by variables based on measurements of more than one motion path. By contrast, the remaining factors, i.e., *ARM MOVEMENTS, CURVATURE OF HEAD MOVEMENTS* and *CURVATURE OF ARM MOVEMENTS* had loadings mainly in variables descriptive of a single movement path. These results rested on the general analysis of the various measurements in Study C (Figure 1). The analyses of the separate measurements carried out in the two studies suggested that factors for each particular movement path were constituted mainly by groupings of variables descriptive of the shape (width and curvature) of the path. Such were for example, *HEAVINESS OF MOVEMENT* in Study A (Table 1) which had loadings in the width-of-path, velocity and variability-of-movement and *WIDTH OF PATH* (arm) in Study C. With both types of factor, the dimensions most important for description proved to be the tempo or velocity of the movement, the width of the movement path, the temporal pattern of the components of the movement or timing, and the curvature of the movement paths. The results of the Study C suggested, moreover, that a kind of ballisticity/tension grouping could be regarded as a factor on its own, separately from *TEMPO*. The reliabilities of the variables were satisfactory, as a rule, except those of a few timing and curvature variables. Regarding the latter variables, methodological improvements would be called for.

4. 2. The correlates of the kinematic characteristics of movement

The correlative associations between physical fitness and the variables describing the movement pattern, explored in Studies A and C were weak. The most uniform connections of *TEMPO* and *WIDTH OF PATH* were those with the *HEIGHT* component

I F

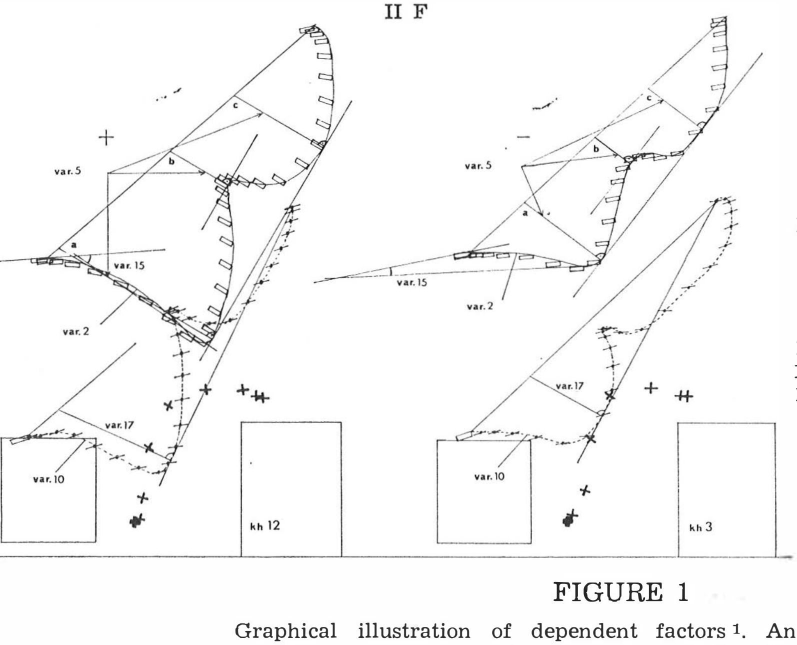


I Factor (varimax loadings)

TEMPO

3. Mean velocity (H)	.88
1. Time of movement (H)	—.83
4. Variance of velocity (H)	.69
20. Time of movement (H)	—.63
11. Maximum velocity (A)	.60
7. Maximum velocity (H)	.59
12. Phase of maximum velocity (A)	.40
6. Curvature of path (H)	—.40

II F



II Factor

WIDTH

2. Length of path (H)	.94
5. Width of path (H)	.88
15. Angle of tilt (H)	.76
17. Width of path (A)	.53
10. Length of path (A)	.45
1. Time of movement (H)	.40

FIGURE 1

Graphical illustration of dependent factors[1]. An analysis across the four measurements, n = 4 x 30 = 120. Examples of subjects with high (+) and low (—) factor score. Paths of motion: H = head, A = arm and L = leg.

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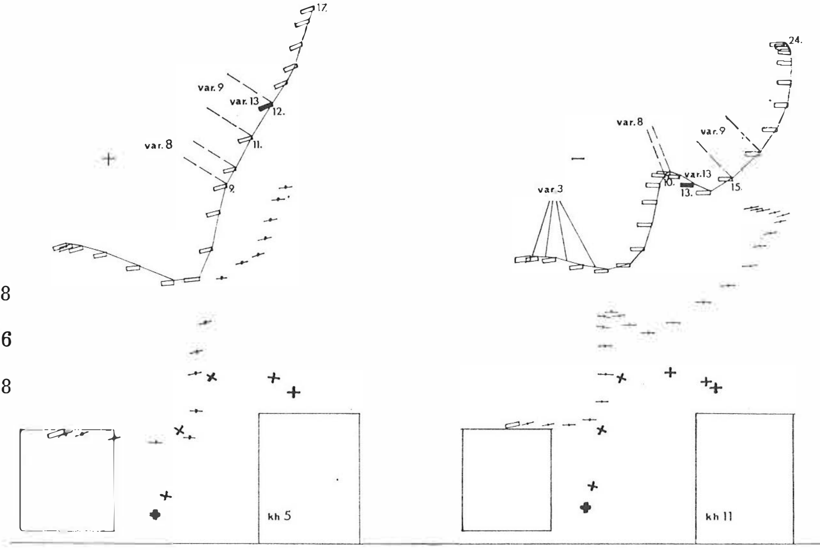
[1] Table of rotated factor matrix. See: Kirjonen, J. & Rusko, H. (1971) Studies in Sport, Physical Education and Health, 2. Jyväskylä: University of Jyväskylä.

III F

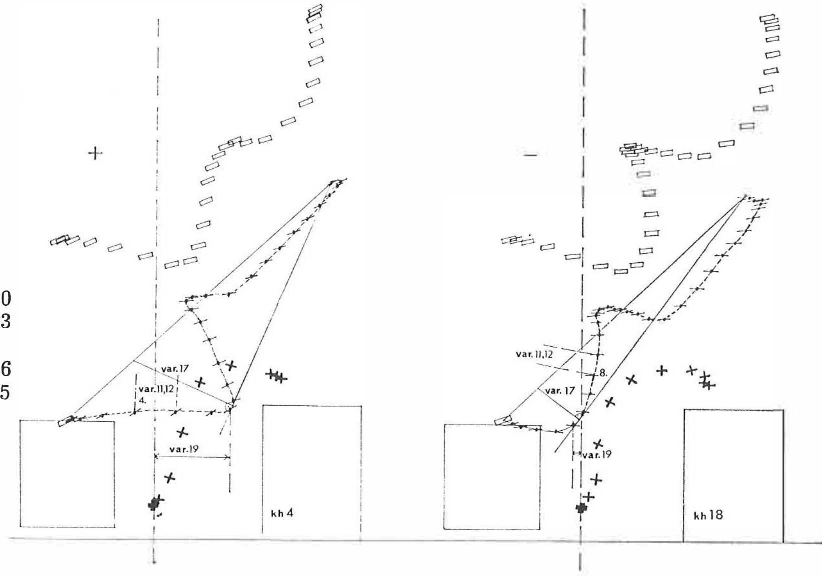


III Factor

TIMING

13. Supporting phase (L)	.88
9. Phase of maximum velocity (H)	.86
8. Phase of minimum velocity (H)	.78

IV F



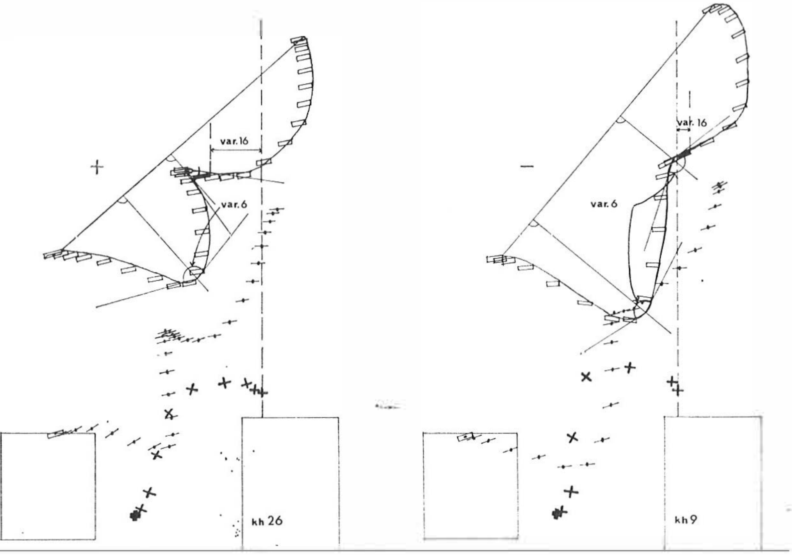
IV Factor

ARM MOVEMENTS

19. Timing (A)	.90
17. Width of path (A)	.73
12. Phase of maximum velocity (A)	—.56
11. Maximum velocity (A)	.55

2

V F

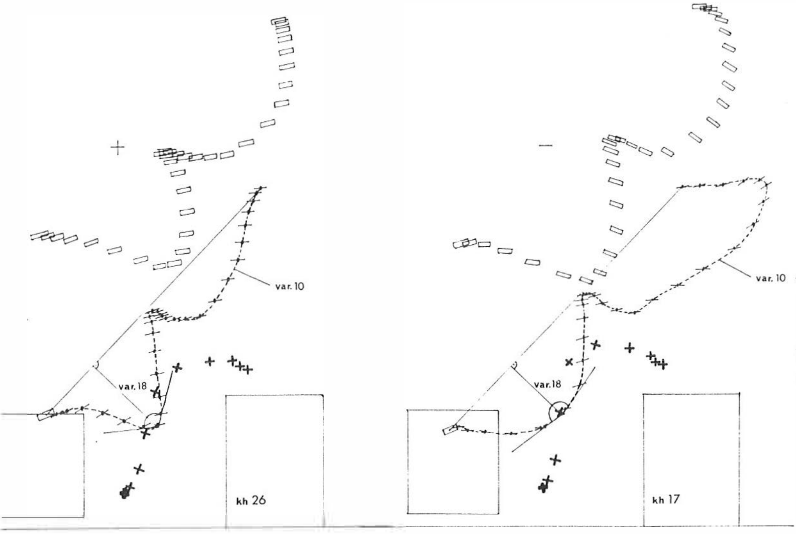


V Factor

CURVATURE OF PATH (H)

16. Timing (H)	.82
6. Curvature of path (H)	—.60

VI F



VI Factor

CURVATURE OF PATH (A)

18. Curvature of path (A)	—.51
10. Lenght of path (A)	.41

FIGURE 1 (cont.)

TABLE 1

Rotated factor matrices: varimax and promax solution.

	Varimax				Promax		
	I	II	III	h^2	I	II	III
Motion time	—95	—15	—04	91	—96	01	—04
Mean velocity	78	14	—46	85	86	—03	—48
Motion variability	—02	11	—60	37	05	06	—60
Width of path	—17	03	—69	51	—08	—01	—70
Smoothness of path	71	16	35	65	67	07	36
Leg timing	17	—03	07	03	17	—06	06
Arm swing	01	82	—16	70	—06	83	—09
Arm timing	14	83	—01	71	05	84	06
Eigenvalues	2.1	1.4	1.2	4.73			
% of starting communality	47.1	31.4	26.9	105.4	(Starting communality 4.46)		

Factors:

I Tempo of motion TM
II Auxiliary arm movements AM
III Heaviness of motion HM

Correlations between oblique factors:

	TM	AM
AM	26	
HM	12	14

of physical fitness. Apart from these positive correlations, ranging from .20 to .45 and interpretable on mechanical grounds, no other close connections with physical fitness factors were found. The measurement carried out in the interval between the two phases of the loading situation yielded negative but low correlations between *POWER* and the variables measuring the alteration-in-velocity (ballistic character) of movement (C); these may be symptomatic and merit attention in the design of future studies (Table 2, Appendix 1).

