Effector Organisation in a Motor Skill

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Table of Contents

CHAPTER II (cont.)

Summary

This study developed from a demand in the literature for a more detailed and comprehensive understanding of the serial organisation involved in skilled performance. Its point of departure from traditional approaches was that the investigation sought to recognise the strategies of organisation used by the human operator, from a detailed multi-level analysis of the response in a repetitive speed skill. The particular interest was in the processes of effector organisation in the task - hand cranking.

Hand cranking in the sagittal plane was selected for it may be regarded as a ballistic type skill in which input and perceptual uncertainty are minimal, and which depends for its execution largely upon the processes of effector organisation. Further this particular task is suited to a detailed multi-level record of the on-going response. A pilot investigation established the suitability of the task for the purposes of the major study. In the major study, motion photography, a strain-gauge record of the force exerted on the handle of the crank, and an electromyographic analysis of the activity of the principal agonist and antagonist muscles about the wrist, elbow and shoulder

joints of the arm were employed to record the details of the on-going response.

The experimental programme required the subjects to crank against a heavy and light load using a large and small amplitude crank handle in a forwards and backwards direction. In all, 8 treatment conditions were involved, enabling an analysis to be made of the modifications in effector organisation with changes in load, amplitude and direction of cranking. 19 male subjects were used in a counterbalanced Treatments X Subjects design.

The effector organisation was evaluated in terms of the serial timing, positional timing and gradation of the response.

1. The serial timing of the response units (muscles and movements of the arm), involves firstly the sequencing of these units by organising them into the most effective sequence or order of occurrence and secondly the phasing or the temporal structuring of these ordered response units.
2. Positional timing is the relationship between the occurrence of the response or some component of the response and an external event or signal. It is a

similar notion to that of coincident timing.

3. Gradation involves the 'amplification' of the response so that the appropriate amount of effort is exerted.

The analysis of the results showed that phasing is of central importance in the effective organisation of the response by effector processes. This form of temporal structuring appears to be more significant than positional timing in the present task. None of the criteria of gradation used was closely related to speed of cranking. However there was some evidence that the faster subjects were also the more consistent, both in terms of the temporal structure and the gradation of the response. Changes in the amplitude of the crank handle and hence in the excursion of movement necessitated only minor alterations in the effector organisation, principally in positional timing. Only when the effective resistance to cranking was large did an increase in load cause considerable changes both in the temporal structure and gradation of the response. Performance on forward cranking was faster, more consistently organised and tended to involve less effort, than the performance on the novel backward cranking condition.

It was proposed that the human operator structures the response by using a hierarchically organised control system involving a general plan and two specific motor programmes, one for forward cranking and one for backward cranking. The general plan, operating in a closed-loop (feedback dependent) manner, controls the operation of each of the open-loop motor programmes. An attempt was made to describe the organisation and control by the human operator in terms of the processing of the feedback at the level of the general plan. Further, the notion of grouping or the formation of larger units of action was discussed in relation to the extent of the motor programme operating in an open-loop fashion.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge and belief, it contains no material previously published or written by another person, except when due reference is made in the text.

Signed

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CHAPTER I

INTRODUCTION

All skill involves the serial organisation of perceptual, central, effector and feedback processes. Lashley (1951) has emphasised the central position of this concept in the understanding of skilled behaviour: "... all skilled acts seem to involve the same problems of serial ordering, even down to the temporal coordination of muscular contractions in such movements as reaching and grasping," (p. 121).

The present study is concerned with an analysis of the serial organisation involved in a repetitive speed skill. In particular, the interest is in the effector organisation of the response. Effector organisation, a part of the general serial organisation process, has received little attention in empirical investigations, and has been largely overlooked in the theoretical formulations of models of skill. There has existed, what Miller, Galanter and Pribram (1960) have referred to as, "a theoretical vacuum between cognition and action", (p. 11). By effector organisation is meant the process by which the basic response units (muscles, groups of muscles or movements) are combined, temporally integrated and related to an on-going series of events. In this investigation an attempt was made by means of a detailed multi-level analysis of the response, to identify the strategies of effector organisation that the human operator uses in structuring and implementing a response. A strategy is regarded as any general approach or mode of organisation, which serves to meet certain objectives, that a subject may use to effect a particular response.

The Nature of Skill

Skill refers to that behaviour in which perceptual, effector and feedback processes are serially organised both spatially and temporally, and are related to some particular outcome. Skill in this sense refers to a process whereby input information is related to past, present and often future predictable events. On the basis of this information, the decision process initiates, and some effector mechanism organises the most effective response. The discrepancy between the response and the desired outcome in the form of feedback information is the basis for modifying subsequent behaviour in this particular situation. In this way the human operator may be considered as behaving as a closed-loop, error actuated servo system (Craik, 1947, 1948).

All skill involves the organisation and integration of component processes, but to differing degrees of involvement or contribution. The final outcome, the response, is an expression of the linkage of these processes. The many different skills and the different levels of skilled performance may be accounted for by the degree of involvement of such components and their effective organisation. Thus such skills as throwing, typing or playing chess may be regarded as a particular combination of the component processes.

Broadbent (1958), Crossman (1964) and Welford (1968) have provided hypothetical 'flow diagrams' of some of the component processes involved in skill behaviour (see Figure I:1). Such diagrams are based on the large amount of evidence now available and reviewed for example by Welford (1968). Even though the flow diagram is composed of a number of apparently separate processes it should be realised that performance depends not only on the operation of each of these, but on the relationships and integration between them. This system is never static or quiescent, but is continually active, organising, integrating and constructing. "Every bit of evidence available indicates a dynamic, constantly active system, or, rather a composite of many interacting systems..." (Lashley, 1951, p. 135).

The classification of skills as open or closed (Poulton, 1950) or as ballistic or strategic (Welford, 1962) describes which components are principally involved. An open or strategic skill, for example playing chess, is characterised by stimulus and perceptual uncertainty and the uncertainty of outcome because of the number of possible solutions. This type of skill clearly involves perceptual and central decision-making processes to a large extent. The effector involvement (for example, moving a chessman) is minimal, and its degree of refinement has little or no influence

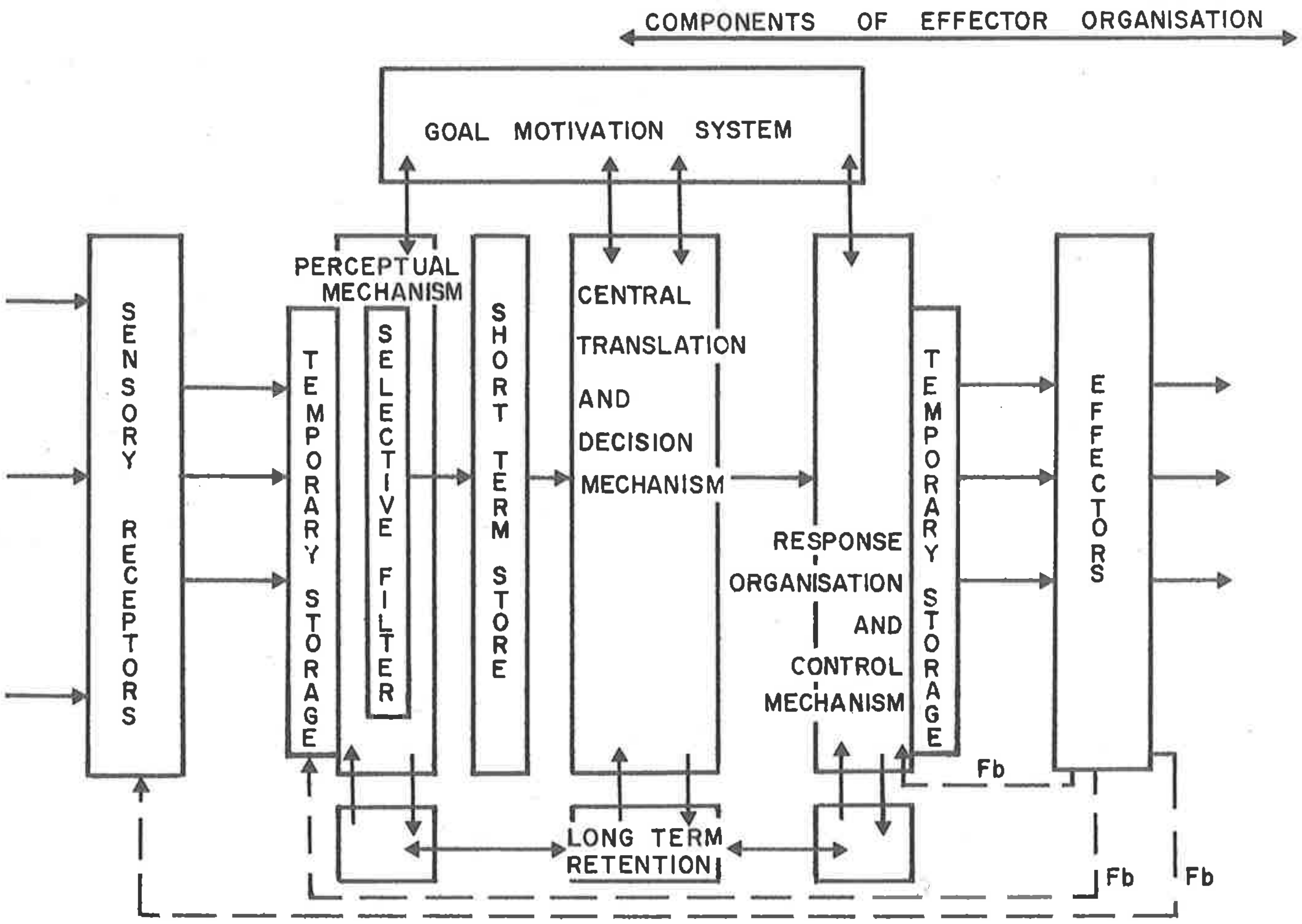

FIGURE I:1. HYPOTHETICAL FLOW DIAGRAM OF SOME OF THE PROCESSES INVOLVED IN SKILL BEHAVIOUR. (Derived from Broadbent, 1958; Crossman, 1964; Welford, 1968.)

on the outcome of the game. On the other hand, with closed or ballistic skills, the outcome is highly predictable and can be performed with little direct reference to the environment, as there is minimal stimulus uncertainty. Many athletic skills are of this nature, for example sprinting, and the shot-put, and involve essentially effector and response organisation processes. The criterion of success is usually dependent upon the effectiveness and degree of precision and accuracy of the response. Provins (1967) mentions a third classification, cognitive skills, (for example, problem solving in mathematics) to describe those tasks which stress the decision-making activities of the operator, in distinction to the perceptual and effector mechanisms which play a minimal role.

Welford (1969) summarised this consideration of skill as a compounding of processes;

> It has come to be recognised that there is no hard and fast line between sensory-motor and mental skills. Much of sensory-motor skill consists essentially of decisions which in turn require the recovery of information from memory, coordination of data in time and more subtly, 'strategies' implying prediction of the outcome of actions. All these are prominent in mental skills: the only major difference between the two types lies in the fact that mental skills typically do not involve the nicely graded motor action and fine perceptual discrimination commonly required in sensory-motor skills (p. 6).

Implicit in the use of the word 'skill' is some quality of performance or behaviour. Common usage of the term implies some expertness or practised ability (Fowler & Fowler, 1960). In general, the traditional definitions of skill in the psychological literature extends this view; "... an integration of well-adjusted muscular performances" (Pear in Henshaw _et al._, 1933, p. v) and "... the learned ability to bring about predetermined results with maximum certainty, often with the minimum outlay of time or energy or both" (Knapp, 1963, p. 165). Skilled performance, as distinct from unskilled performance, implies that the component processes have been effectively organised to produce a response that is a close approximation to the desired outcome. Such a response is said to be well coordinated, or integrated, to be accurately timed and appears unhurried and effortless.

The Control of Movement

In the serial organisation of a skilled response, two modes of the voluntary control of the movement seem to be involved, and will be discussed briefly. Movement sequences that take longer than about half a second to complete are usually under sensory and feedback control, and may be regarded as closed-loop in nature. On the other hand, movement sequences that are completed in less than this time are beyond sensory control, and may be considered to be controlled in an open-loop manner.

The fact that voluntary movement is monitored and modified by sensory feedback has been clearly demonstrated in a number of studies, where delaying or distorting the feedback has led to a breakdown in the serial organisation of the skill. The contribution of vision (Smith *et al.*, 1960), audition (Chase *et al.*, 1961a), touch and pressure (Provins, 1957) and proprioception (Lazlo, 1966) have been assessed in a variety of movement tasks by delaying or distorting the feedback. Sensory control and monitoring clearly plays an important part in the serial organisation of movements, for the most obvious effect of manipulating the feedback is to disrupt the temporal sequential nature of the skill. Speech becomes blurred and stuttering commences, hand tapping becomes irregular and drawing movements lose control and direction "... motor events which are more complex in time are more easily disturbed by delayed sensory feedback" (Chase *et al.*, 1961b, p. 164).

The second type of movement control occurs in movements of short duration in which there is insufficient time for sensory control. The delay in processing information and the central intermittency of the operator do not permit voluntary control over movements of short duration. Hick (1948) and Vince (1948a, 1948b, 1949) provide evidence that for a discrete task "... it appears that the least interval of intermittent functioning must be about half a second" (Hick, 1948, p. 51). Although there is some doubt about the actual extent of the delay and the factors influencing it, the intermittency characteristic of the human operator appears to be well established; see for example Davis (1965), Welford (1959, 1968). Bertelson (1966) provides a comprehensive review of the present status of the intermittency hypothesis.

Clearly then fast movements of short duration must be pre-set or organised in advance and run their full course without sensory control, after being triggered into activity. Woodworth (1899) recognised such a mechanism when he suggested that voluntary movement is composed of two components, the 'initial impulse' and the 'current control'. The initial impulse refers to the ballistic component of the skill that is beyond sensory control. 'Current control' alludes to that stage when the movement is monitored and modified by sensory feedback, as discussed at the beginning of this section. The little-referred-to work by Hartson (1939), and Stetson and McDill (1923) also recognised the distinction between ballistic movements which ran their course largely independent of sensory control, and tension movements or moving fixations which are under sensory control. Developing this work Peters and Wenbourne (1936) referred to ballistic type movements as being under the control of a motor impulse effect which determines the appropriate course, speed and pattern in in anticipation. Once started the movement continues independently of sensory control.

More recently the concept of a ballistic type of movement sequence has been described in cybernetic and communication models as under the control of a motor programme (Keele, 1968),

> The concept of a motor program may be viewed as a set of muscle commands that are structured before a movement sequence begins and allows the entire sequence to be carried out uninfluenced by peripheral feedback (Keele, 1968, p. 357).

That such a centrally organised mechanism of control exists, has been supported by the recent work of Festinger and Canon (1965) and Taub and Berman (1968), reviewed by Greenwald (1970).

Recognition of the Problem

Two stages of organisation appear to be involved in the production of a skilled response (Fitts, 1965; Provins, 1956; Schmidt, 1968). According to Provins these two are, "... one concerning judgement of the appropriate moment for the movement to be made in relation to external conditions, and the other ... concerning the serial organisation of each muscle contraction comprising the movement" (p. 93).

The former stage to which Provins referred is essentially a perceptual problem, and has been extensively investigated as anticipatory behaviour and timing in tracking studies (reviewed by Adams, 1961 and Poulton, 1966), coincident response studies (see for example Conrad, 1951, 1955a, 1956), and time perception studies (Bartlett & Bartlett, 1959; Fraisse, 1964, and Michon, 1967), and will not be reviewed here. These studies have by manipulating sensory and perceptual variables and temporal uncertainty, investigated the manner in which the human operator can anticipate the time course of events as indicated by the discrepancy between the response and the signal (see also, Adams & Creamer, 1962; Noble et al., 1966; Poulton, 1963, 1964; and Trumbo et al., 1965). However, this work has been largely confined to the essentially perceptual problem of the temporal relations between external signals and the response, and has ignored the question of response complexity and effector organisation, the second stage which Provins (1956) discussed. The formulations of theoretical models have concentrated on the strategies of perceptual organisation and minimised the role of the effector processes, (see especially Conrad, 1955b, 1956; and Michon, 1967).

There is need for a better and more complete understanding of the effector organisation process structuring the response, not only because it is a neglected area of interest, but also because it is an integral part of skilled behaviour. This is suggested by a limited number of studies which have shown that response complexity affects timing in a coincident response situation (Grose, 1967a, 1967b, 1969; Norrie, 1964, 1967b; Schmidt, 1969). Also it has been demonstrated that complex movement sequences take longer to organise and initiate than do simple movements (Henry & Rogers, 1960;

Norrie, 1967a, 1967c; Peters & Wenbourne, 1936). In addition, a series of studies and reports (Fenn, 1938; Fitts, 1954; Fitts & Petersen, 1964; Searle & Taylor, 1948; Taylor & Birmingham, 1948) have indicated that the limitations to the speed of movement are set by some central organising process.

Review of Empirical Studies

The limited number of studies on the question of effector organisation have in large been descriptive, discussing the changes that occur with practice, or outlining the differences in a comparison of skilled and unskilled performers. However several investigations have attempted to describe the strategies employed by the operator.

The classical work of Bryan and Harter (1899) demonstrated that as telegraphic operators became more proficient they dealt with larger and larger units of action. It was proposed by these workers, that the transition from the lower-order to higher-order units of behaviour indicated some hierarchically organised mechanism of control. Such a mechanism reduced the attention required, so that the response became 'automatic'. Using typewriting, Book (1908) demonstrated a similar change in control. Book (1925) reviewing this work later said that acquiring skill is a "process of progressive organisation and coordination of the simpler activities into higher and more economic and direct methods ..." (p. 235). Other pioneer workers, Freeman (1917), Kirkpatrick (1899), Pear (1924) and Woodworth (1899) in their work on voluntary movement and skill, emphasised this structuring and organising characteristic. However despite the apparent awareness of some form of hierarchically organising process, the notion failed to be incorporated in theoretical frameworks and conceptual models at that time.

More recently Pew (1966) provided further evidence consistent with the view of Bryan and Harter (1899), and Lashley (1951) that skill learning involves the hierarchical organisation and control of temporal structuring of the response. Subjects in the study were required to control the position of a continually moving target on an oscilloscope, by using 2 response keys operated by the index finger of each hand. The task required rapid alternating between the operation of the two keys. Although there were individual differences in response pattern, Pew reports evidence that demonstrates changes from a closed-loop (feedback dependent) strategy to an open-loop strategy. This latter technique involved larger units of action, which permitted a more rapid rate of responding, than if the responses were being made under closed-loop control. A similar strategy is reported by Vince (1948b). Pew also hypothesised a second higher-level strategy. This he called modulation-mode behaviour which is characterised by a high rate of responding, but with no pauses for correction.

Pew (1966) extended the understanding of Bryan and Harter's (1899) hierarchy of habits, by proposing that the level of skilled performance depends on the way in which the subject organises and uses the feedback associated with the task.

Of the descriptive studies, little attempt has been made to relate the findings to strategies of effector organisation. In large, these investigations have been concerned with an analysis of the movement patterns in industrial and commercial tasks or with athletic skills.

Changes in the Temporal Structure of the Response

One of the most frequently reported changes in the organisation of a response with practice is a temporal restructuring of the response units.

Lundervold (1951, 1958) in an electromyographic analysis of typewriting reported that skilled subjects used fewer muscles which were active for a shorter period of time, than unskilled subjects. Person (1958) demonstrated a change in the temporal structuring of muscle activity in filing and cutting with a chisel. With training, the agonist muscles' activity appeared as a regularly occurring short burst of activity in the movement cycle. The antagonist's activity now occurred out of phase with the agonist. Another change with training recorded in this study was an increased consistency and regularity of the strain-gauge torque record from the handle of the file. Thus the more precise phasing of the muscle activity is accompanied by an increase in consistency of the torque record and hence the movement pattern. Kamon and Gormley (1968) demonstrated that in a gymnastic stunt there is a reduction in the duration of muscle activity with training and that the timing of the peak activity of the four principal muscles became coordinated sequentially.

The restructuring of the response seems to involve not only a refinement of the temporal patterns, but also the more effective discrimination of the appropriate response units (Provins, 1967). Such effector discrimination is indicated by a reduction in extraneous movement, effort or muscle activity as practice proceeds (Bair, 1901; Lundervold, 1951).

Gradation of the Response

Effector organisation also involves the amplification or gradation of the response, so that an appropriate amount of effort is exerted. Liu (1968) demonstrated that a response is graded in terms of effort in a key pressing task in which the resistance was changed from 1000 to 500 grams, or 500 to 1000 grams. The results revealed that the appropriate amount of force or energy is prepared in advance, in anticipation of the signal.

Additional evidence of the gradation mechanism is provided by the changes in 'degree of effort' as skill learning proceeds. Ghiselli (1936) in a key press task reported that the subjects exerted less pressure on the keys as learning progressed.

Electromyographic studies by Kamon and Gormley (1968), Person (1958) and Kitzman (1964) provide evidence of a differential or selective amplification control, whereby with practice some muscles show greater activity, whilst others show a reduction in the degree of activity. Comparing skilled and unskilled typists, Lundervold (1951, 1958) reported that the less skilled subjects contracted more muscles, over a longer period of time and used more muscle power. On the other hand, Kitzman (1964) demonstrated that skilled baseballers recorded greater activity in five of the eight muscles analysed in batting.

This review serves to demonstrate that the amplification control operates in a variety of ways; to reduce the effort, to increase the effort or to effect a redistribution of the effort.

Response Consistency

The outcome of the temporal restructuring and the modified gradation of effort appears to be a greater consistency and stability of performance. Certainly the skilled performer is characterised by highly consistent and reproduceable movement patterns. Such a finding has been reported by Carlsöö (1967), Ghiselli (1936), Lindahl (1945), Provins (1956, 1958), Slater-Hammel (1948, 1949) and Windle (1955).

Provins (1956, 1958) used strain-gauge techniques to record the torque-patterns of the response in a number of tasks including hand cranking and repetitive tapping. The effect of practice on these two tasks was to reduce the variability and thus increase the consistency of the movement patterns. Provins assessed consistency as the extent of variation of the inter-peak interval determined from the force peaks on the torque record. Comparing performance on the preferred and non-preferred hand, differences occurred in those tasks involving the timing or serial organisation of the response. The superiority of the preferred hand was attributed by Provins (1956) to the effects of training and practice.