The size of the second subject group (C) was too small (n = 30) to provide a firm basis for interpretations of the relationships observed. Regression analyses revealed, however that the highest regression coefficients were those for *TEMPO* and, in particular, those for the alteration-in-velocity (ballisticity) variables loaded on it. The correlations with *RESPONSE ORIENTATION* (arm/visual stimuli) were positive and those with *NEUROTICISM* factors were negative. Negative, though lower, coefficients were obtained, in addition, for the *SPATIAL VISUALIZATION, RESPONSE ORIENTATION* (leg/auditory stimuli) and *EXTRAVERSION* factors.

The regression analyses (IBM 1967, Ralston & Wilf 1960) were found to explain no more than some 30 per cent of the

TABLE 2

The multiregression analyses, 2nd and 4th measurement, initial experiment. Summary of the analyses with significant R at the 5 % level. See: Kirjonen, J. & Rusko, H. (1971)

Sign ‡ or = : β-coefficient significant at the 5 %-level.
Sign + or — : The contribution of the factor to R exceeds 5 %.
Sign (+) or (—) : The highest β-coefficient; R is not significant.

Dependent variables

	I																II						III						IV						V		VI			
independent factors	I TEMPO		1. Time of movement (H)		3. Mean velocity (H)		4. Variance of veloc.(H)		7. Maximum velocity (H)		11. Maximum velocity (A)		14. Latency (H)		20. Time of movement (L)		1. Time of movement (H)		5. Width of path (H)		17. Width of path (A)		III TIMING		9. Phase of max.veloc.(H)		13. Supporting phase (L)		IV ARM MOVEMENTS		11. Maximum velocity (A)		17. Width of path (A)		16. Timing (H)		VI CURVATURE OF PATH (A)		18. Curvature of path (A)	
measurement	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.	2.	4.
Power		-		+		=			=	=						(+)		+				+						(-)						+	-					
Height	+	‡			‡	+	‡	‡			‡	‡									+								+		‡	‡	+							
Endurance																				(-)																				
Response orientation	+	‡		-	+	‡	‡	‡	+	‡	‡	+			=			-					-	(-)		(-)	-				‡	+					-	(-)		-
Spatial visualization						-		=	-	-			+	‡	+						‡	‡	+		+		+		‡				‡	‡						
Response orientation							=					-							=				‡		‡		‡					-			=	(-)				
Perceptual speed													=		-															+					+					‡
Neuroticism							=		=				+	+									+												+		=		(=)	
Extraversion	-		(+)	+	-						-						(+)	+	+												-									
100 x R^2 (%)	27	37	12	26	26	42	57	41	38	40	35	37	29	31	33	8	12	26	22	5	26	23	38	5	29	5	30	6	22	10	35	37	26	23	35	12	23	10	17	27

variances of *TEMPO* and of the variables loaded on this factor; mainly psychomotor variables and bodily constitution variables contributed to the explanations, but personality traits also played a part. The percentages ranged from 53, for the variance of the velocity variable, to 12, obtained for the time of movement variable. It seems that gross motor behaviour can be accounted for partly in terms of certain characteristics of the individual that must be regarded as permanent, at least in the sense that they are independent of the task in question and do not depend principally on his physical fitness. They may, however, also be related to individual differences in the interpretation of the situation (instructions, contents of the questionnaires, etc.).

4. 3. Effect of loading on movement characteristics

The analyses of variance (Winer 1962) computed from the results of the two subject groups (B and C) showed, first, that the largest changes in the means were those that occurred from the measurement performed immediately before loading either to the one performed after it (B) or to the one carried out between the two phases of the loading task (C); Figures 2 and 3). The results of Study C suggested that a return to the initial level began soon after the cessation of loading. In both studies the loading was of such intensity and duration that it was not difficult for the organism of a healthy individual to adjust and equilibrate its functioning adequately.

Physical loading mainly speeded up the tempo of the movement and increased the variability of its velocity as well as the width of its paths. In the psychomotor loading situation an increase was found in tempo and width of path (but not in the variability of velocity) variables; moreover, arm movements became much more expansive. It should be noted, however, that by far the largest increase observed in velocity (tempo) in the latter study (C) took place prior to the beginning of the loading task. This increase was perhaps due to the strong motivational incentives used (competitive situation and money prize). An observation compatible with this explanation was the decrease in velocity that was observed after completion of the task. Perhaps the most distinct difference between the effects of the physical and psychomotor loading situations was that in the latter case the variability of velocity did not change from one measurement to another, despite the increases that took place in velocity and in the width of the paths. The differences between the effects of physical and psychomotor loading make plausible the assump-

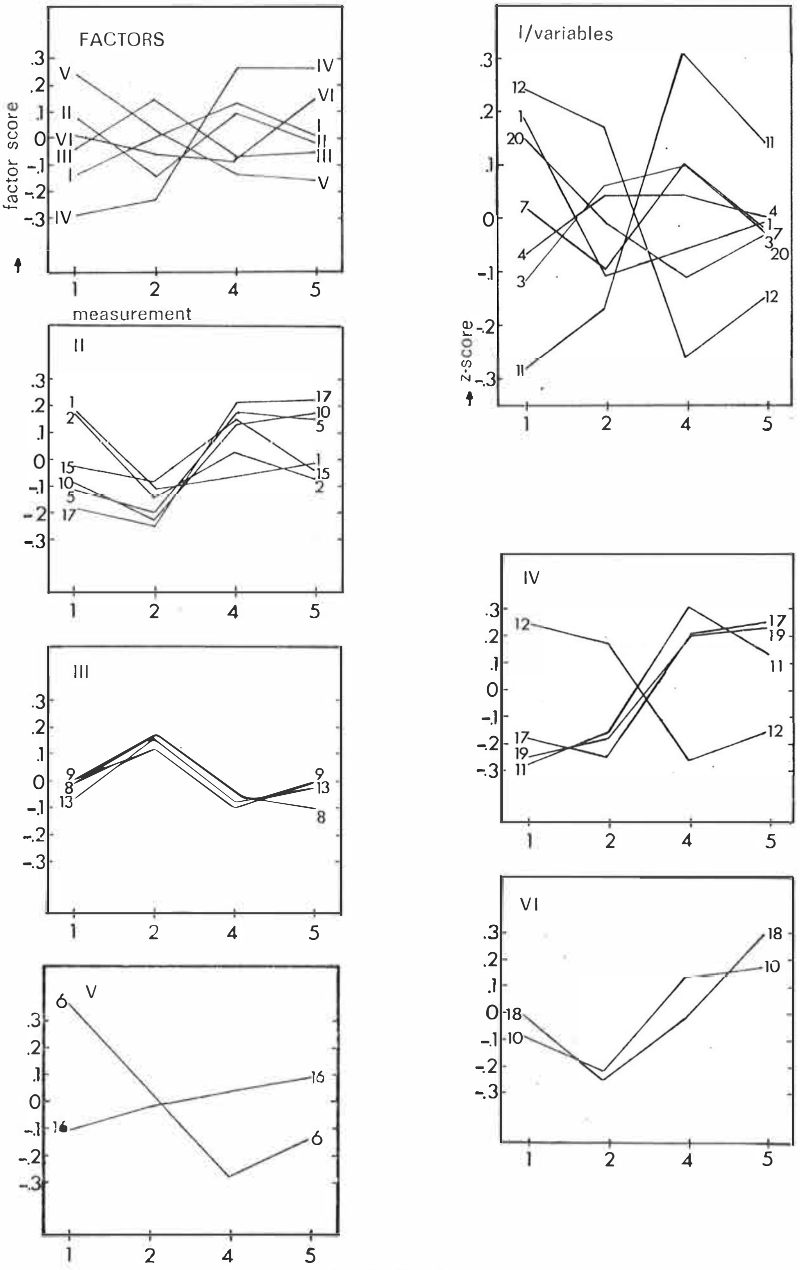


FIGURE 2

Changes in the means of factor and z-scores in the initial experiment. Factors: I = TEMPO, II = WIDTH, III = TIMING, IV = ARM MOVEMENTS, V = CURVATURE OF PATH (H) and VI = CURVATURE OF PATH (A).[1]

List of variables See: Appendix 2.

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[1] Tables of means and standard deviations. See: Kirjonen, J. & Rusko, H. (1971) Studies in Sport, Physical Eduction and Health, 2. Jyväskylä: University of Jyväskylä.

tion that the origin of variability in motor reactions is mainly peripheral (Deese 1962, Gellhorn 1967, Grandjean 1968).

Not only alterations in the means but those in the standard deviations for the groups of subjects in both studies were considered. The pattern common to both samples was an increase in variables of arm movements and a decrease in other variables.

Symmetric transformation analysis (Mustonen 1966) was used to render the results of rotation yielded by the factor analyses (Harman 1967) similar. This made it possible to compare the structural deviation coefficients obtained and to find out how they were distributed among various factors and variables (C) and how they were related to the changes in means reported above. The structural changes capable of reliable interpretation proved to be few in number. Some of the largest of these had occurred in the variables with the largest changes in the means (arm movements). Others had taken place in the timing variables, but the reliability of these variables was found to be questionable.

4. 4. Interactions of loading and certain subject variables

The modifying effect of physical fitness upon the changes observable in a loading situation was analysed in both subject groups. The analyses revealed (Figures 2, 3 and Appendix 2) that in both cases those subjects who scored higher than the average on *ENDURANCE* and/or *GENERAL STRENGTH-POWER* (B) exhibited a significant increase in the velocity of the movement. In the same subgroups of subjects there was a tendency for the width of the paths and for the variability of velocity to diminish, although less uniformly, whereas the means of thease variables for those who scored lower displayed a tendency to increase. In the physical loading experiment the measurement carried out after the loading task revealed a significant rise in velocity for those who scored lower than the average on *POWER*. In the psychomotor loading experiment this was not the case. On the other hand, auxiliary arm movements were strikingly in evidence in the psychomotor loading situation; this was particularly so for those scoring low on *HEIGHT* and high on *POWER*, with whom the inceases in the width-of-path variables were also most conspicuous.