The significance of consistency of performance by the skilled operator has been further emphasised in the work of Annett, Goldby and Kay (1958), Fitts (1954), Fitts and Petersen (1964) and Kay (1962). These workers regard the inconsistency of performance to be associated in part with the random variation in the human motor system, resulting in a wider range of feedback signals that must be processed.

However although a particular skilled individual is characterised by consistency of performance, there do exist large individual differences in styles between performers on a specific task. Such individual differences are evident not only from gross movement patterns, but also from the organisation of muscle activity.

Slater-Hammel (1948, 1949) investigating tennis and golf strokes, reported that the skilled performer's individual movement pattern and periods of muscle activity are extremely consistent from one effort to the next. However, there are also wide individual differences in styles, indicating that the same end result may be achieved in a variety of ways. The reason for such individual differences is not clear, but the marked variation in the temporal patterning of the muscle activity would suggest that organisational as well as idiosyncratic postural factors are involved. Even in the highly practiced skill, walking, Battye and Joseph (1966) showed considerable individual differences in the periods of muscle activity. Houtz and Fischer (1959) and David, Hamley and Thomas (1968) also demonstrated large individual differences in the duration of activity of the leg muscles during pedalling.

Despite the early recognition of the significance of serial organisation in skilled behaviour, little advance has been made in understanding the process of effector organisation (Crossman, 1964; Welford, 1968). On the other hand, considerable attention has been directed towards the understanding of perceptual organisation and the central decision-making processes. The paucity of investigations into the output processes has left a considerable gap in our knowledge and any contribution to this area must lead to a fuller understanding of the nature of skill.

CHAPTER II

INTRODUCTION TO THE EXPERIMENTAL PROGRAMME AND A PILOT INVESTIGATION

A Methodological Point

One approach to the investigation of effector organisation processes, is to minimise the input and perceptual elements of the task and restrict the decision-making to the organisation of the on-going response. In this way the effector organisation, largely unconfounded by the influence of variable input characteristics, can be inferred from an analysis of the response. Further by studying a ballistic type skill, these conditions can be more adequately satisfied.

The present study is designed in recognition of the need for a detailed analysis of on-going complex behaviour, as emphasised by Bartlett (1955, 1964), in which both the task organisation and the qualitative changes in the response pattern are evaluated (Trumbo *et al.*, 1965).

> While it is widely held that an understanding of skill must come from investigations of the continuous time-varying response functions, researchers continue for the most part to deal with outcome indexes such as time-on-target or integrated error scores. It is our contention that investigation of conditions of task organisation on the one hand and detailed analysis of the consequent response organisation on the other is a fruitful approach to skilled performance (Trumbo *et al.*, 1965, p. 254).

An attempt has been made in this study to determine the strategies and modes of effector organisation by an analysis of both the quantitative and qualitative aspects of the response. Such a procedure has been effectively employed by Michon (1967) and Von Wright (1957) on other aspects of the serial organisation question, and by Pew (1966).

Adams (1961) and Von Wright (1957) have both emphasised the need for a more detailed analytic study of the on-going serial organisation process. Von Wright (1957) in particular said it is important to look at the inter-relations between the different parts of the activities and the conditions determining the organisation of the responses. His technique of using linear or temporal mazes exemplified this approach. Conrad (1953) from his coincident-response studies suggested the importance of sequence analysis of the on-going simultaneous record of signal and response sequences.

Michon (1967) demonstrated the use of sequential analysis techniques in his temporal tracking (tapping) task, in which response interval distributions as well as a sequential analysis of the effect of one interval on the next, were investigated. That is, not only were the mean or average responses assessed, but also the variation in the subject's response from one interval to the next determined.

In another attempt to vary the traditional techniques, Pew (1966, 1967) suggested the need for analysis at both the molecular and molar levels of the response. This is particularly relevant if the interest is in the mechanisms of control that may be hierarchical in nature, where there is a shift or change in control from individual units to integrated sequences. Such changes can best be detected by a sequential, multi-level analysis.

Other attempts to assess serial organisation in skill include measures of consistency (Provins, 1956, 1958), and changes in the organisation of muscles or movements making up the response (Kamon & Gormley, 1968; Person, 1958). However, in general, the limitation of these studies is that the evidence of the levels of organisation is presented descriptively rather than statistically. The complexity of the experimental details usually means very few subjects are used in such experiments, and a detailed analysis of the response other than at the descriptive level, is a monumental task.

The present study is an attempt to apply the principles of analysis suggested by Michon (1967), Pew (1966, 1967), and Provins (1958) to the serial organisation involved in a repetitive speed skill. Efforts are made to integrate a fine grain as well as a gross analysis of the on-going components of a skilled response, using enough subjects to permit limited statistical analyses.

The Task

The purpose of the major study was to investigate the strategies of effector organisation used in a repetitive speed skill. It was also proposed to describe the change or modifications in strategies with the variation of a number of task conditions. To this end, and on the basis of the work by Provins (1956, 1958) simple hand cranking was selected as a suitable task. The task has the following characteristics;

i. The task is repetitive and thus involves the serial organisation of the response units.

ii. The task is essentially ballistic and involves minimal input and perceptual uncertainty. The speed of cranking is essentially the result of the effectiveness of effector organisation.

iii. The task involves a restricted set of response units which are 'common' to all subjects, namely the movements and muscles of the arm. It is these response units that have to be organised and integrated into an effective movement pattern.

iv. The cranking task permits the manipulation of a number of variables including;
   a) the load or frictional resistance
   b) the amplitude of the crank handle and hence the excursion of movement
   c) the direction of movement in cranking

v. The task permits a variety of techniques to be used in recording the response, and thus makes possible a multi-level analysis of the subject's performance.

vi. Because the cranking rate ranges from about 3 to 5 cycles per second, at least one cycle of movement must be beyond sensory control and thus be 'open-loop' in nature. However, the whole task may be considered to be under 'closed-loop' control. Thus both forms of voluntary control may be investigated.

vii. It is possible to select directions of movement and related postural positions, that permit a comparison of the organisation in a novel or unfamiliar situation with that in a familiar situation.

Pilot Investigation

A pilot investigation (Glencross, 1970) was conducted to confirm the suitability of the task for the major study and to provide information as to the manner in which effector organisation could be evaluated.[1]

Provins (1956) and Schmidt (1968) recognised two stages in the serial organisation of a skilled response. Positional timing, the first stage, involves a coincident response. The operator is required to effect an appropriate response when a signal or stimulus appears or arrives at a certain position. The second stage, serial timing refers to the timing of successive movement patterns, and hence the serial organisation of each muscle's activity comprising the movement.

In order to determine which aspects of serial organisation are important in skilled performance the pilot study was

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[1] The pilot study is based on some unpublished records from an experimental programme conducted by Professor K. A. Provins, Australian National University.

designed to investigate the positional and serial timing of the preferred and non-preferred hands in a repetitive hand cranking task. A comparison of the preferred and non-preferred hands was undertaken, as they represent two levels of skilled performance (Provins, 1956, 1958; Provins & Glencross, 1968).

Method

Apparatus

The apparatus, a hand crank resisted by a friction band has been described in detail elsewhere (Provins, 1956, p. 89), but essentially consisted of a 11 cm. handle, which could be resisted by a friction band placed over a drum fixed centrally on the axle. A resistance of 10 kg. weight was used and suspended from the unattached end of the friction band. The crank was mounted on two ball bearings and free to rotate on the shaft of the machine. The torque during cranking was determined from two strain gauges fitted either side of a beryllium - copper bar, which was linked to the crank by means of two steel balls which allowed movement of the two units with respect to one another in all directions except in the direction of rotation. The leads from the strain gauges were taken to three rhodium-plated slip rings which rotated with the shaft and on which three silver palladium wires made continuous contact. To the framework of the machine was attached an ebonite block which mounted the wire brushes from which leads were taken to the remainder of a Wheatstone bridge circuit and through an A.C. amplifier to a Brush pen recorder (see Figure II:1). Simultaneous records were gained of the torque of the crank, as determined from the strain gauges, and the crank's position from a potentiometer linked with the crank and pen recorder.

Procedure

The axle of the machine was positioned transversely to the operator, so that the subject's arm moved in the sagittal plane when cranking. The subject sat in a typist's chair, with a restraining belt fitted around the waist to prevent any gross body movement. 12 male subjects were used.[2] During the testing session the subject was required to turn the crank for 10 seconds at his maximum possible speed, first with one hand, and then with the other hand. Subjects were

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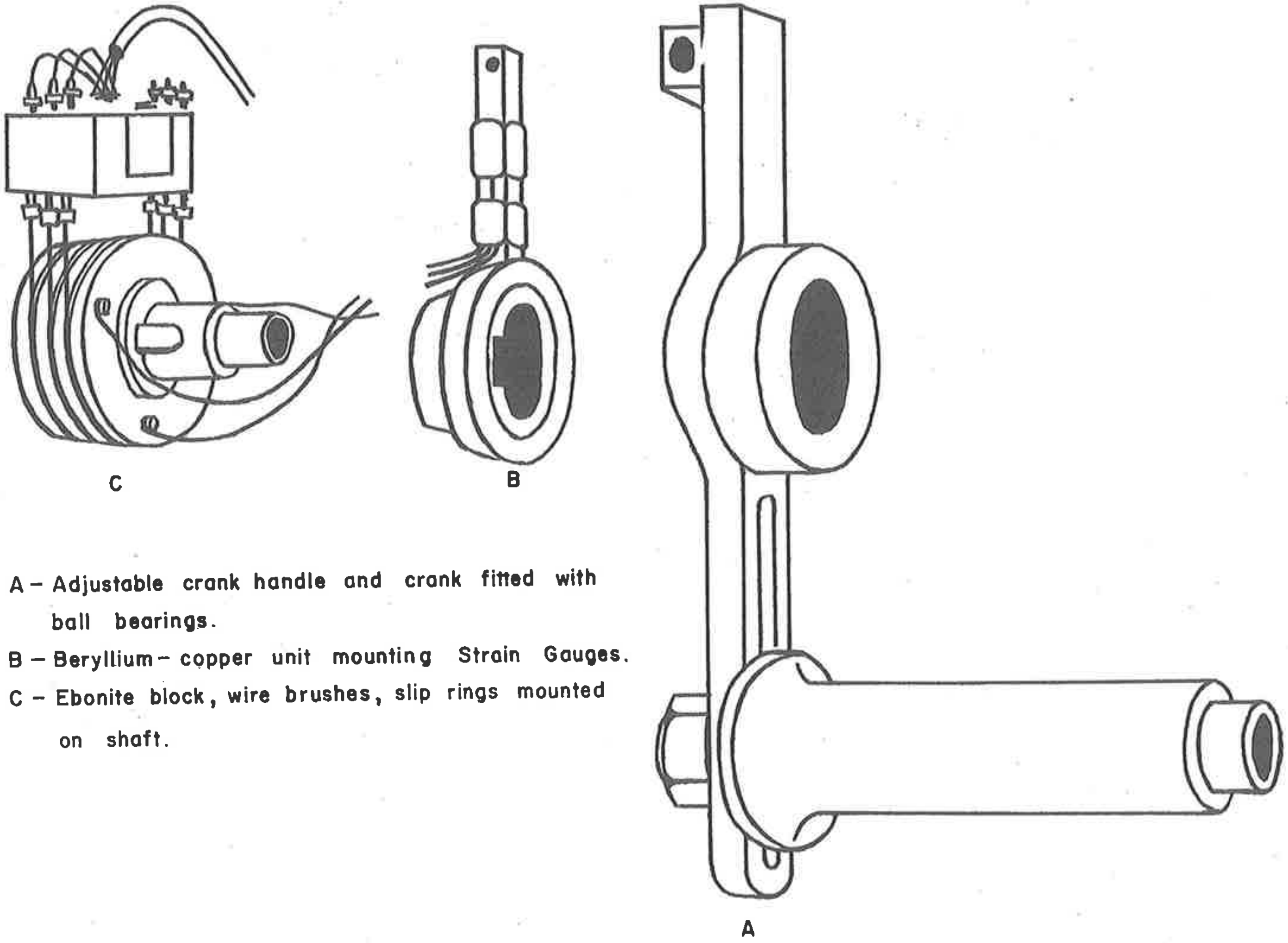
[2] One subject was rejected due to confusion of the record.