Certain components of physical fitness, such as endurance, apparently had a bearing upon the changes of the shape of paths observed in the total movement pattern both in the physical and in the psychomotor loading experiments. Better

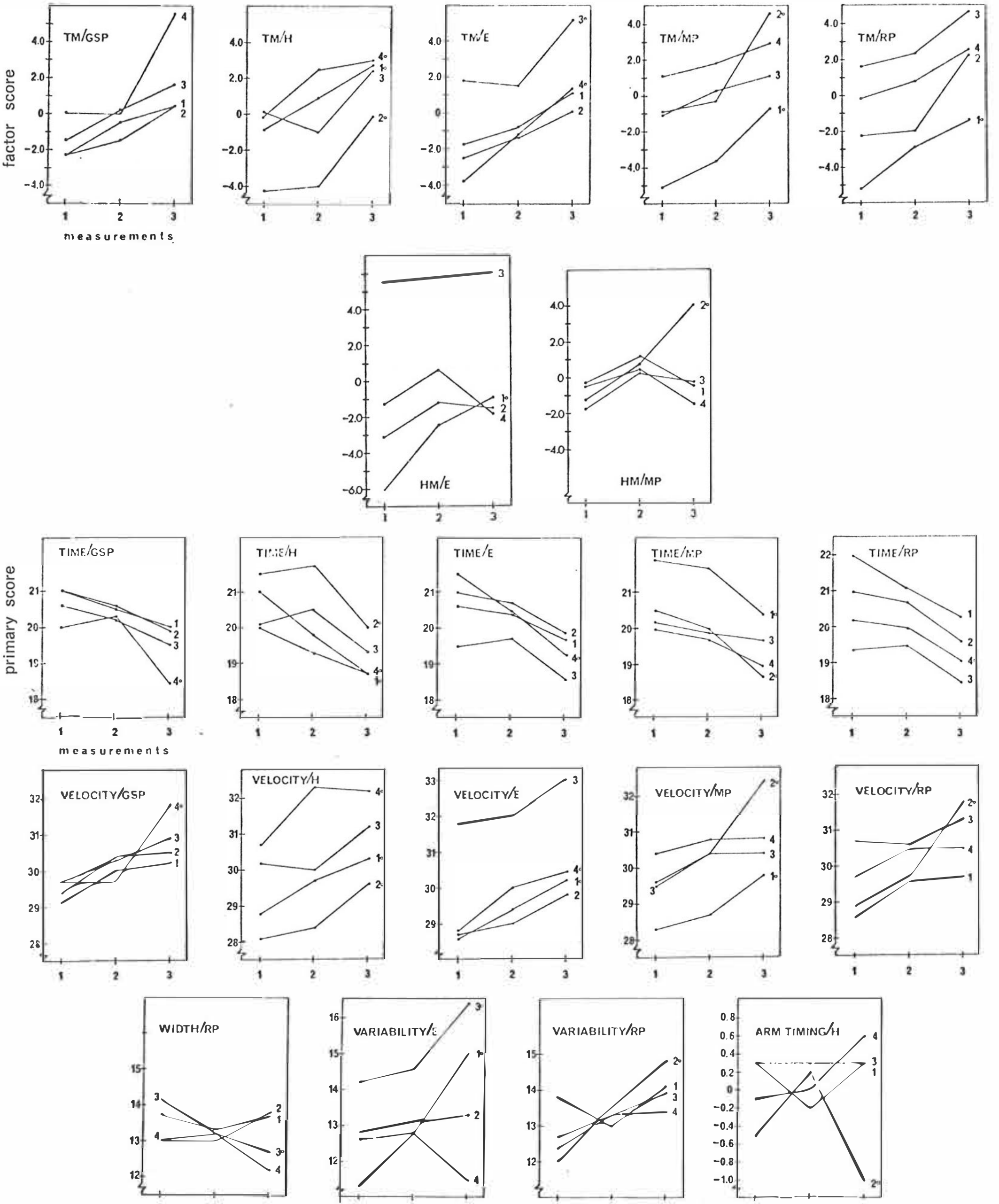

FIGURE 3

Profiles for repeated measurements at levels of fitness factors. The graphical presentation includes significant main effects, simple main effects and interactions obtained by means of analyses of variance. Symbols: TM = Tempo of motion, HM = Heaviness of motion, GSP = General strength-power, H = Height, E = Endurance, MP = Moving power, RP = Running power. o = The level with significant simple main effect.

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[1] Kirjonen, J. (1970)
The relationship between some components of physical fitness and the modification by muscular exercise of the movement pattern in rising from a sitting position and stepping up to a platform. Reports from the Department of Psychology 101, University of Jyväskylä, Finland.

than average endurance (and general physical fitness) was associated with smaller than average changes caused by the loading situation: the width of paths increased less.

The two general personality factors, *NEUROTICISM* and *EXTRAVERSION*, and *RESPONSE ORIENTATION* (leg/auditory stimuli) were also found to modify the effect of loading. The subjects who were high in neuroticism hastened to take the step earlier than the other subjects; the performance was not speeded up, however. In the high extraversion subgroup, again, the width of arm movements increased and these movements became more curved. These findings, although in the same direction as those of some previous studies, permit merely tentative conclusions. The interactions of the *RESPONSE ORIENTATION* factors were less consistent than the effects described above, and were found in analyses of variables of rather low reliability. It seems woth while to consider them in greater detail in future studies.

4. 5. Effect of loading and endurance conditioning

One of the goals in Study C was to examine whether the effect of a psychomotor loading situation differend after endurance conditioning of approximately ten weeks' duration from the one observed initially.

The general observation was made (Figure 4) that in the subgroup for which the load per exercise period was most strenuous (working heart rate about 160/min.) no significant alterations occurred in the means from the first measurement to the one performed between the two phases of the loading task, whereas such alterations were recorded in the means of several *WIDTH OF PATH* and *ARM MOVEMENT* variables for the other two subgroups. In comparison with the changes found in the middle group (working heart rate about 140/min.) the control group (working heart rate about 90/min.) did not behave in a clearly different way. The standard deviations displayed tendencies similar to those found in the means during the corresponding intervals. The standard deviations in the third group mostly diminished — whereas those in the other two groups increased — over the interval concerned.

Juding by these results, the conditioning that the subjects received during a period of approximately ten weeks — with four half-hour exercise periods per week — seemed to reduce those changes in gross motor behaviour generally observed during the loading situations that were examined here (cf.

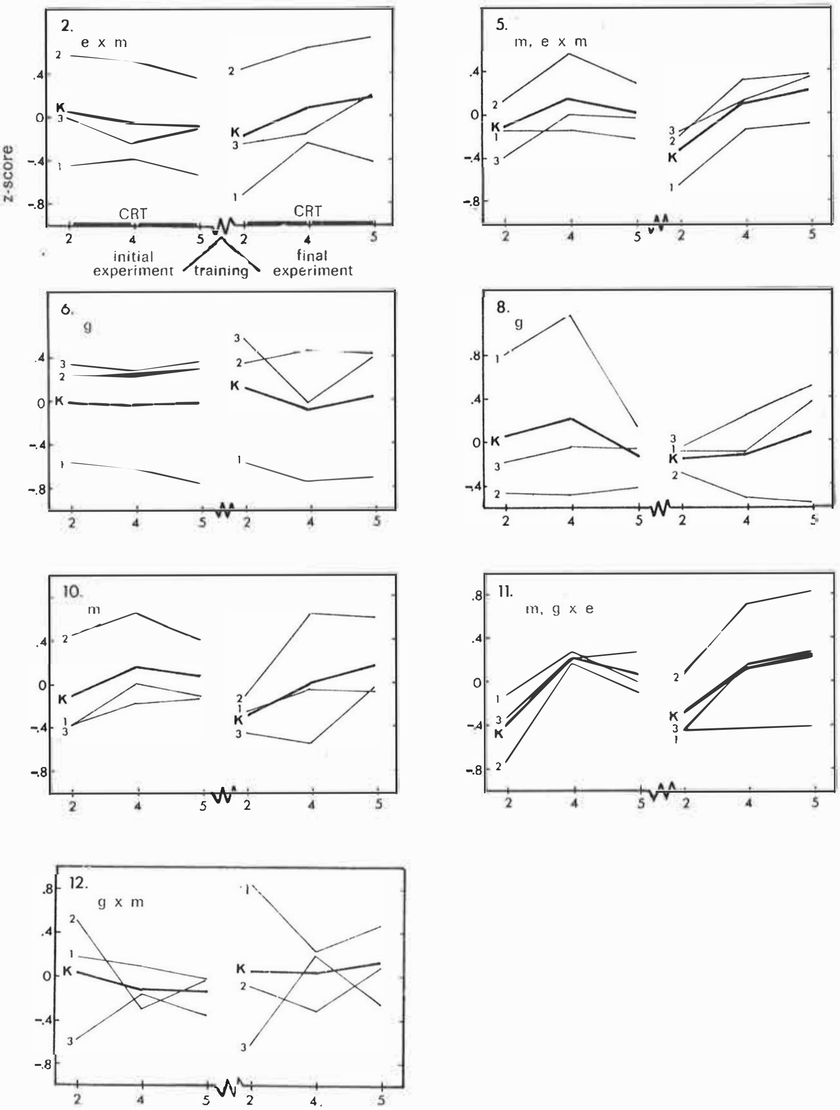


FIGURE 4

Analyses of variance. Significant (at the 5 %-level) changes in the group means of dependent variables. Source of variation: g = group, e = experiment, m = measurement and the first and second order interactions. 1, 2 and 3 = experimental groups, K = all subjects (n = 24).

List of dependent variables. See: Appendix 2.

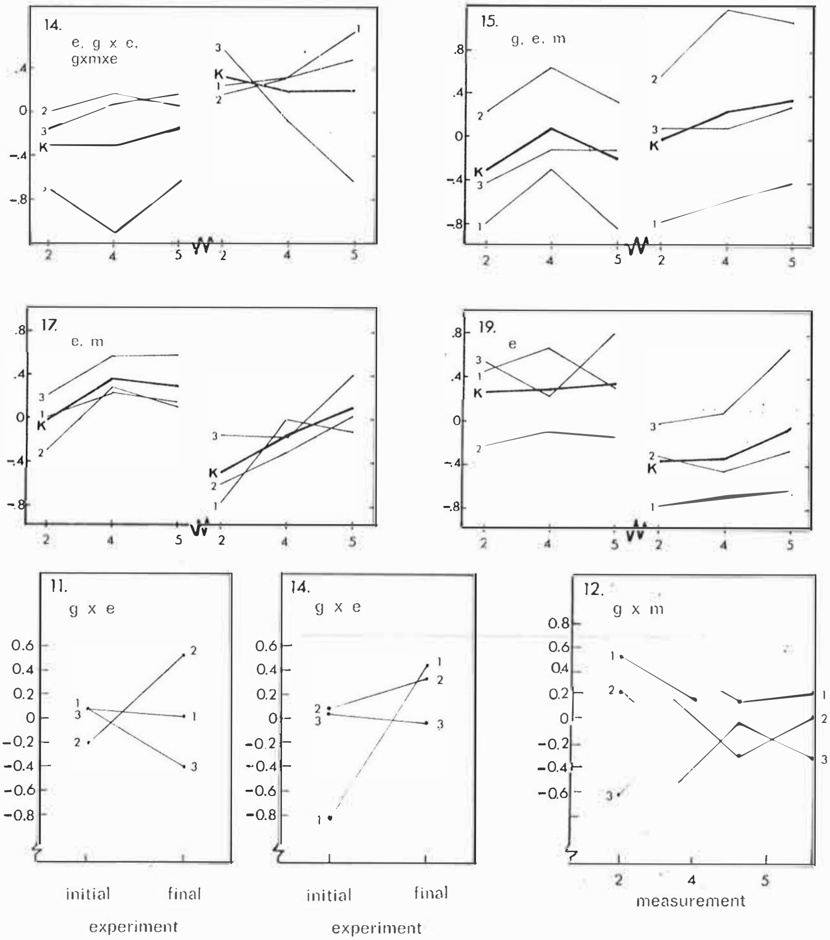


FIGURE 4 (cont.)