A – Adjustable crank handle and crank fitted with ball bearings.

B – Beryllium – copper unit mounting Strain Gauges.

C – Ebonite block, wire brushes, slip rings mounted on shaft.

FIGURE II:1. SCHEMATIC DIAGRAM OF STRAIN GAUGE ARRANGEMENT AND HANDLE OF CRANKING APPARATUS.

given practice with the crank prior to the test trial. The commencing hand, preferred or non-preferred hand, was alternated from subject to subject. Hand preference was determined by usage on a number of manual tasks (for example, writing, cutting with scissors, throwing).

Analysis of Records

For the purpose of the analysis 20 successive cycles were chosen from the middle of the record of the performance for the preferred and non-preferred hand.

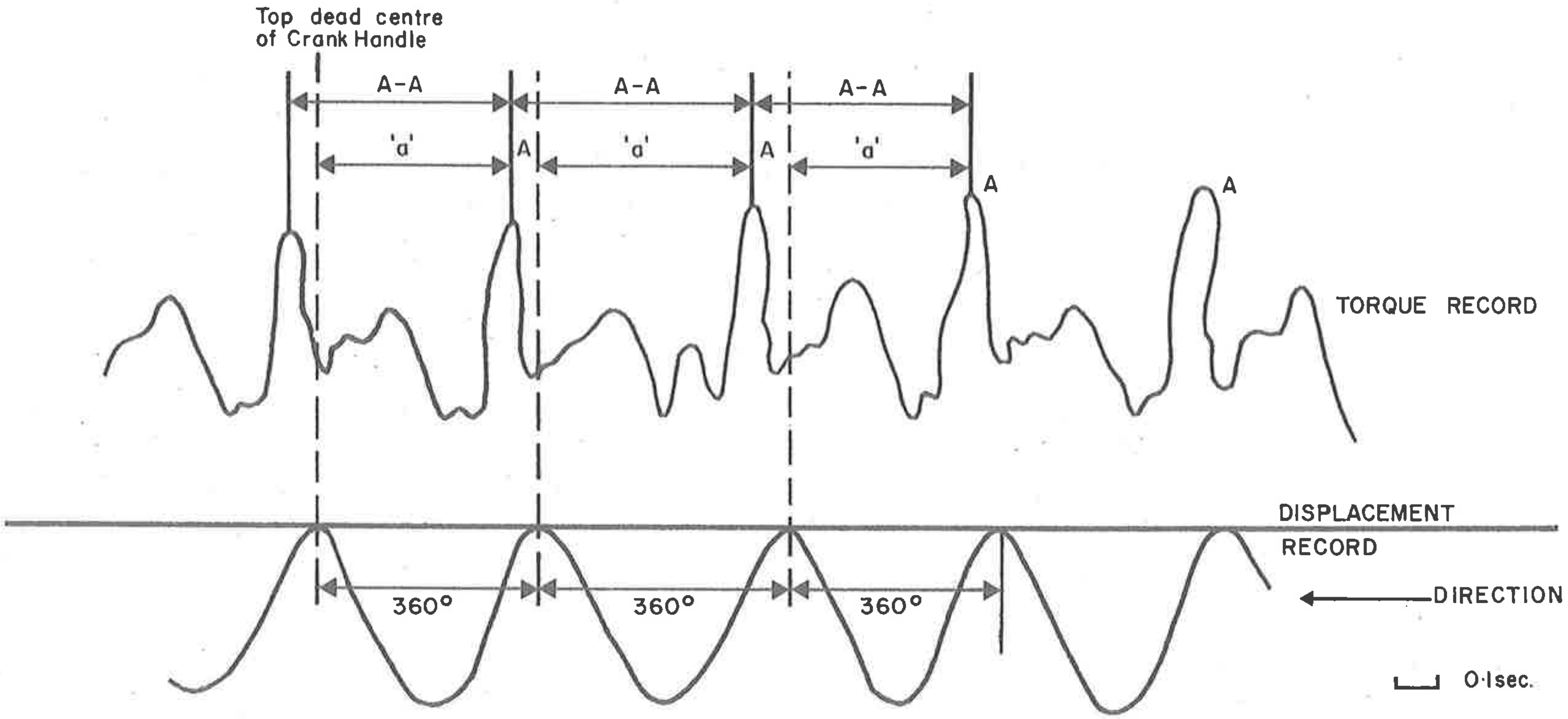
Speed of cranking was determined as the mean cycle time.

Criteria of Effector Organisation. All measures were read from the torque trace, recorded by the strain-gauges (see Figure II:2):

(a) Positional Timing (PT) was determined from that position in the cycle when the principal force was exerted (distance 'a' in Figure II:2). This measure was expressed as a proportion of the cycle length.

(b) Consistency of Positional Timing (CPT) was assessed in two ways;

i. The standard deviation of the positional timing score for each individual, based on the actual



PRINCIPAL FORCE PEAK — A

POSITIONAL TIMING (PT) — MEAN DISTANCE 'a'

CONSISTENCY OF POSITIONAL TIMING (CPT) — SD of DISTANCE 'a'

SERIAL TIMING (ST) — SD of A–A DISTANCES

(ANALYSIS OVER 20 CYCLES)

FIGURE II : 2. DIAGRAM OF CRANKING RECORD WITH DETAILS OF ANALYSIS time of occurrence of the force was used (CPT_A).

ii. The standard deviation of the positional timing criterion as a proportion of cycle time was the second index (CPT_P).

(c) Serial Timing (ST) was assessed as the degree of variability of the cycle length between successive principal force peaks (A - A in Figure II:2). This variability was expressed either as a standard deviation, based on actual times (ST_A) or as a standard deviation corrected for differences in cycle length (ST_P).

Results

Table II:1 summarises the product moment correlations between the timing measures and speed of cranking, for the preferred and non-preferred hands. With the preferred hand the correlations between speed and CPT_A, and the two serial timing measures ST_A and ST_P are all significant ($p < 0.01$). This finding indicates that fast subjects are also the most consistent, especially on the serial timing criteria. The faster subjects show marked consistency or lack of variation

Table II:1

Correlations between Speed of Cranking and the Timing Criteria (N = 11)

Speed (Cycle Time)	Positional Timing (PT)	Consistency of Positional Timing		Serial Timing	
		Actual (CPT_A)	Prop. (CPT_p)	Actual (ST_A)	Prop. (ST_p)
Speed Pref. Hand	-.291	.734**	.223	.941**	.758**
Speed Non-pref. Hand	.295	.543	.254	.638*	.496

* Significant 0.05 level

** Significant 0.01 level

on the real or actual time measures. Although the pattern of results is similar for the non-preferred hand, only one of the correlations with speed, (ST_A), is significant ($p < 0.05$)

Comparing the performance of the two hands, speed of cranking is highly correlated, $r = 0.966$ ($p < 0.01$) and the preferred hand is significantly faster than the non-preferred hand, $t(10) = 4.12$ ($p < 0.01$). These results are summarised in Table II:2. Related sample 't' tests between the means of the timing criteria on each hand are not significant, except for the positional timing (PT) measure where $t(10) = 8.13$ ($p < 0.01$), which indicates that the point in the cycle of action where the principal force peak A occurs is different for the two hands. There is a tendency for the means of the two serial timing measures for the preferred hand to be smaller suggesting greater consistency of timing. Further evidence of the difference in serial timing between the preferred and non-preferred is provided by 't' tests of the difference between the correlations of ST_A and ST_p with speed on each hand. Both of the correlations tend to be larger for the preferred hand, although only the 't' value between the correlations based on ST_A and the speed is statistically

Table II:2

Comparison of Performance Between Preferred and Non-Preferred Hands

	Speed (Cycle Time – Secs.)	Positional Timing (PT)	Consistency of Position Timing		Serial Timing	
			Actual (CPT_A)	Prop. (CPT_p)	Actual (ST_A)	Prop. (ST_p)
Preferred Hand						
Mean	0.265	41.125	1.110	4.134	1.539	5.444
S.D.	0.056	4.398	0.414	1.145	0.952	2.242
Non-Preferred Hand						
Mean	0.289	24.243	1.243	4.212	1.973	6.513
S.D.	0.044	6.997	0.635	1.997	1.367	3.867
Preferred Hand V Non-Preferred Hand						
'r'	0.966^{**}	$-.837^{**}$	0.203	-.283	0.561	0.422
't' (between means)	4.117^{**}	8.126^{**}	< 1	< 1	1.472	1.000
't' (between 'r's)		< 1	< 1	< 1	3.083^{*}	1.111

* Significant 0.05 level

** Significant 0.01 level

significant ($p < 0.05$).

The correlations between the preferred and non-preferred hand timing criteria are not significant, except for the positional timing measure, where $r = -.837$ ($p < 0.01$). The negative correlation indicates that subjects who exert the force relatively early in one performance, do so relatively later in the cycle when using the other hand. Such evidence indicates an organisational difference between the response of cranking with preferred and non-preferred hands. Although the correlations of the serial timing measures on the two hands are not significant ($p > 0.05$) values of 0.561 and 0.422 suggest that subjects who show greater consistency of timing on one hand also tend to be consistent with the other hand.

There is little relationship between the positional timing measures and the consistency criteria CPT_A, CPT_p, ST_A and ST_p. These latter four measures, consistency of positional timing and serial timing, in general are significantly interrelated, particularly the actual or real time measures. The intercorrelations suggest that the positional timing criteria and the consistency and serial timing criteria are sampling different aspects of performance on this task, (see Table II:3).

Table II:3

Intercorrelation Between Timing Criteria

Timing Criteria	Consistency of Positional Timing				Serial Timing			
	CPT_A		CPT_P		ST_A		ST_P	
	Pref. Hand	Non-Pref. Hand	Pref. Hand	Non-Pref. Hand	Pref. Hand	Non-Pref. Hand	Pref. Hand	Non-Pref. Hand
Positional Timing PT	-.319	.182	-.212	.062	-.155	.213	.057	.145
Consistency of Positional Timing CPT_A			.807**	.948**	.720**	.593*	.616*	.564
CPT_P					.237	.429	.258	.452
Serial Timing ST_A							.930**	.981**

* Significant 0.05 level

** Significant 0.01 level

Discussion

The results, demonstrating a general relationship between speed of performance and the timing criteria, supports earlier work in this field by Provins (1956, 1958).

The significant correlations between speed of cranking and serial timing indicates that the temporal aspects of effector organisation are important characteristics of skilled performance. Serial timing refers to the consistency with which a regular event occurs in an ongoing cycle of movements. Specifically serial timing relates to the consistency of the cycle length between successive force peaks. The skilled subject apparently, is able to construct a consistent temporal pattern, whereby the time interval between princip~~le~~al events remains very constant. Considered in terms of the variability in actual time, the relationship between serial timing and speed of cranking is highly significant, and is only slightly reduced where serial timing is corrected for differences in the cycle length between individuals. Thus differences in serial timing appear to be a real effect contributing to differences in speed of cranking in this task. Skilled subjects are better able to maintain a consistent temporal relationship between principal events in a repetitive skill than are unskilled subjects.

The non-significant results of the positional timing analysis suggests that within limits the actual position of the force exertion in the cycle is not important to success on this task. Clearly there must be some location where the effort must be exerted due to body position and leverage. However, within this range the actual position of the force impulse does not markedly affect speed of cranking.

The importance of temporal factors in effector organisation is further supported by the results of the consistency of positional timing analysis. Although the actual position of effort in the cycle of movement is not important, the consistency or stability of this point is of some significance. These results indicate that the faster subjects exhibit less actual or real time variations of the position where the force is exerted in the cycle of movement. Because of the low intercorrelations between the consistency criteria and the positional timing criterion, it is apparent that these two measures are relatively independent components of performance on the cranking task.

Comparing the performance between the preferred and non-preferred hands, the results of the cranking experiment indicate that performance between the two hands is highly correlated and that the preferred hand is significantly faster. These results are in support of those reported in the field (for example, Provins, 1956, 1958; Provins & Glencross, 1968). With the timing criteria the same pattern of results is seen for both hands. However, there are clearly organisational differences as indicated by the significant 't' value for the differences in positional timing. With the preferred hand the principal force peak occurs near top dead centre, whereas for the non-preferred hand the corresponding point is more mid-way through the cycle. Although there are obvious differences in the mean values of positional timing between the preferred and non-preferred hands, the correlations of this measure with speed are not significant. Such a finding indicates that differences in performance between the two hands are not due to differences in positional timing. Comparing the mean values of the other timing criteria on the preferred and non-preferred hands, the 't' values are not significant ($p > 0.05$) although there is a tendency for the differences between these means to be greatest on the serial timing criteria. Support for this trend is indicated by comparison of the size of the correlations. The correlations between serial timing and speed are considerably larger for the preferred hand than the corresponding correlation on the non-preferred hand, although only one of these, ST_A, is statistically significant. The evidence suggests that differences in speed between the two hands can be accounted for in part by the more effective serial organisation by the preferred hand. The preferred hand shows greater consistency and stability and hence less variability in the temporal organisation of the response. Higher levels of skill appear to be characterised by more effective temporal structuring by the effector organisation process resulting in less variability of the events placed in a temporal sequence.

Introduction to the Major Study

Experimental Conditions

In the major study, the strategies of effector organisation and the modification of these strategies were to be investigated by an analysis of the response in hand cranking under the following task conditions;[3]

i. Load. The effect of a change in load or frictional resistance to cranking was investigated by requiring the subjects to wind against a light or heavy effective resistance, by attaching a 5 kg. or 10 kg. weight respectively to the friction belt.

ii. Amplitude. The effect of a change of amplitude or excursion of movement was investigated by using a small radius handle (5 cms.) or a large radius handle (10 cms.).

iii. Direction. A comparison of two levels of organisation was investigated by having the subjects wind backwards in the sagittal plane, an unfamiliar or novel movement, as well as forwards in the same plane, a more familiar and common movement.

The task was restricted to winding with the right arm.

Recording Techniques

Hand cranking appears to be a suitable task to permit the analysis of the serial organisation of effector processes.

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[3] The details of the task and apparatus are outlined in Chapter III.

In the pilot study the analysis of this organisation was based on the strain-gauge torque record of the patterns of force exerted on the crank handle by the subject. Although this proved a useful technique such a record is however only an index of the final or resultant effort of several different aspects of the response. The force exerted at the handle is some composition of the activity patterns of a number of muscles, and the related movements of several joints. It would be of greater value in the analysis of effector organisation if the structure of the response units could be observed at several levels, viz., at the level of muscle activity and movement of the joints and limb segments, as well as at the level of the final resultant force and speed of movement.

It was proposed in the major study to use electromyography and motion photography as well as the strain-gauge techniques to provide more detailed information as to the organisation of effector processes. The use of electromyography is particularly significant for it will indicate not only which muscles are active, but when and for how long they are active, as well as the level or degree of activity. Such information will be of value for it represents directly the decisions or instructions by which the effector organisation implements the response. Motion photography has its value in providing a record of the whole task, including the movement patterns of the crank and the limb segments as well as any postural idiosyncrasies of the subject.

Experimental Design

Because electromyography was to be used to investigate the temporal organisation of muscle activity under varying peripheral conditions, it is essential to use the same electrode position each time. The most effective way of achieving this is to not remove the electrodes, but to complete all the testing under the same experimental conditions. Thus, using electromyography, prevented the use of a practice or training paradigm to determine the changes in effector organisation. Although such a procedure has been used by other workers (Kamon & Gormley, 1968; Lundervold, 1951), there always exist some doubt about the reliable replacement of electrodes from one trial to the next. This is of particular importance if comparisons of temporal sequences are to be made between trials as in the present study. For this reason it was felt necessary for all treatment conditions to be completed in the one sitting, using the same electromyographic set-up.

Further, it was proposed to use the same subjects, apparatus and procedure in each experimental condition and thus increase the precision and efficiency of the experiment (Lindquist, 1956, p. 157). Thus each subject was required to wind against a load of 5 and 10 kgs., using a radius of 5 and 10 cms., in a forward and backward direction. All subjects performed each of the 8 conditions (see Table II:4).

Although the effects of order and sequence were not considered to be large, it was felt necessary to counterbalance the order of presentation of each condition. Further, because the interest in this study was in how the subject varied or altered his strategy of organisation under each condition, the effects of differential practice should be controlled or at least counterbalanced. Again, because of the necessity to change the friction-loading arrangement for forward and backward cranking, the 4 experimental conditions in one direction were completed (in a counterbalanced order), and then the procedure was repeated in the other direction. Each condition was presented in accordance with a 4 x 4 Latin square (Lindquist, 1956, p. 259) and commencing in the

Table II:4

Treatment Conditions in the Major Experiment

Code	Direction	Load on Friction Belt	Handle Radius	Effective Resistance at Handle
AB	Backward	5 kg.	5 cms.	2.4 kg.
BB	Backward	10 kg.	5 cms.	4.8 kg.
CB	Backward	5 kg.	10 cms.	1.2 kg.
DB	Backward	10 kg.	10 cms.	2.4 kg.
AF	Forward	5 kg.	5 cms.	2.4 kg.
BF	Forward	10 kg.	5 cms.	4.8 kg.
CF	Forward	5 kg.	10 cms.	1.2 kg.
DF	Forward	10 kg.	10 cms.	2.4 kg.

Comparisons:		
	Effect of Load	AB v BB CB v DB
	Effect of Amplitude	AB v DB
	Effect of Direction	AB v AF BB v BF CB v CF DB v DF

forward or backward direction was alternated. In this way any order or sequence effects in this Treatments x Subjects design were counterbalanced.

Finally, for the purpose of the present report, the effects of manipulating the task conditions will be reviewed and discussed separately. However, it should be remembered that the 8 treatment conditions were conducted in one testing session and for this reason the treatment of the results by analysis of variance was in accordance with the design used.

CHAPTER III

EFFECTOR ORGANISATION IN THE BASIC TREATMENT CONDITION

Abstract

Backward handcranking with a small radius and light load (AB) was regarded as the basic treatment condition. The modes of effector organisation of 19 male subjects were investigated by a detailed, multi-level analysis of the response, from photographic, torque and EMG records. Several criteria of organisation were used and included serial timing (sequencing and phasing), positional timing and the temporal structure of the response units. The amount of effort or gradation of the response was analysed in terms of the torque and EMG records. The results indicated the extreme complexity of the pattern of organisation involved, together with a wide range of individual differences. Individual differences in the sequencing of the muscle activity and movement of the joints of the arm were not related to speed of performance. Of the timing criteria, phasing appears to be of central importance, being highly related to speed of cranking. On the other hand, positional timing, although related to speed, does not appear to be as important as the phasing process

> of effector organisation. There is a general trend of all measures of consistency to be related to performance. Despite an extensive analysis of the effort involved in hand cranking, none of the criteria of gradation based on the force and EMG records were significant. Because of the speed and complexity of the task an open-loop control system in the form of a motor programme is discussed as a possible strategy of effector organisation.

The aim of this first experimental treatment was to investigate the strategies of the effector organisation in the basic hand cranking condition. This condition, AB (backward cranking with a 5 cm. radius handle, and 5 kg. load), was selected as the basic criterion condition for the purposes of a detailed analysis of the effector organisation process. The reasons for this selection was that backward cranking in the sagittal plane could be considered to be a relatively novel skill, requiring the subject to organise patterns of movement that had not occurred systematically before. Again the load and radius combination was intermediate in terms of the other possible peripheral changes.

It was proposed that a multi-level analysis of the response would provide information as to the strategies of effector organisation used by the operator.

Criteria of Effector Organisation

From the literature review and in particular the work of Provins (1956, 1958), together with the results of the pilot investigation, three criteria of effector organisation are proposed;

1. Serial Timing

'Serial timing' refers to the serial organisation of the response units making up the response, and has been variously referred to as; "... the grouping and stability of the constituent items in full performance", (Bartlett, 1947, p. 836); "... the (...) problem of serial ordering ...", (Lashley, 1951, p. 121); "the serial organisation of each muscle contraction comprising the movement." (Provins, 1956, p. 93). It is convenient to distinguish two components of serial timing; sequencing and phasing.

i) Sequencing, is the organisation or ordering of the response units into the most effective sequence or order. It involves not only the sequence of actions and movements, but also the order of muscle activity and the decisions or instructions to initiate this activity.

ii) Phasing, is the temporal structuring or patterning of the response units placed in sequence. That is, each unit must be phased into the appropriate temporal sequence, and occur at the appropriate moment in time in relation to the other units making up the response.

2. Positional Timing

'Positional timing' involves a coincident response situation and refers to the temporal relationship between the response and some external event or signal. This is commonly called 'timing' and is achieved by a process of anticipation (Helson, 1949; Poulton, 1950, 1952). Anticipation is any means the human operator uses to reduce delays, due to sensory and motor conduction times, to the limited capacity of the system which connects them and to the organisation of incoming information (Broadbent, 1958, p. 282). Criteria of positional timing give some index of the effectiveness of this anticipatory behaviour in making preparatory adjustments and decisions designed to overcome the limitations of the delay in responding to a signal.

3. Gradation

Not only are response units linked temporally and sequentially, but also the response as a whole is characterised by a particular amount of 'effort'. The effort is expressed as a certain amount of force exerted or as a resultant speed of movement. All overt actions are the result of a distribution of force in space and time, ranging from the movements of speech to the movements in running. In some skills the force characteristics of the response are relatively unimportant to the effective performance of the task, as for example in speech. On the other hand, the successful completion of such tasks as lifting heavy objects, and running are, in part, dependant upon the organisation of a force in space and time. This process of organising the appropriate force characteristics of the response is referred to as 'gradation'.