Hammerton & Tickner 1968, Teichner 1968). When the general effects of conditioning on the various components of performance ability were controlled (Figure 5), it was found that the test value of the heart rate as measured in the work experiment had decreased significantly in the heavy exercise group and in the middle group. Moreover, in the heavy training group specific exercise effects were observed in the scores for certain variables representing *POWER* (standing jump and shuttle run). By constrast, in the middle group negative transfer effects were observed, not only in these variables but also in all the other

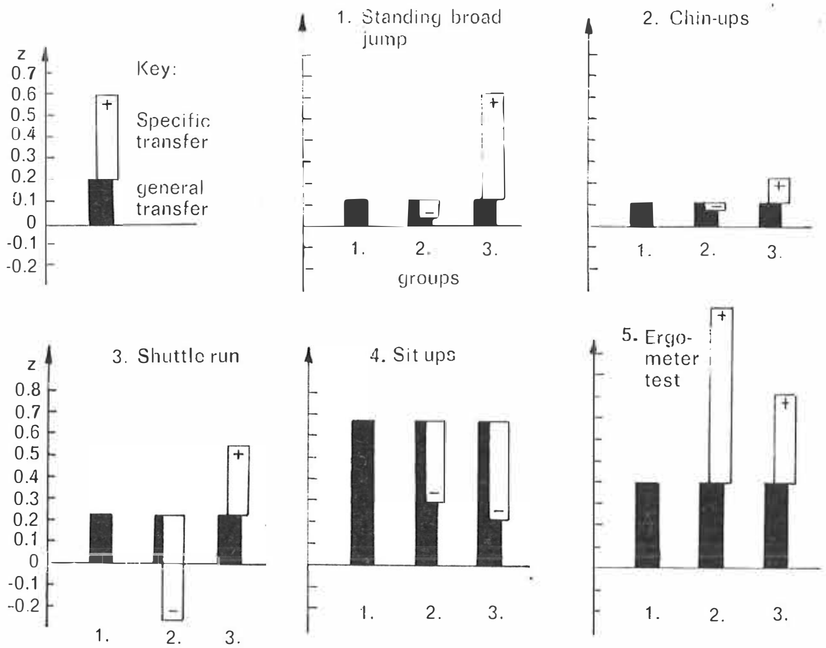
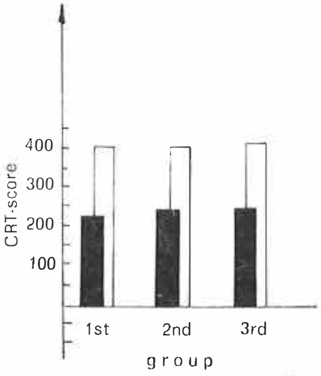


FIGURE 5

The mean alterations of the fitness test scores (z-transformed) during the endurance conditioning period. The direction of the specific transfer is indicated by the sign + or —.[1]

POWER variables (Kirjonen & Nieminen 1970). When all the observed effects of the conditioning are taken into consideration, it can hardly be regarded as pure endurance exercise. In none of the three groups was conditioning found to have an impact on the mean scores for the choice reaction test employed in psychomotor loading (Figure 6).



Means of the CRT-scores before (black column) and after (white column) the endurance conditioning.

1, 2 and 3 = experimental groups.

FIGURE 6

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[1] Table of means. See: Kirjonen, J. & Rusko, H. (1971) Studies in Sport, Physical Eduction and Health 2. Jyväskylä: University of Jyväskylä.

5. GENERAL DISCUSSION

One central object of this project was the development of a kinematic system of description for the characteristics of gross motor behaviour. I tried to design such a system in terms of measurements made on the movements of the lever system of the body: the velocities, the variability of the velocities, the width and curvature of the motion paths, etc. Following this I made use of factor analysis, in an attempt to group the variables so as to make them fit into a description of the dimensions of movement on a general level. The factor structures yielded by the factor analyses and various rotational solutions proved comparatively constant, even when the measurements were repeated at intervals of ten weeks. The factor dimensions employed here to describe a gross body movement cannot be assumed to cover the entire range of characteristics of motion; nevertheless, the experiences gained will provide clues for continuing analytical studies of complex, multi-phase movements.

The reason for using statistical multivariate methods was that the classical time and motion study of work is insufficient for the analysis of complex movement reactions. The task is analysed in small pieces or actions. Thus the cumulative scores of time and errors are the only measures of the whole performance (Barnes 1963, Blum 1956, Hasselqvist et al. 1965, McGormick 1964). Certain methodological inventions (e.g. Nadler 1963) apparently offer new opportunities for research, but the adoption of those methods has proceeded quite slowly. The long series of investigations carried out by Fleishman (1967) has comprised a plan for mapping out human psychomotor dimensions and abilities. One of the initial goals of his project has been to develop a system of task-taxonomies by means of a large set of empirical correlative data. The attempt, in which factor analysis has been applied, has been very successful even with complex motor activities (e.g. psychomotor apparatus tests). I applied the same methodological principles in these studies concerning a moderately complex movement task involving several activities of the lever-pendulum system of the body. The interpretable movement factors (tempo, arm movements etc.) showed that the method suggested by Fleishman is suitable also for this purpose. Most of the factors have counterparts in the general dimensions of time and motion study and of the study of expressive movements. The results also suggest that advances could be made in the description of the cooperation of different motor actions (width, timig). This amounted to a new approach to the analysis of the methods and strategies used by the subjects in solving motor tasks (Bernstein 1967, Crossman 1959, Oeser 1936). It is too early to say whether this method — called here ”kinematic taxonomy” — can offer definite advantages compared with other methods. Such analyses might, for example, shed new light on the question concerning the existence of a general coordination factor (ability) (Howell & Alderman 1967). In reference to Fleishman (1967) I think, however, that ”coordination” is tied so closely to specific skills that there is no general coordination ability. Further investigation concerning the kinematic structure of various movement tasks is called for. More information is also needed on the correlative relationships between the basic dimensions of movement and the external reference variables (mechanical and psychomotor). The inter-individual and intra-individual variability of the modes (strategies) should also be analysed. I would like to emphasize that the criteria for evaluating the model of strategy can be the optimal conditions for the subject (Crossman 1959, Miller et al. 1960) as well as the maximum output (performance).

The sensomotor regulation system has to be taken into consideration in selection of the task or tasks. In the present studies the movement was strongly automatized. Nevertheless, a two-phase pattern of movement introduces variability into the performance. One method of performance is that of ballistic action in which an initiation of muscle contraction wholly determines the chaining of successive phases of movement. Another method is characterized as action with continuous sensory regulation. In this method certain phases of movement appear accentuated, as a result of some kind of tenseness. If the timing and coordination of movement are the principal object of a study, it is obviously not very expedient to analyse precisely ballistic movements (e.g., several athletic events). We need more psychophysical facts about the selection of the regulation mechanisms and about the initiation of voluntary (willed) actions (Bernstein 1969, Greenwald 1970).

Particularly in the last phase (C) of the project, the point of departure was the assumption that the characteristics of a spontaneous movement pattern are explicable at least to some extent in terms of certain general components of physical fitness, spatial-visualization, psychomotor functions and personality. The components of spontaneous motor actions were not expected to be highly specific, despite the well-known specificity of psychomotor abilities (Fleishman & Hempel 1956, Nicks & Fleishman 1962, Vernon 1964).

As far as physical fitness was concerned these assumptions were at least partly erroneous. Even the results of the first part (A) of the project, where the group of subjects was substantially larger in size and far more heterogeneous than in the second part, seemed to contradict such an assumption. The correlations in fact indicated that two relatively different areas were in question.

These findings show that the kinematic characteristics of the movement are more closely associated with body constitution than with motor fitness. This might be due partly to instructions and partly to the basic movement variables (measures of time and distance). Despite the fact that the effects of body constitution were controlled through the experimental design, the way in which the movement variables were constructed must be taken sufficiently into consideration. The body shape of a subject may be a criterion for the physical requirements of a movement task. Variables measuring changes in angles and angular velocities might also be useful in the description of a movement. In another respect, however, the inclusion of physical fitness variables proved well founded: certain components of it — notably endurance — were found to be of signifiance in the study of the effect of loading on gross motor behaviour. It might in fact be important to explore separately how far non-linear analysis models could be helpful in the description of the interrelations between physical fitness and the characteristics of movement.

The independent variables explaining the normal performance of a movement task need not necessarily be indicators of the maximal range of scores, but they may indicate the optimal range of performance. This presupposes that the scores will vary within average limits of some kind. The normal limits of variation will be exceeded in both directions. Thus regressions with certain components of fitness (A and C) might also be nonlinear.

Among the linear relationships that were found to account for the characteristics of the movement pattern, those with psychomotor factors were the strongest, whereas those with reaction speed factors and motor fitness factors were the weakest. The general components of spatial visualization and personality, measured here by paper and pencil tests and questionnaire tests, did not explain the variance of the kinematic characteristics of the movement to a significant extent. It seems possible, however, that tasks representing a higher than average item complexity may have clearer associations with motor bahaviour than the measures employed in this study. With a view to the study of expressive movements, it might be worth while to experiment with more complex measures of personality traits, with the object of following certain of the clues furnished by the present study.

It would evidently be necessary to increase the complexity of the movement tasks if a greater variability in the modes of performing the task is wanted. Higher correlations could then be expected between the characteristics of movement and variables of personality and motivation than in the case of simple (ballistic) motor action.

The performance readiness of the upper limbs and, on the other hand, the tenseness perhaps reinforced by a competitive situation (Germana 1968, Ross et al. 1954) are likely to account for the characteristics of the composite performance (uniform velocity). Spatial visualization had negative correlations particularly with alterations in velocity; and thus, these connections were also interpretationally logical. The corresponding correlations of *extraversion* (positive with time of movement and width-of-path measures) are likely to be signs of individual differences in need for achievement (Brengelman 1957, 1968, Corcoran 1965, Eysenck 1956). Since only the questionnaire technique was employed in this study, the part played by the verbal factor must also be taken into consideration. Direct interpretations are therefore not possible. In fact it remains to be studied how far neuroticism and extraversion, as measured by employing other techniques also, will have connections with the individual's gross motor behaviour and what other characteristics of the individual may modify these connections (Konttinen 1968, a and b).

Ergometer work and other psychomotor loading of approximately an hour's duration, which was based on sensory overloading in a situation characterized by intensive motivation, seemed to have nearly similar effects on movement velocity, on the shapes of the paths and on arm movements. Physical fitness — and endurance in particular — were associated with lower than average changes in the values of the variables (except the motion velocity variables). If the changes are interpreted as compensatory responses of the organism's regulation system to loading (Darcus 1953, Gagne 1953, Welford 1968, Wilkinson

1965), the results of the present study suggest that a physically fit individual has a lesser than average need for regulatory activities.

The general alterations in movement velocity observed in both subject groups were in agreement with expectations and consistent with previous research results concerning the impact of arousal on motor behaviour (Deese 1962, Duffy 1967). The alterations were not, however, uniformly similar: the subjects with low physical fitness scores differed from those high in fitness. How could this difference be accounted for? One of the suggested interpretation models involved the summative interaction of fatigue and arousal as an explanatory factor.

As already stated, all sense modalities have afferent collateral link to *ARAS* (Duffy 1957, French 1960, Teichner 1968). On the other hand, the functions of the activating reticular system might be inhibitory or facilitatory to the motor cortex. A simple explanatory model is that of alternating effects of facilitative and inhibitory function in *ARAS* (Grandjean 1968). Summation of afferent impulses increases arousal in an organism when these impulses exceed certain limits of normal variation. Afterwards an active inhibitory function will dominate, as a result of sensory overloading. Thus cortical activity can be reduced. The antagonism of the two functions might cause symptoms of disorganization in the output, such as compensatory activities and fatigue.

Another plausible interpretation could apparently be offered by a model implying that there is an optimal motivation corresponding to each particular task (Duffy 1962). When loading remains the same, there may be some parallelism between the individual's ability (or willingness) to tolerate it and his physical endurance: if his physical fitness is good, loading may have a favourable influence (as arousal is approaching the optimum), whereas the influence may be unfavourable if his physical fitness is poorer (Study C). Simultaneous accumulation of fatigue may be a factor increasing the likelihood of an unfavourable end result (Darcus 1953). There might be reason to examine in greater detail the connections possibly existing between the various factors of physical fitness and the ability to tolerate pain or other discomforts (French 1951, Gellhorn & Thompson 1944, McConnel 1957, Petrie et al. 1959, Ryan 1969).