The physiological mechanism of the graded response involves essentially two processes; (i) the number of motor units active, and (ii) the frequency of discharge in each unit (Adrian & Bronk, 1929; Wilkie, 1968, p. 59; and Winton & Bayliss, 1955, p. 328).

However such a physiological explanation of the graded response is an oversimplification of the process, when man is involved in skilled performance. The limitations or restrictions of such an approach have been pointed out by, for example, Fenn (1938), Whitney (1958) and Wilkie (1968). When talking about skilled performance, not only are the physiological grading mechanism taking place in every active muscle, but this process must be temporally regulated so that the resultant force of one muscle is integrated with the activity of all other muscles. The complexity of this integration can be appreciated when it is realised that the resultant force exerted by a muscle will be influenced in addition by such factors as the angle of attachment of the tendon to the skeleton (Provins & Salter, 1955), the pulley action of bi-articular muscles (Landsmeer, 1961; Molbech, 1965), the degree and extent of antagonistic, fixator and synergistic muscle activity (Steindler, 1955), and the temporal integration of the periods of activity and inactivity of the muscles (Wilkie, 1968, p. 56-7).

Method

Apparatus[1]

The apparatus consisted of a hand crank resisted by a friction band passing over a metal drum fixed on the axle of the crank (see Figure III:1). It was a modification of the hand crank reported in the pilot investigation (see p. 28). The handle of the crank could be adjusted to provide an effective radius of from 4 to 13 cms. Positioned centrally on the axle was a polished metal drum of 8.5 cms. diameter. A band made of webbing acted as a friction belt as it passed over the drum. This belt was firmly fixed at one end, whilst from the other end a weight could be freely suspended. The arrangement of the friction belt could be reversed to enable the crank to be rotated in both directions.

The crank shaft and beryllium-copper unit fitted with the strain-gauges remained the same as for the pilot study. The leads from the strain-gauges were taken through a 4 core screened cable to the rest of the wheatstone bridge circuit,

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[1] Full technical details of the apparatus are reported in Appendix A, p. 225.

A - 4 core screened cable which is wound around crank axle during cranking
B - Friction belt
C - Weight attached to friction belt
D - Crank with adjustable handle
E - Body markers used in photographic analysis
F - Electromyography electrodes
G - Shoulder strap
H - Adjustable chair
I - Electromyography leads
J - Gantry frame to which crank is attached

BK - Backward cranking direction
FD - Forward cranking direction

Figure III:1 Captions for the Arrangement of the Subject and Cranking Apparatus (see next page).

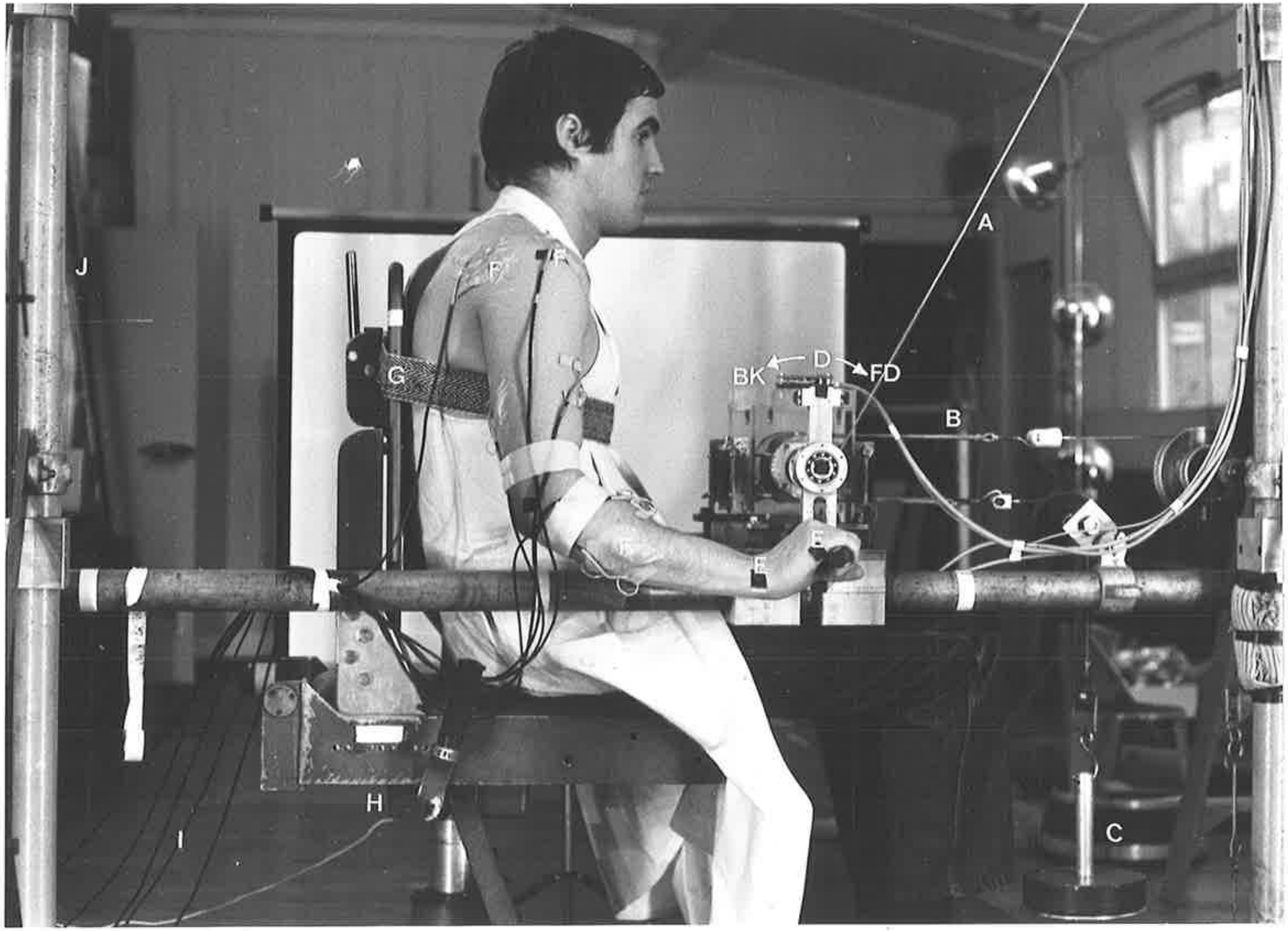

Figure III: 1. Arrangement of the Subject and Cranking Apparatus then through a carrier amplifier and regulated power supply to the 16 channel, ultra-violet galvanometer recorder. The cable was in fact so arranged that during cranking it wound around the axle of the crank and at the same time raised a light weight through a vertical distance of 9 feet.

The movement of the crank handle was monitored by means of a 350° rotary potentiometer. This displacement was recorded on the U/V recorder.

The crank was firmly fixed to a gantry such that the handle rotated in the sagittal plane of the seated subject.

In order to be able to relate the movements of the body and in particular the arm with the movement of the crank handle, 16mm motion photography was used at a filming speed of 32 frames per second. The lens of the camera was 3 metres from the axis of rotation of the crank handle at a vertical height level with the axle. The film record was synchronised with the crank activity by means of a displacement deflection on the base line of the paper record of the U/V recorder. To facilitate the analysis of the film, markers were placed at the following locations on each subject;[2]

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[2] For details see Appendix A, p. 229.

Shoulder marker - Acromium process of scapula
Elbow marker - Lateral epicondyle of the humerus
Wrist marker - Styloid process of the ulna
Hand marker - Fifth metacarpel joint

Electromyographic records were made simultaneously from six sites on the right arm (see Figure III:1).[3] Especially constructed 'floating' surface electrodes were used in the form of a rubber grommet. Electrical contact was made via the electrode jelly from the surface of the skin to a floating silver wire loop. In this way movement artifacts were effectively eliminated or minimised. The electrodes were placed 2 cms. apart with the long axis parallel to the underlying muscle fibres. Electrodes were so positioned that they recorded the agonist and antagonistic muscle activity about each of the shoulder, elbow and wrist joints. Positions of the electrodes were as follows;

Shoulder flexion - anterior deltoid
Shoulder extension - posterior deltoid
Elbow flexion - biceps brachii
Elbow extension - triceps brachii
Wrist flexion - wrist flexor group
Wrist extension - wrist extensor group

The patient ground electrode was placed on the posterior surface of the left hand.

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[3] For an outline of preliminary EMG investigations and details of the technique see Appendix A, p. 232.

The muscle action potentials were directed via a screened cable through a pre-amplifier to a Medelec DM82 Electromyographic unit and recorded on the U/V recorder. The signals from the strain-gauge, 6 EMG channels and displacement potentiometer were recorded simultaneously on a 16 channel U/V recorder. The paper speed was 7.5 cms. per second and one second time markers were automatically placed on the record during the recording process.

The paper records thus contain the following information (see Figure III:2):-

1. Crank displacement
2. Crank torque - strain-gauge record
3. Electromyogram - Channel 6 Wrist Extensors
4. Electromyogram - Channel 5 Wrist Flexors
5. Electromyogram - Channel 4 Tricep Brachii
6. Electromyogram - Channel 3 Bicep Brachii
7. Electromyogram - Channel 2 Posterior Deltoid
8. Electromyogram - Channel 1 Anterior Deltoid
9. Event Marker

Procedure

19 male subjects, with an age range from 20 to 37 years were used in all experiments. 16 of the subjects