The effects of afferent stimulation or neuronal noise (Welford 1968) on the central nervous system is likely to depend upon the physiological state of the organism (Teichner 1968). One indicator of physiological state is physical fitness. At least two different explanations could be suggested. The increase in afferent impulses due to loading is less in an organism that is well-balanced and fit in respect to the load compared to one that is labile and unfit. On the other hand the variability of reactions may be determined by previous experiences through which the organism has learnt to tolerate unpleasant or even painful stimuli in loading situations. The compensatory and other reactions after physical and psychomotor loading in the present studies were fairly similar. These reactions were modified by physical fitness in both experiments (B and C). Thus the latter explanation suggested for these findings seems to be more adequate.

The reducing effect of ten weeks' endurance conditioning on the intra-individual and intra-group variability of the scores representing characteristics of the movement pattern was in the most intense exercise groups in the same direction as the modifying effect of physical fitness on the alterations caused by loading. The stability of motor functions and their low susceptibility to disturbing outside influences may be regarded as desirable goals, and the results suggested that at least the endurance component of fitness and endurance conditioning may have a favourable impact on them. However, the effects of endurance conditioning were clearly demonstrable only in the group for which the exercise program was very strenuous (Christensen 1953) and in which physical fitness improved extensively both in the endurance and the power areas. The effects of a similar conditioning program may be more clearly in evidence in individuals whose initial physical fitness is poorer as compared with the present subjects.

The results indicated that the responses to loading by the subjects with comparatively high neuroticism and extraversion scores (C) differed to some extent from those of the other subjects. No precise conclusion concerning the direct and indirect effects of these components on the various dimensions of motor behaviour can, however, be presented without further investigation.

An interesting finding is, however, that the most sensitive measure of the loading effect is the movement of the contralateral arm, as some early studies already indicated (Luria (1932). Thus it is reasonable to ask whether motor disturbances of this kind, in combination with symptoms of neuroticism, presuppose the existence of some individual personality trait contributing to the explanation of the disorganization tendency of performance in a loading situation.

The subjects in these studies were young males, and both groups of subjects were samples drawn from fairly homogeneous populations in respect of, e.g. educational and vocational background. Moreover, the subjects in both samples had participated in an organized training program for several months immediately before the experiments. Here we are confronted with a classical problem, typical of studies where students are used for subjects. The homogeneity of the sample entails certain drawbacks. An example are the hazards implicit in making generalizing conclusions. Also, the variability in one relevant variable or another may be rather small, and the significant differences are likely to be few in number (resp.: matching procedure for equating experimental groups). On the other hand, the homogeneity of the sample is an advantage in experiments where motivation, for example, should remain within a certain normal or desired range. The more homogeneous the group, the more consistently will the subjects interpret the verbal instructions.

Therefore it seems reasonable to assume that the positive findings and invariances arrived on the basis of the present data on homogeneous samples, though perhaps few in number, will also prove valid for heterogeneous samples of subjects.

Another important question was the selection of the movement task. Which are the most relevant criteria and what is the order of priority of those criteria in the selection of a task? How could most of the following criteria be taken into consideration simultaneously? The object is to choose a movement task which

a. involves actions of several groups of muscles and lever systems (gross body movement);
b. shows sufficient variation between individuals (inter-individual variability);
c. can be measured reliably (intra-individual stability);
d. is mechanically simple enough to be recorded by means of a photographic technique (two-dimensional recording);
e. is sensitive to different kinds of loading situations (sensitive indiacator of loading).

At the beginning of the project (A) major emphasis was placed on criteria a—d. Closely related to this choice were some preliminary results (Jones & Hanson 1961) concerning the analysis of a simple stepping movement. The outcome of the choice might have been different had the last criterion been considered to be as important as the other ones. The results might have been the same had complexity and continuous sensory regulation been included in the required task criteria. Furthermore, with a view to possible generalization of the results it would have been advisable to select more than one task. This was not done, mainly because the development of an effective movement analysis is methodologically a complex task, and a more detailed and multi-dimensional approach concerning a single task was regarded as preferable here.

In order to ensure that all the subjects would understand the movement task similarly, natural and spontaneous performance was emphasized in the instructions. It was also pointed out that the experiment had nothing to do with the selection of students or the evaluation of their academic achievement. It is not completely clear, however, how the subjects interpreted the experimental situation. In the last experiments (C) the situation may have been more strongly motivating than during the first ones, because of the money prize (for the CRT-test), the laboratory conditions with social pressure (several experimenters) and the verbal incentives (to the CRT-test). The homogeneity of the samples and the relatively high degree of educational training of the subjects are apt to reduce variability also in this case. It seems that there were no essential differences between the samples in the way the instructions were understood. In further research in this field varied and even unexpected effects of the instructions upon motivation have to be taken into consideration. This is a particularly relevant aspect in studies concerning the effect of loading.

In study C correlative statistical methods were used in a rather unconventional manner. Factor analysis was one of the principal methods in analysing data on a relatively small sample of subjects (n=30). The data was not sufficiently comprehensive for generalizations relevant to a larger population group. Neither was this an immediate goal of this project. Attempts were made to increase the reliability of the results of the factor analyses by careful selection of variables, by interpretations of several factor solutions, by checking the factor invariance and by transformation analyses. Furthermore the factor dimensions were employed in the principal statistical analyses of all experiments.

Another important decision was the one concerning the method of the analysis of repeated measurements. Preliminary studies had revealed that the use of gain scores, which was another alternative, presented much difficulty in interpretation. This alternative was given up, and recent studies have indicated that the decision was justified (Cronbach & Furby 1970, Harris 1967). The analysis of variance (multi factor experiment with repeated measurement) was then chosen as the principal statistical method. In estimating the error term (variance due to experimental error) the intra-individual variance had to be taken into consideration (Winer 1962).

6. OUTLOOK

In any movements performed with the object of achieving some goal, action against the gravitation of the earth is almost invariably involved to some extent. Gravitation tends to press down, to overturn, and to rotate. The human organism adjusts to this from the beginning, with the help of a number of innate reflexes controlling the maintenance of posture. The organism is able to reduce the impact of gravity on its movements in ordinary life situations through regulating postures, movement components and muscle tonus, and in many cases, by making use of gravity as a means to attain the goal of action.

All human movements consist in fact of combinations of two components only, the movement directed toward (or away from) the goal of action being combined with a movement meant to reduce the impact of gravity (or simply with an alteration of muscle tonus). In principle, any movement whatever can be described by a physical equation which determines the displacement over time of the centre of gravity of the body or of a part of the body in the direction of the earth's field of gravity and in directions perpendicular to this. Through a kinetic analysis of the lever system of the body it can be demonstrated that one and the same movement of the centre of gravity can be achieved by means of various component activities. Kinematic analysis examines the properties of motion paths and the temporal relationships of component activities and their alterations. With regard to direct and indirect applications the most important merit of such analysis in comparison with kinetic analysis is that it makes use of variables which can be observed and classified even visually when necessary. Thus, the kinematic analysis technique is, in principle, analogous to the performance of a human observer and can be used in the training of such people. The efforts to keep the amount of work necessary for statistical multi-variate analysis within reasonable limits are likely to be most successful when the kinematic technique is applied.

Since the invention of photography, technical difficulties have no longer constituted the central problem in the study of human movements. This is clearly indicated by early studies and publications (Muybridge 1955). The movement of a point in a three-dimensional coordinate system and the corresponding alterations in velocity, acceleration and even in forces have been measurable, in principle, since this invention. Physically, motion has been very easy to analyse, and many basic types of human motor behaviour have in fact been subjected to analysis (Amar 1920, Bernstein 1967 and Fischer 1906). Fruitful applications of the results of these early analyses to fields of psychology have, however, been rare, the only important exception being the time and motion study procedures of engineering and industrial psychology. This state of affairs has certainly been due in large measure to the very low "efficiency" of motion analysis: the usefulness of the results is small in comparison with the necessary labour input and costs. The branches of investigation serving production have not felt a need to develop methods for purposes other than the analysis of those factors that have a bearing on the efficiency and accuracy of human work. Motion study has in fact constituted a kind of preliminary phase of the time and error study applied in job analysis.

On the other hand, not much attention has been devoted to motion analyses concerned with the development and learning of human motor patterns or to inter-individual differences in these. The areas of application of the results of such analyses would be likely to consist of prophylactic and rehabilitative health services, physical education and the education of the handicapped.

Thus, one of the most important points to which attention should be paid, in considering the lines along which the present project should be continued, is in fact the question concerning the efficiency ratio of the techniques of analysis. Three-dimensional recording, automatic data processing and the application of cybernetic theories may prove important in the further development of appropriate methods in this field.

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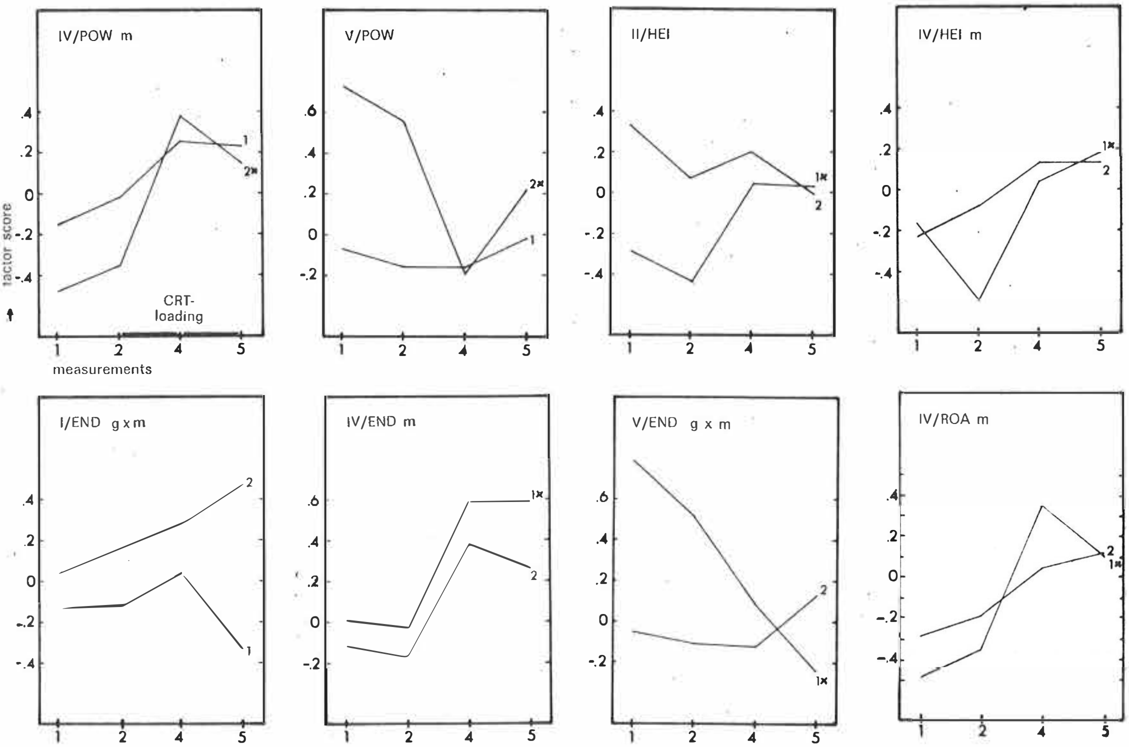
Appendix 1. Correlations between dependent (1-20) and independent (21-48) variables and factors, 2nd and 4th measurement; n = 30.

2nd mittaus measurement																											4th mittaus measurement																									
Time of movement (H)	Length of path (H)	Mean velocity (H)	Variance of velocity (H)	Width of path (H)	Curvature of path (H)	Maximum velocity (H)	Phase of minimum velocity (H)	Phase of maximum velocity (H)	Length of path (A)	Maximum velocity (A)	Phase of maximum velocity (A)	Supporting phase (L)	Latency (H)	Angle of tilt (H)	Timing (H)	Width of path (A)	Curvature of path (A)	Timing (A)	Time of movement (L)	Tempo	Width	Timing	Arm movements	Curvature of path (H)	Curvature of path (A)		Time of movement (H)	Length of path (H)	Mean velocity (H)	Variance of velocity (H)	Width of path (H)	Curvature of path (H)	Maximum velocity (H)	Phase of minimum velocity (H)	Phase of maximum velocity (H)	Length of path (A)	Maximum velocity (A)	Phase of maximum velocity (A)	Supporting phase (L)	Latency (H)	Angle of tilt (H)	Timing (H)	Width of path (A)	Curvature of path (A)	Timing (A)	Time of movement (L)	Tempo	Width	Timing	Arm movements	Curvature of path (H)	Curvature of path (A)
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	I	II	III	IV	V	VI		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	I	II	III	IV	V	VI
04	22	05	-05	15	11	-36	12	08	15	16	-07	-07	07	31	01	21	04	32	-06	04	21	07	21	04	-05	21. Standing jump	21	21	-17	03	17	14	-29	-18	-26	10	13	00	-29	25	15	08	26	03	25	04	-09	17	-26	24	-06	07
14	01	-19	-23	-06	25	-17	17	30	-11	-24	02	32	37	02	06	-01	00	01	03	-28	-04	28	-07	-02	03	22. Chins	24	00	-33	-24	00	19	-24	-06	04	-10	-30	01	-02	39	-06	03	02	-01	-10	00	-34	-07	-03	-06	-09	19
12	06	-09	-23	09	-09	00	06	09	19	-01	-11	13	-11	07	07	17	23	04	24	-16	06	11	11	-14	02	23. Shuttle run	-09	-09	08	-21	-14	-12	-01	37	23	18	14	-04	23	-12	-04	-17	-05	21	03	-19	03	-09	27	04	10	-08
-29	16	37	22	14	10	24	15	-04	22	45	15	01	18	00	22	34	-23	22	-05	38	23	10	23	-05	-17	24. Sit ups	-09	12	18	16	08	05	20	27	22	24	45	26	42	-12	03	18	27	-04	04	-10	11	20	35	11	-08	-16
-21	10	26	15	13	-08	18	-04	01	01	09	15	-02	-15	-04	-08	-04	-07	-03	-06	28	13	04	-10	08	-04	25. Working pulse	-07	19	19	09	21	-14	06	-09	-10	13	12	09	-08	-11	01	05	-01	-27	-05	11	16	24	-03	-07	-07	-20
-16	-33	-03	-02	-33	-01	00	-06	01	-18	-02	-12	-14	08	-25	-14	-16	-14	-12	17	05	-33	-08	-02	16	-06	26. Hold hand grip	-08	-30	-06	06	-28	01	-01	-07	06	-31	00	02	07	03	-21	11	-11	09	-06	21	-05	-33	01	-03	-05	12
-18	18	32	27	20	-23	-19	30	03	27	39	-08	10	-02	14	20	35	03	26	03	24	24	18	28	-22	-12	27. Height	-06	03	17	32	08	-25	04	10	06	26	41	18	03	-10	00	-01	17	-15	16	08	16	16	08	17	-02	-20
13	-04	-18	-19	-30	32	-40	02	26	06	-12	-12	24	19	-03	-23	-09	-25	03	28	-24	-11	18	-01	26	-34	28. Weight	33	12	-33	-26	-20	20	-44	-04	22	23	01	-34	11	04	-15	-19	26	09	22	41	-38	-02	09	29	15	-15
-18	04	26	27	08	-21	03	13	07	24	29	-18	06	-06	05	24	17	-19	10	-07	19	11	12	16	-20	-24	29. Height of leg	-17	-08	22	41	09	-28	20	09	-11	08	37	28	-05	-13	03	14	06	-24	02	-14	26	05	-04	05	-17	-06
15	08	-11	-12	15	-03	09	04	-03	07	-06	-09	15	07	10	08	00	-19	00	12	-17	08	04	-02	-19	-04	30. Extraversion	22	13	-19	-13	-03	-13	04	04	06	30	03	-29	12	-17	07	-24	16	11	11	-06	-20	07	02	20	06	-15
18	20	-07	-39	13	-14	-31	-01	02	14	-10	-24	-09	37	28	-03	08	-16	21	07	-15	16	00	12	-09	-17	31. Neuroticism	28	28	-16	-13	00	17	-12	-03	03	12	23	-26	-05	24	28	-14	18	10	34	07	-16	20	-04	28	21	-18
-12	-13	04	39	-08	10	39	-33	-17	-12	00	14	-38	-15	-13	-22	-04	34	-15	-02	26	-11	-31	-05	34	26	32. Lie-scale	-17	-16	12	15	14	11	-12	07	-06	00	04	24	-08	-18	-07	-03	05	05	-07	-08	20	-05	-03	-04	03	27
07	-12	-17	-22	-26	09	-06	-11	21	17	03	-10	15	18	-03	-27	04	-11	20	-04	-14	-16	09	20	24	-28	33. Bases	03	-13	-13	-33	-19	-02	-05	-14	-12	11	-17	-04	02	21	-07	07	14	-12	13	10	-13	-17	-06	16	-14	-11
04	-13	-12	-27	-23	-08	-39	08	18	22	22	-40	26	06	-08	07	20	-12	38	16	-20	-16	19	41	-13	36	34. Rotated figures	02	-29	-19	-35	-34	-21	-14	-08	01	-03	-04	-23	05	32	-20	17	11	-07	24	36	-22	-36	00	27	-28	-11
40	33	-28	-23	22	33	-19	-02	17	21	-11	-31	12	37	36	-09	30	14	23	36	-32	26	10	20	07	02	35. 3-dimensional space	36	14	-41	-36	18	08	-38	-02	12	24	01	-37	-07	51	30	-25	45	24	27	22	-38	10	-01	39	00	11
12	08	-09	03	06	-04	07	-03	14	24	21	-38	16	27	01	15	36	01	27	07	-12	08	11	37	-15	-13	36. Imaginary rolling	-04	-08	00	-07	-06	-08	04	-08	12	08	14	-13	22	26	-03	11	27	05	27	05	-03	-07	14	29	-14	-08
08	18	04	-17	08	09	-33	25	34	19	22	-15	30	33	16	-02	31	01	28	12	-09	18	35	25	00	-16	37. Dial reading	04	00	-05	-26	06	-04	-22	09	14	-03	14	-06	04	56	16	-02	22	-07	16	21	-10	02	14	18	-11	-01
21	17	-14	-20	14	30	-33	33	48	-08	02	07	44	23	14	-03	33	12	24	13	-26	15	45	16	00	18	38. Mechanical movements	17	00	-20	-34	16	-02	-31	22	16	-14	-16	-02	06	55	01	01	37	08	15	00	-26	00	16	18	-24	35
08	11	01	-07	06	21	01	12	11	26	22	-18	11	-07	12	00	44	24	45	00	01	12	12	44	06	04	39. Complex attention	-08	-11	08	-21	-07	-01	-02	32	28	08	07	-13	33	04	-06	-06	44	42	39	-09	03	-09	34	38	00	19
-20	-14	10	04	-21	-04	17	-06	-03	-08	05	22	-14	16	-29	-17	-30	-15	-21	09	17	-15	-07	-20	22	-14	40. RT	00	07	01	08	-10	04	06	-21	-14	02	11	28	-10	-12	-18	04	-35	-42	-28	00	02	03	-15	-28	06	-30
09	-01	-13	15	-06	04	17	-15	-04	08	-02	-12	-17	20	-21	-24	00	15	-05	23	-02	-06	-16	04	23	07	41. RT (time-limited)	00	-07	-08	11	-09	-13	11	-18	-11	09	-02	17	-09	-13	-14	03	-20	-33	-14	02	-03	-09	-15	-12	-05	-18
09	-16	-13	-30	-17	15	06	09	14	-12	-07	-02	05	12	-38	-12	06	-02	15	06	-14	-19	07	12	12	16	42. Reaction errors	00	-27	-09	-01	01	-16	20	12	08	-31	-28	18	23	04	-18	18	-01	-04	03	-11	-14	-24	11	-04	-33	35
-17	03	19	33	06	-12	21	-12	-09	23	33	-06	-15	16	15	02	02	-13	15	-44	28	09	-11	14	04	-22	43. CRT-score (arm)	-20	12	29	36	05	21	34	-20	-23	22	23	02	-13	-02	18	00	-07	-28	09	-26	38	20	-16	02	25	-33
-02	-29	-09	-40	-36	-03	-09	29	40	13	-01	10	37	14	-15	-29	-14	-02	-05	-05	-18	-28	34	-02	19	21	44. CRT-score (leg)	-12	-26	03	-08	-21	-04	08	01	07	-07	-23	11	04	21	05	-29	-27	-09	-08	06	04	-23	04	-15	19	-06
08	-13	-15	-34	-13	11	-08	15	05	-28	-28	13	12	-20	-21	-11	-08	23	-15	33	-19	-17	08	-14	05	29	45. CRT, time (arm)	14	-16	-24	-41	-10	-16	-26	20	27	-23	-28	04	20	-08	-24	-11	-01	29	-13	20	-33	-23	21	-08	-14	32
-19	-08	16	24	-07	-18	19	-08	-10	29	39	-19	-16	13	10	-03	07	-12	23	-40	27	-02	-12	28	06	-30	46. CRT (right-wrong)	-24	01	28	25	-09	19	38	-09	-11	19	32	-02	-01	-05	13	-08	-02	-19	19	-16	37	06	-05	12	31	-34
18	38	-04	34	43	11	03	-33	-44	-09	-08	-13	-43	-08	19	28	17	-08	-01	14	04	34	-41	00	-20	28	47. CRT, time (leg)	18	26	-13	12	26	04	-13	-16	-16	-01	06	-10	-13	-10	08	40	16	06	-02	-01	-12	23	-16	04	-29	09
09	-14	-14	-41	-30	09	-14	27	39	32	08	00	31	21	-07	-26	-01	-04	15	02	-21	-17	31	14	22	-29	48. CRT (right-wrong)	13	06	-13	-05	-04	10	-08	-18	-10	19	-08	02	-08	23	09	-24	02	01	14	10	-09	02	-13	09	18	-10
09	07	-08	-09	-07	20	-39	07	11	00	-01	-05	02	17	14	-11	03	-05	16	02	-08	02	07	07	14	-08	Power	28	15	-29	-07	02	21	-35	-23	-10	03	-05	-14	-19	24	02	-01	21	04	20	23	-25	06	-19	21	02	06
-20	12	32	29	14	-24	-08	22	01	27	39	-11	06	-07	08	19	29	-06	20	03	26	19	13	24	-19	-18	Height	-13	02	23	35	05	-28	12	14	06	23	45	20	07	-18	-01	02	13	-15	12	03	22	11	10	14	-04	-20
05	-15	-14	-12	-21	11	-18	06	10	-03	-03	-17	04	21	-04	02	01	-09	03	11	-15	-17	05	08	02	-08	Endurance	08	-20	-20	-03	-20	12	-12	01	06	-16	-03	-02	06	16	-09	05	04	15	03	04	-18	-24	00	08	-03	17
-18	04	21	39	08	-14	23	-17	-15	23	35	-09	-22	14	16	05	04	-14	16	-44	32	10	-17	16	02	-23	Response orientation (A)	-21	14	30	38	05	22	36	-20	-24	22	29	01	-13	-06	17	03	-05	-28	11	-26	40	21	-17	04	25	-34
27	23	-17	-18	12	22	-26	10	28	22	11	-31	24	32	19	-03	42	11	36	26	-24	18	23	36	01	-05	Spatial visualization	18	-02	-25	-36	05	-06	-27	05	13	08	03	-21	06	52	10	-01	42	09	28	21	-27	-04	10	36	-20	10
-03	-33	-10	-48	-42	-02	-11	34	45	12	-02	11	43	13	-22	-32	-16	-05	-02	01	-20	-33	40	-01	21	-24	Response orientation (L)	-07	-25	-02	-15	-24	-07	04	04	10	-04	-21	11	08	18	-04	-32	-22	-06	-04	10	-02	-25	07	-10	18	-05
-02	03	08	-01	13	-06	-14	09	-04	-06	-02	-03	10	-34	22	26	14	05	10	-23	01	08	06	06	-26	10	Perceptual speed	-10	-06	14	-03	07	02	-03	28	16	-13	-04	-18	13	00	11	00	23	43	19	-05	10	-01	21	16	00	30
12	18	-03	-36	09	-14	-43	15	05	14	03	-22	14	27	16	20	03	-38	17	09	-19	14	14	08	-29	-33	Neuroticism	26	25	-19	-14	-08	00	-17	-20	-05	04	12	-27	-05	26	14	10	-01	-13	13	18	-24	13	-10	11	-04	-34
31	20	-22	-04	26	10	10	-02	-04	11	-17	-15	08	09	17	07	10	-02	00	16	-26	18	-03	00	-15	12	Extraversion	25	17	-22	01	11	-08	00	-05	01	28	-08	-27	04	-12	15	-18	18	17	11	-10	-20	12	-06	18	03	-02

Level of statistical significance;
5 % and 1 % points of r:
.36 and .46 respectively

Changes of the group menns of *dependent factors (factor scores)*.