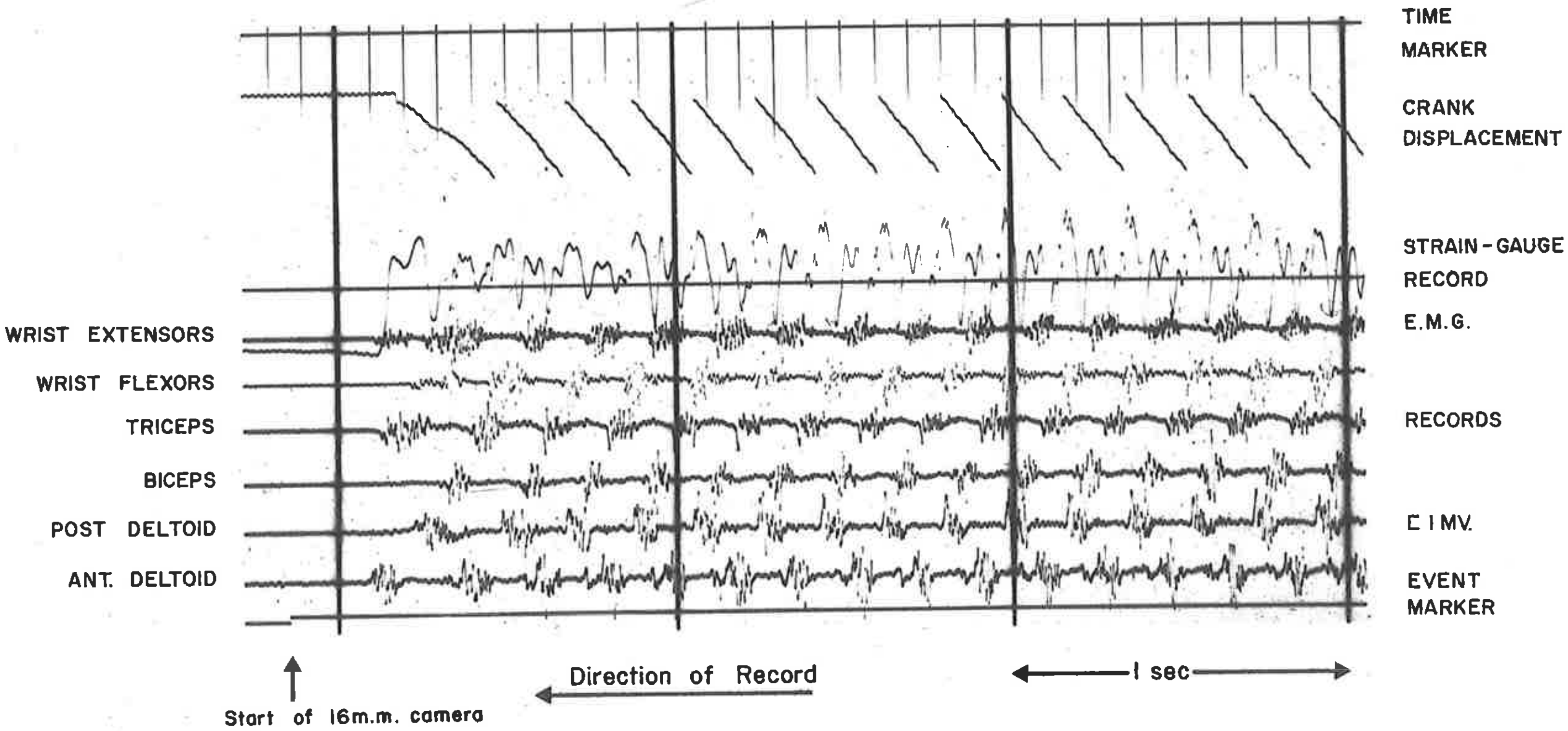

FIGURE III : 2 CRANKING AND ELECTROMYOGRAPHY RECORD were right hand dominant as determined by a verbal questionnaire (for example, the hand used in writing, throwing, cutting with scissors).

Prior to the testing session, each subject was informed of the nature and purpose of the experiment, and the task was explained. The actual testing period lasted approximately 2 hours. During the initial stages information was gathered regarding age, height and weight. Limb segment lengths of the right arm were measured. The subject answered a verbal questionnaire designed to determine hand preference as well as any previous cranking or winding experience. Finally, during this preparatory stage, the EMG electrodes were placed in position on the right arm. The electrode impedances were measured and the corresponding muscle activity monitored on the oscilloscope, both in an isometric contraction and during the cranking action.

The subject was placed into a standardised starting position by adjusting the vertical and horizontal position of the chair (see Figure III:1). In the standardised position the elbow marker was in a horizontal line with the axle of the crank and the hand marker was in the same position as the axle. A shoulder strap secured the subject firmly in position and minimised any extraneous body movement.

The task required the subject to wind the crank handle as fast as possible and in so doing wind up a light weight a vertical height of 9 feet. The subject could observe the progress of the pulley, but at the same time the experimenter indicated to the subject when the pulley had reached the quarter, half, and three quarter way markers. The time taken for the pulley to reach the top of the gantry was recorded on a stop watch and told to the subject after each trial.

Several practice trials were permitted to enable the subject to be familiar with the task. This procedure was repeated for all of the 8 treatment conditions using specific load, amplitude and direction combinations. At least three minutes rest was given between each test trial, although considerably more rest occurred during the changeover in direction of cranking.[4]

At the completion of the testing session, the electrode impedances were checked and the strain-gauges and displace-

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[4] As outlined on p. 46, the 8 treatment conditions were presented in one sitting, in accordance with a counter-balanced Treatment x Subjects design.

ment marker calibrated.

Results

Analysis of the Records[5]

The records for each subject were analysed manually in terms of the movement of the joints of the arm in relation to the positions of the crank handle, the manner in which the force was exerted and the periods of activity of the muscles. Subsequently these details were used to determine the speed of movement, positional timing, sequencing, phasing and gradation of the response. The analysis was conducted on 20 successive cycles of the record, taken after the first 2 seconds of cranking.

Briefly the preliminary analysis involved:-

i. The photographic records (16mm negatives) were graphed frame by frame and the location and range of movement at each joint in relation to the position of the crank handle

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[5] For further details see Appendix A, p. 241.

was determined.

ii. The strain-gauge torque record was related to the displacement record, and the positions in the cycle of movement that the principal force efforts occurred were determined.

iii. Each of the 6 electromyograph records was related to the displacement record and the position in the cycle of movement where each muscle commenced and ceased activity was determined. Muscle activity was considered to exist when the record of activity was regular and exceeded 500 µv.

For the sake of clarity the details of the analysis of the records into the criterion measures and the corresponding results, will be discussed separately, each in turn.

Detailed Results

Speed of Cranking

Cranking speed was determined as the mean number of cycles per second, calculated from the 20 cycles used in the analysis.

For the basic hand cranking condition the mean speed is

4.71 cycles per second with a standard deviation of 0.71. Thus on the average a cycle of movement took 0.21 seconds to complete, with a range from 0.17 seconds for the fastest subject to 0.30 seconds for the slowest subject.[6]

Serial Timing

Sequencing - Criteria

i. Sequencing was regarded as the order in which each joint of the arm changed direction in a cycle of movement. Specifically, for each subject the turning points of shoulder flexion, shoulder

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[6] The effectiveness of counterbalancing any order or sequence effects resulting from the design used was tested using an F test based on the speed of cranking data for the 19 subjects, organised into four, 8 x 8 x 8 Latin squares. Different combinations of subjects were used in each analysis of variance (S. 1-8; S. 9-16; S. 4-11; S. 12-19). The four F values obtained for the order of treatments were F = 2.44; 0.15; 0.56; 0.73. Combining the probabilities of these F values a non significant $X^2(4) = 6.67$, p 0.10. Because this value failed to reach significance, any order or sequence effects were regarded to be unimportant from the point of view of further analysis of the data.
The summary tables of the analyses of variance are reported in the Statistical Appendix B, p. 248.

extension, elbow flexion, elbow extension, wrist flexion and wrist extension, were determined by an analysis of the photographic record.[7]

ii. The second criterion of sequencing was the order in which the activity of each of the 6 muscles was initiated, as determined from an analysis of the EMG records. In particular this was based upon the position in the cycle of movement of the crank handle when the muscles, anterior deltoid, posterior deltoid, biceps brachii, triceps brachii, wrist flexor group and wrist extensor group, were active.

In each case the order of the joint and muscle activity was related to each event in turn, as the first event, and the remaining five events ordered from this one.

<u>Sequencing - Results</u>

Figure III:3 presents the mean pattern of temporal organisation in terms of when the activity of each muscle started and ceased, and when each joint reached a turning point in the cycle of movement, in relation to the position

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[7] For further details see Appendix A, p. 229.

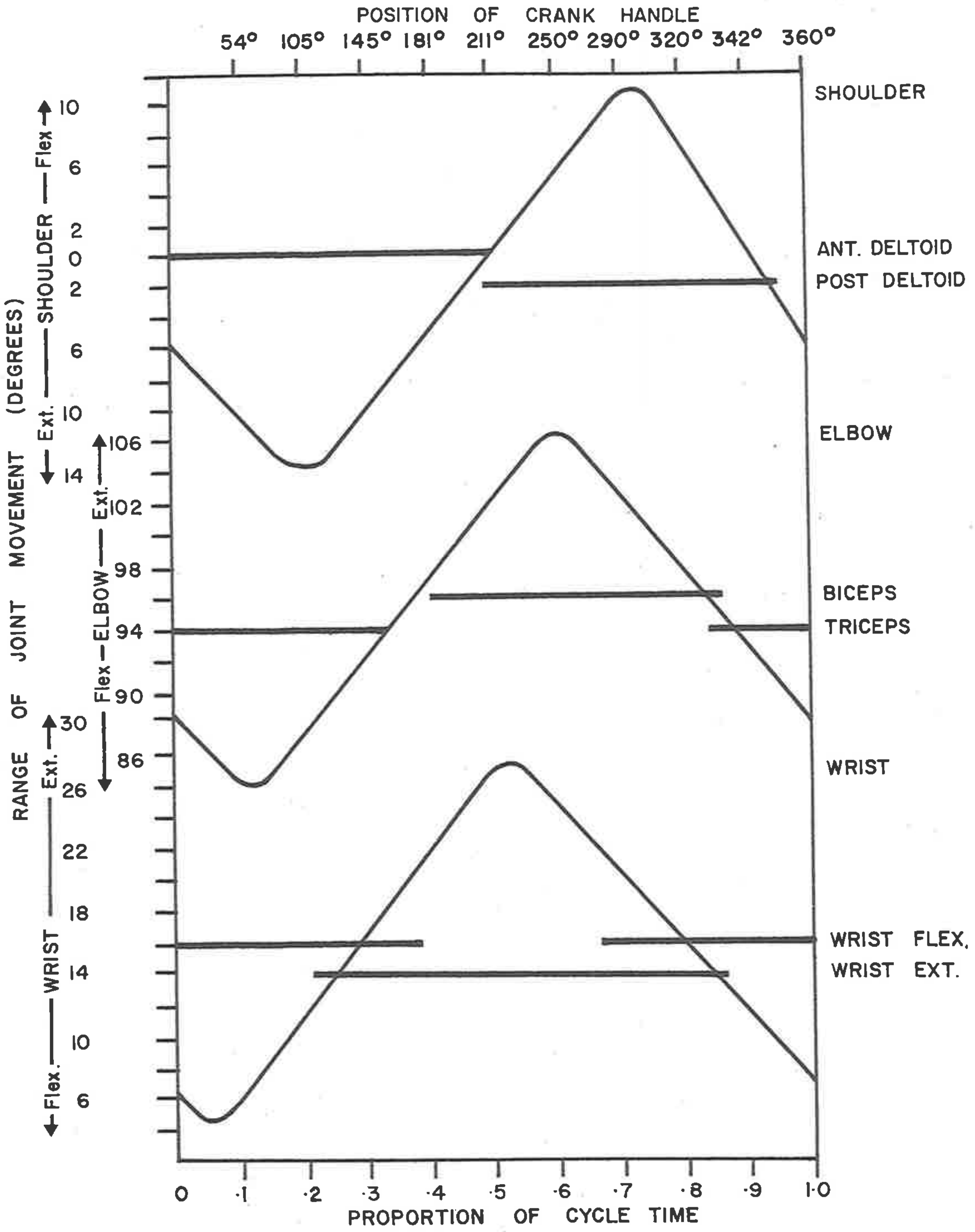

FIGURE III : 3. TEMPORAL ORGANISATION OF MUSCLE AND JOINT ACTIVITY of the crank handle. The order of firing of the muscles is wrist extensors, bicep, posterior deltoid, wrist flexors, tricep, anterior deltoid. The order of occurrence of the turning point for each joint movement is wrist flexion, elbow flexion, shoulder extension, wrist extension, elbow extension and shoulder flexion. These orders or sequences are based on the mean position of occurrence of the event in the cycle of movement for the 19 subjects. However individual differences do exist and there is a wide variation about each mean value.

Common Order or Sequence. Kendall's coefficient of concordance W was used to determine the extent of common sequencing or ordering of the two sets of events. The values of 'W' and 'S' are summarised in Table III:1.