APPENDIX 2

The analyses of variance.[1] Initial experiment. Changes in the group means of *dependent factor scores:* at the 5 %-level significant main effects (m = measurement, g = group) the interactions (g x m) and the simple main effects (x) in the low (1) or high (2) group of the independent factor. Groups are classified by factor scores; n = 10 in both group.

Dependent factors: I = TEMPO, II = WIDTH, III = TIMING, IV = ARM MOVEMENTS, V = CURVATURE OF PATH (H), VI = CURVATURE OF PATH (A).

Dependent variables:

1. Time of movement (H)	11. Maximum velocity (A)
2. Length of path (H)	12. Phase of maximum velocity (A)
3 Mean velocity (H)	13. Supporting phase (L)
4. Variance of velocity (H)	14. Latency (H)
5. Width of path (H)	15. Angle of tilt (H)
6. Curvature of path (H)	16. Timing (H)
7. Maximum velocity (H)	17. Width of path (A)
8 Phase of minimum velocity (H)	18. Curvature of path (A)
9. Phase of maximum velocity (H)	19. Timing (A)
10. Length of path (A)	20. Time of movement (L)

Independent factors: POW = POWER, HEI = HEIGHT, END = ENDURANCE, ROA = RESPONSE ORIENTATION OF ARM, ROL = RESPONSE ORIENTATION OF LEG, NEU = NEUROTICISM and EXT = EXTRAVERSION.

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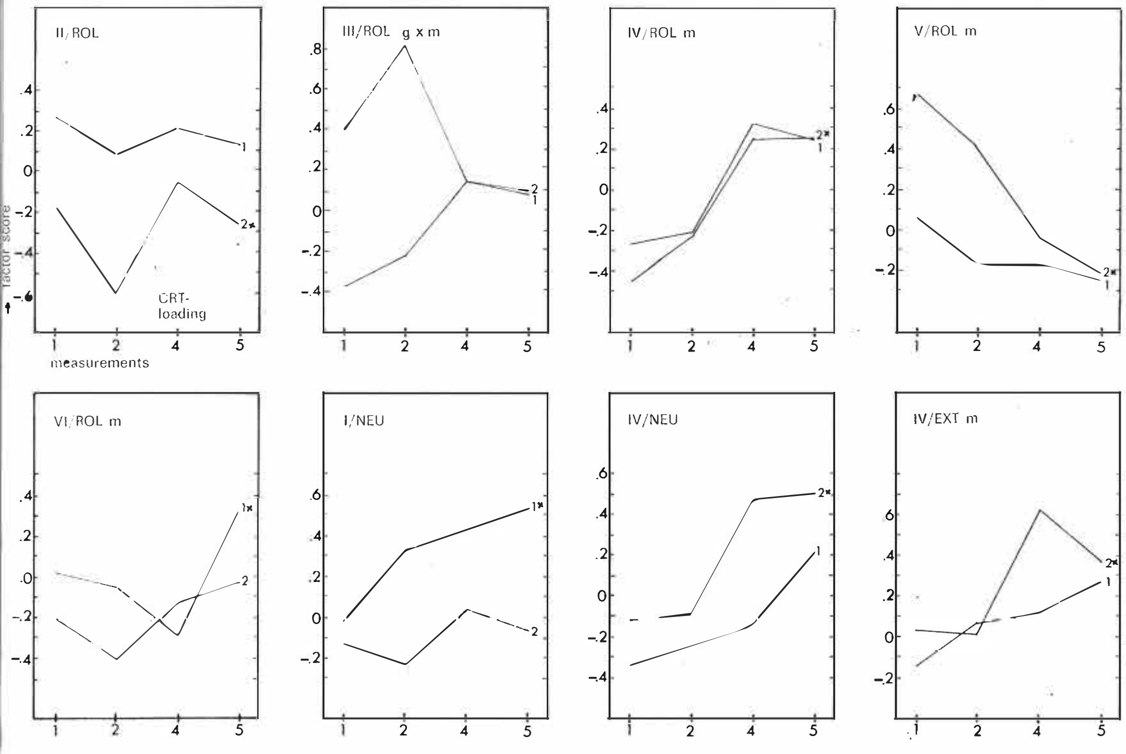
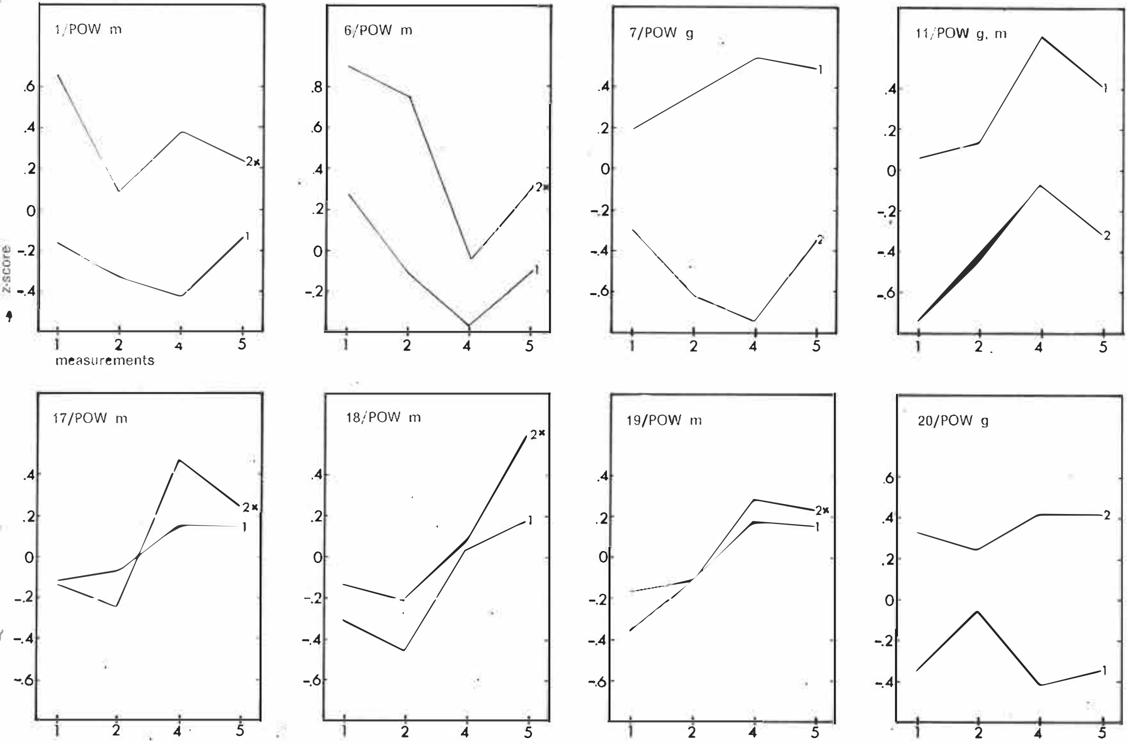
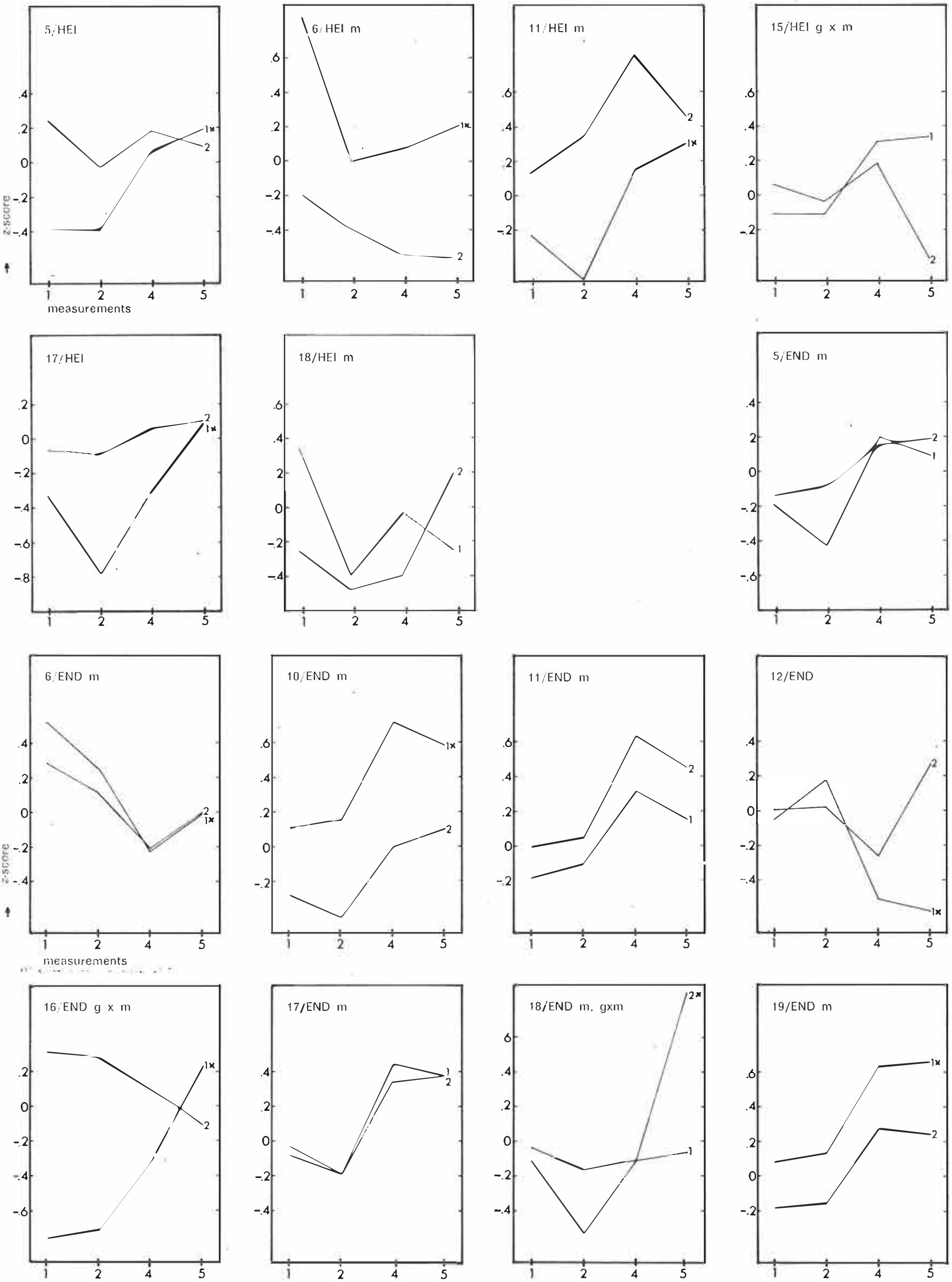
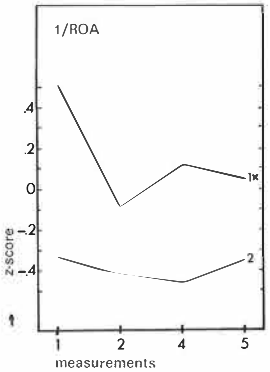
[1] Summary tables of analyses. See: Kirjonen, J. & Rusko, H. (1971) Jyväskylä studies in Sport, Physical education and Health 2. Jyväskylä: University of Jyväskylä.

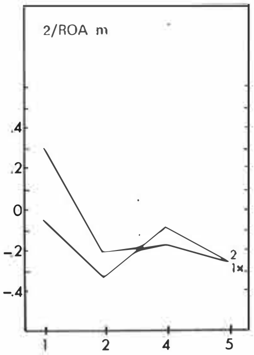


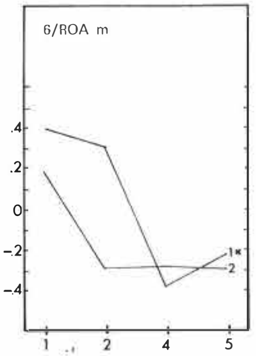
Changes in the group means of *dependent variables (z-scores).*

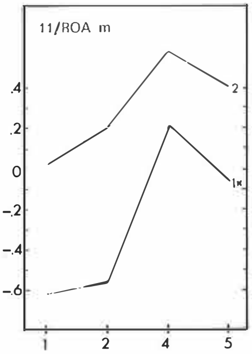


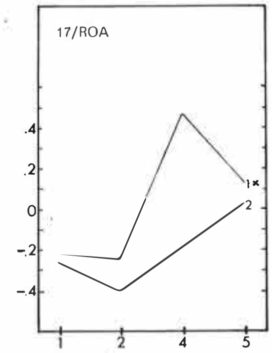

5/HEI
6/HEI m
11/HEI m
15/HEI g x m
17/HEI
18/HEI m
5/END m
6/END m
10/END m
11/END m
12/END
16/END g x m
17/END m
18/END m, gxm
19/END m
z-score
measurements
1
2
4
5
1x
2x
1
2

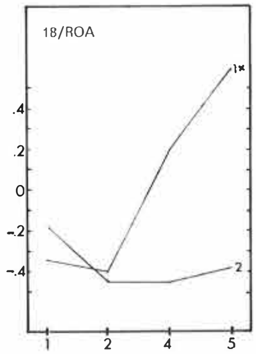

1/ROA
.4
.2
0
-.2
-.4
z-score
1
2
4
5
measurements
1x
2

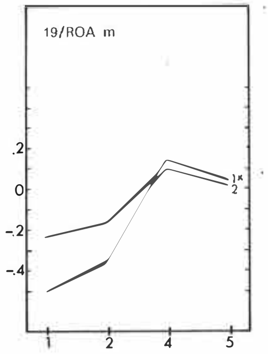

2/ROA m
.4
.2
0
-.2
-.4
1
2
4
5
2
1x

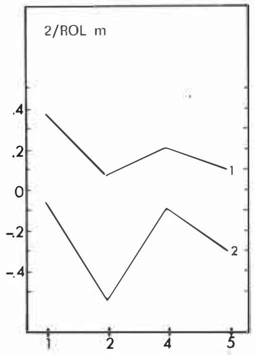

6/ROA m
.4
.2
0
-.2
-.4
1
2
4
5
1x
2

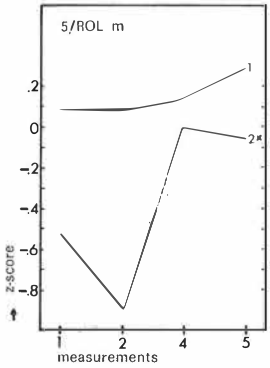

11/ROA m
.4
.2
0
-.2
-.4
-.6
1
2
4
5
2
1x

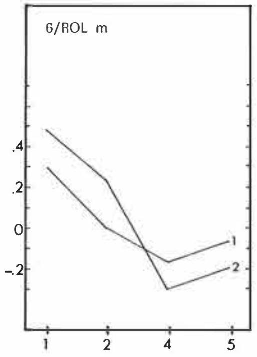

17/ROA
.4
.2
0
-.2
-.4
1
2
4
5
1x
2

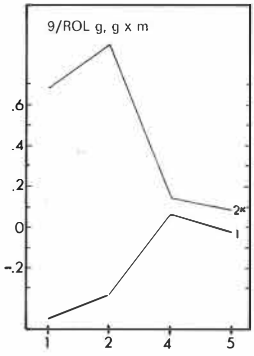

18/ROA
.4
.2
0
-.2
-.4
1
2
4
5
1x
2

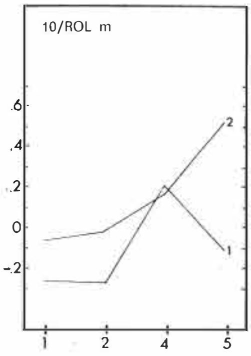

19/ROA m
.2
0
-.2
-.4
1
2
4
5
1x
2

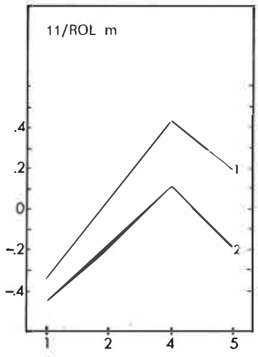

2/ROL m
.4
.2
0
-.2
-.4
1
2
4
5
1
2

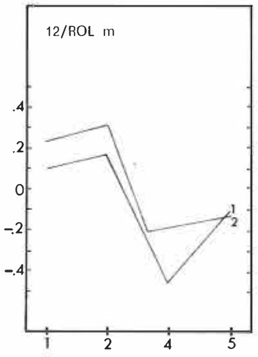

5/ROL m
.2
0
-.2
-.4
-.6
-.8
z-score
1
2
4
5
measurements
1
2x

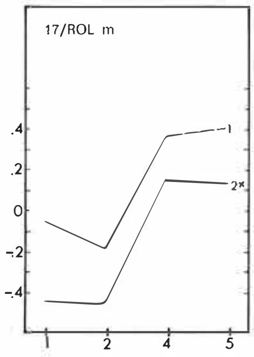

6/ROL m
.4
.2
0
-.2
1
2
4
5
1
2

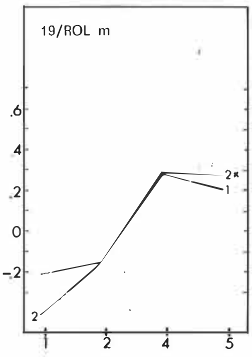

9/ROL g, g x m
.6
.4
.2
0
-.2
1
2
4
5
2x
1

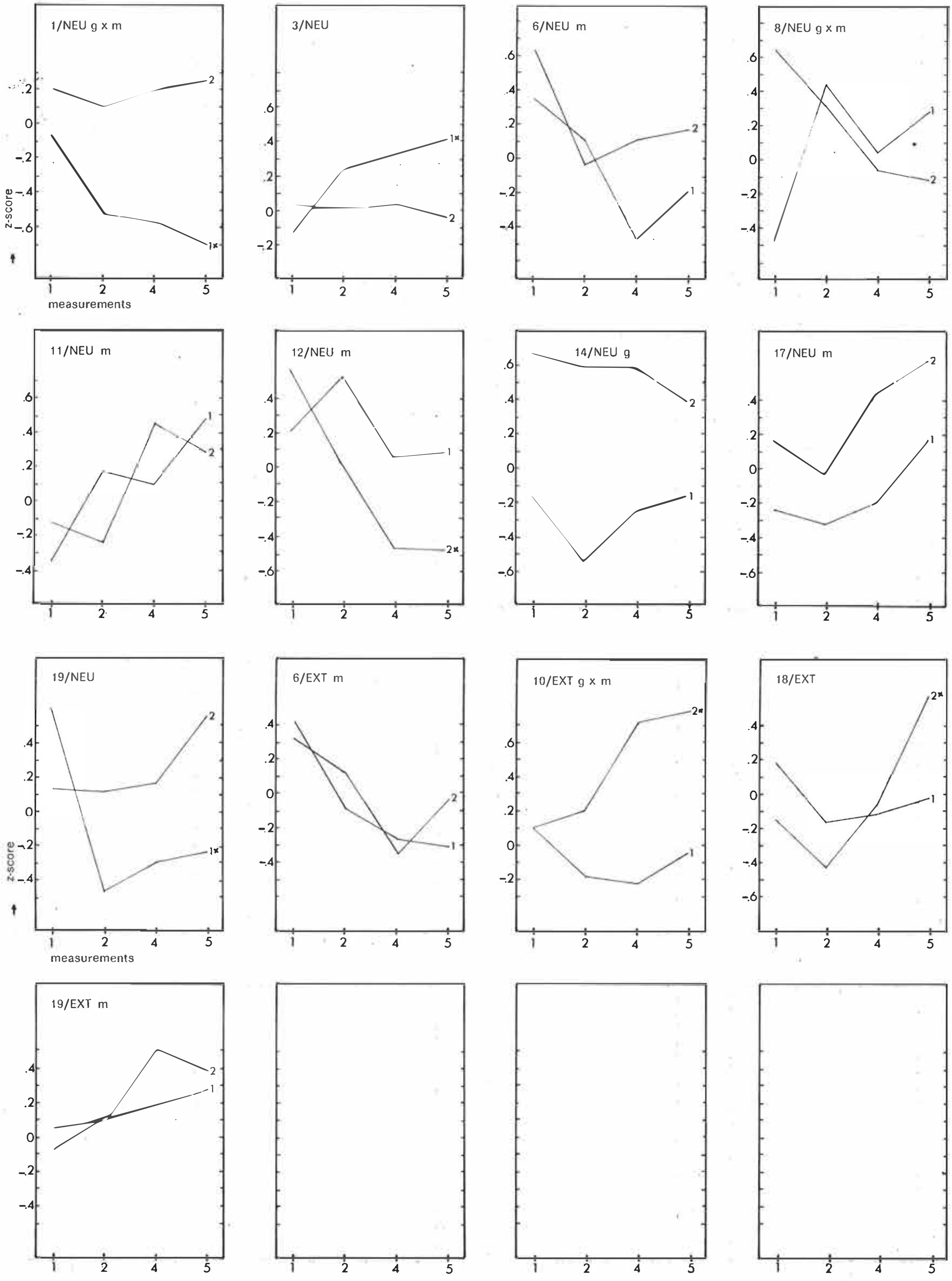

10/ROL m
.6
.4
.2
0
-.2
1
2
4
5
2
1


11/ROL m
.4
.2
0
-.2
-.4
1
2
4
5
1
2


12/ROL m
.4
.2
0
-.2
-.4
1
2
4
5
1
2


17/ROL m
.4
.2
0
-.2
-.4
1
2
4
5
1
2x


19/ROL m
.6
.4
.2
0
-.2
1
2
4
5
2x
1
2


1/NEU g x m
3/NEU
6/NEU m
8/NEU g x m
11/NEU m
12/NEU m
14/NEU g
17/NEU m
19/NEU
6/EXT m
10/EXT g x m
18/EXT
19/EXT m
z-score
measurements
1
2
4
5
1*
2*
.6
.4
.2
0
-.2
-.4
-.6