The mean coefficient of concordance W is 0.326 with an $S = 1177$ which is significant $(p < 0.01)$, for the turning points of the joint movements. A value of $W = 0.473$ and $S = 1839$ which is significant $(p < 0.01)$ indicates also that there does exist a significant relationship between individuals in the order or sequence in which the muscle activity occurred.

Considering the individual values of W in Table III:1,

Table III:1

Kendall's Coefficients of Concordance for Joint Movements and Muscle Activity

First Event In Sequence	JOINT		First Event In Sequence	MUSCLE	
	W	S[a]		W	S[a]
Sh. Ext.	.408	1474**	Ant. Delt.	.639	3610**
Sh. Flex.	.513	1852**	Post. Delt.	.437	1576**
Elb. Flex.	.290	1048**	Bicep	.427	1540**
Elb. Ext.	.453	1636**	Tricep	.413	1492**
Wr. Flex.	.171	616*	Wr. Flex.	.352	1270**
Wr. Ext.	.121	436	Wr. Ext.	.429	1550**
Mean	.326**	1177		.473**	1839

[a] 'S' is the sum of the differences in rank used in the test of significance for 'W' (see Kendall, 1955).

* Significant $p < 0.05$

** Significant $p < 0.01$

derived from taking each event in turn as the start of the cycle, for the joint turning points the values ranged from 0.513 (shoulder flexion) to 0.121 (wrist extension). The latter value is not significant ($p > 0.05$), whilst using wrist flexion as the start of the cycle, $W = 0.171$ is just significant ($p < 0.05$). All values of W based on the onset of muscle of activity are significant ($p < 0.01$), ranging from 0.639 (m. anterior deltoid) to 0.352 (wrist flexors). This variation of the individual coefficients of concordance provides some indication of the degree of stability of occurrence of the initial event. A low coefficient of concordance indicates that the initial event does vary considerably more than the other events in the sequence, particularly if the coefficients are high when the other events are used as the initial event for the purposes of determining the order or sequence, see for example, wrist flexion and extension in Table III:1.

Difference between Fast and Slow Subjects in Sequencing.

The subjects were divided into two groups on the basis of the speed of cranking. The mean coefficients of concordance were calculated for the fast group and slow group of subjects and are summarised in Table III:2. Only one value of W is not significant at the 0.01 level of confidence; this is for the slow subjects on the joint movement sequence, $W = 0.285$, $S = 285$ ($p < 0.05$). However this analysis indicates that fast and slow subjects have similarly consistent sequencing patterns of the order of occurrence of the turning points for shoulder, elbow and wrist, and the occurrence of the activity of each muscle.

Table III:2

Kendall's Coefficient of Concordance for Joint Movements and Muscle Activity for the Fast and Slow Groups of Subjects

		Fast Subjects (N = 9)	Slow Subjects (N = 10)
Joints	W	.416	.285
	S	$.337^{**}$	285^{*}
Muscles	W	.598	.437
	S	484^{**}	437^{**}

* Significant $p < 0.05$

** Significant $p < 0.01$

Sequencing Discrepancy and Speed of Cranking. The significant value of W indicates that there is some common sequence or order of events. Each subject was assessed for the degree of discrepancy from the best estimate of the true order or sequence (Kendall, 1955, pp. 100-103). Discrepancy was determined on the principle of the least number of moves or reorganisation to restore the sequence to the 'true' order (see Kendall, 1955, p. 7). Using this principle, the discrepancy was calculated for each subject from the ranking of events for the largest and smallest values of W reported in Table III:1.

The rank order of speed of cranking was correlated with the rank of the discrepancy measures, using Kendall's Tau for tied ranks (Kendall, 1955, Chap. 3). These values of Tau 'T' are summarised in Table III:3. None of the correlations are significant indicating that sequencing differences between subjects are not related to the speed of cranking.[8]

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[8] Tests of significance based on Kendall (1955) Chapter 4.

Table III:3

Kendall's Tau based on Speed of Cranking and

Total Discrepancy

	T (Large W)	T (Small W)
Joints	-0.195	0.073
Muscles	0.240	0.257

$p > 0.05$

Considering the individual order or sequence of events, in general half the subjects had the same common sequence, and another 3 or 4 subjects had only one event out of place. Seldom did a subject have more than 2 events out of sequence.

Sequencing - Discussion

Sequencing is clearly evident in the skill of hand cranking. Considering the sequence or order of activity of the joints of the muscles about these joints, a significant order or pattern of activity is revealed. That is, the order of occurrence of these events in the cycle of movement showed a definite sequence.

It is not surprising that there does exist a common sequence of joint actions in the cranking action, for the path of movement of the arm is dictated in part by the path of the crank handle. The arm in cranking forms a closed kinetic chain (Steindler, 1955). If the crank handle is held by a subject and the crank arm rotated by the experimenter, the arm passively moves through the sequence (after top dead centre) of elbow flexion, shoulder extension, elbow extension and shoulder flexion, the same sequence as reported for these 4 turning points whilst cranking (see Figure III: 3). The wrist joints showed no pattern and invariably remained stationary in this passive situation. Thus it follows that the coefficients of concordance for both the sequence of joint and muscle activity controlling the movements of these joints should be significant.

What is surprising however, is the fact that there do exist individual differences within this apparently restricted ballistic skill. It is clear that even in such a simple task as hand cranking the same end result can be achieved in a variety of ways. This inter-individual variation which characterises skilled performance (Kitzman, 1964; Slater-Hammel, 1948, 1949) provides a problem of measurement and analysis and from a practical point of view increases the difficulty of teaching and training the operator.

An appreciation of how such variations in style can occur, even in a restricted movement as in the present study, can be seen from Figure III:4. This figure presents the spatial distribution of the movements traced out by the shoulder, elbow, wrist and hand markers and thus represent the movement pattern for each of these body parts. Although only 3 subjects' movement patterns have been illustrated it is clear that large individual differences exist. Subjects A_{10} and A_{11} show a considerable shoulder abduction as evidenced by the apparent small distance between the shoulder and elbow positions.

Even though each subject was placed in a standardised starting position and a shoulder strap used to provide support, subjects still showed evidence of synergistic postural adjustments. One of these adjustments was the abduction of the shoulder, which meant that the elbow was raised above the level of the axle of the crank. A second postural adjustment was to lean forward within the restrictions of the shoulder strap and to place the shoulder forward on the elbow.

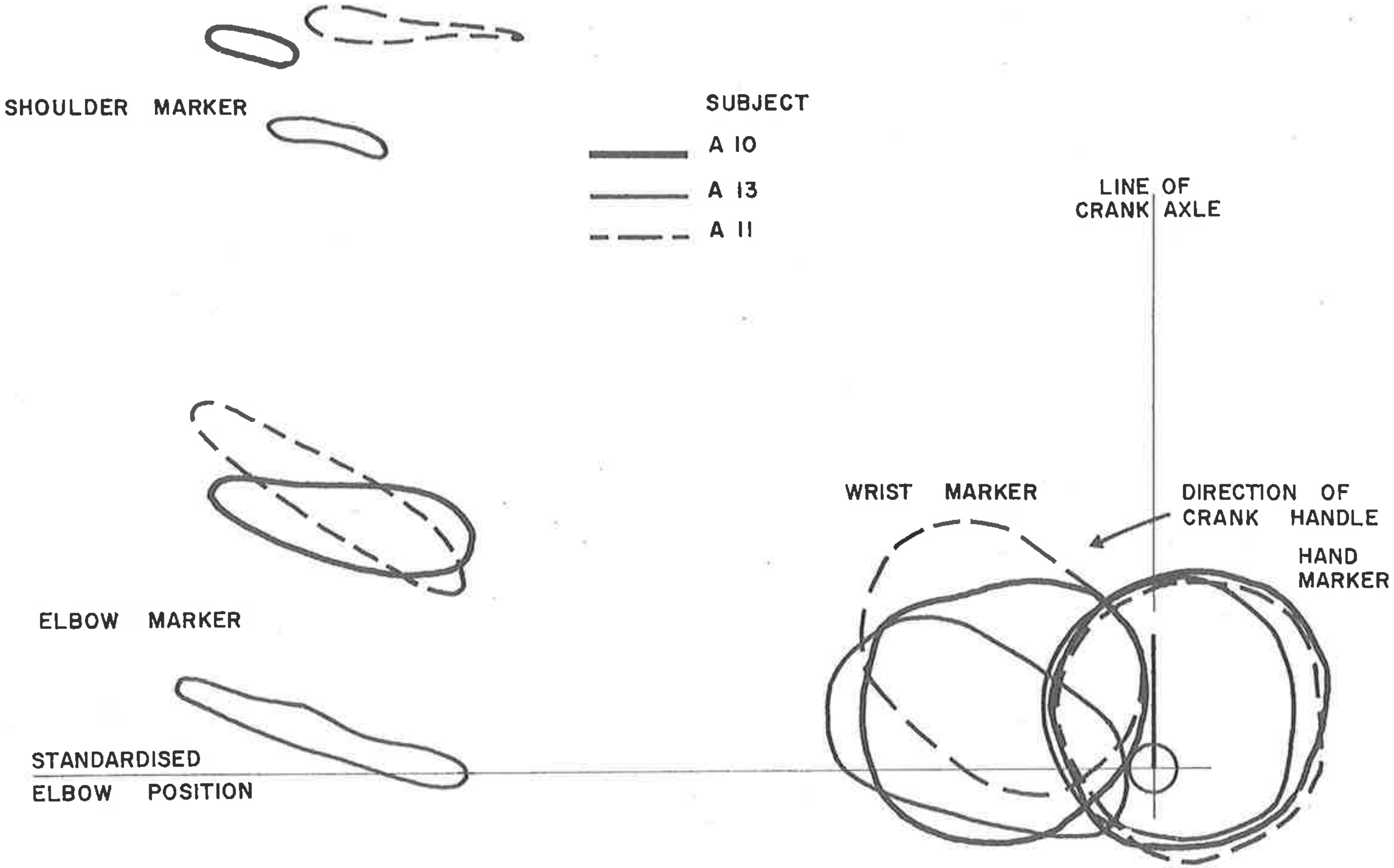

FIGURE III :4. SPATIAL DISTRIBUTION OF MOVEMENTS IN THE SAGITTAL PLANE OF THE SHOULDER ELBOW AND WRIST JOINTS FOR THREE SUBJECTS.

The individuality of style is further indicated in an analysis of the pattern of wrist movements. When the arm is moved passively by the crank, the wrist tends to remain fixed or show no definite pattern. However an analysis of the film cranking records reveals an interesting pattern.

The subjects appear to fall into two groups on the basis of their organisation of the wrist movement. The differences between the two groups is most clearly seen in Figure III:5. One pattern of movement is virtually the reverse of the other. The larger group of subjects ($N = 12$) reaches peak wrist flexion early in the cycle and peak wrist extension later in the cycle. The $N = 7$ group shows the opposite pattern. Another noticeable difference between these two groups is the range of movement. The ranges are 28° and 14° for the larger and smaller groups respectively, but the two are not significantly different, $t = 1.782$ ($p > 0.05$) because of the large standard error of the mean. There is no systematic bias between the groups in the extent and position of shoulder and elbow movements, and no difference in the speed of cranking, $t = 0.443$ ($p > 0.05$). Clearly then, here is a secondary movement pattern which is very difference from what may be considered a basic pattern, and yet having no apparent special

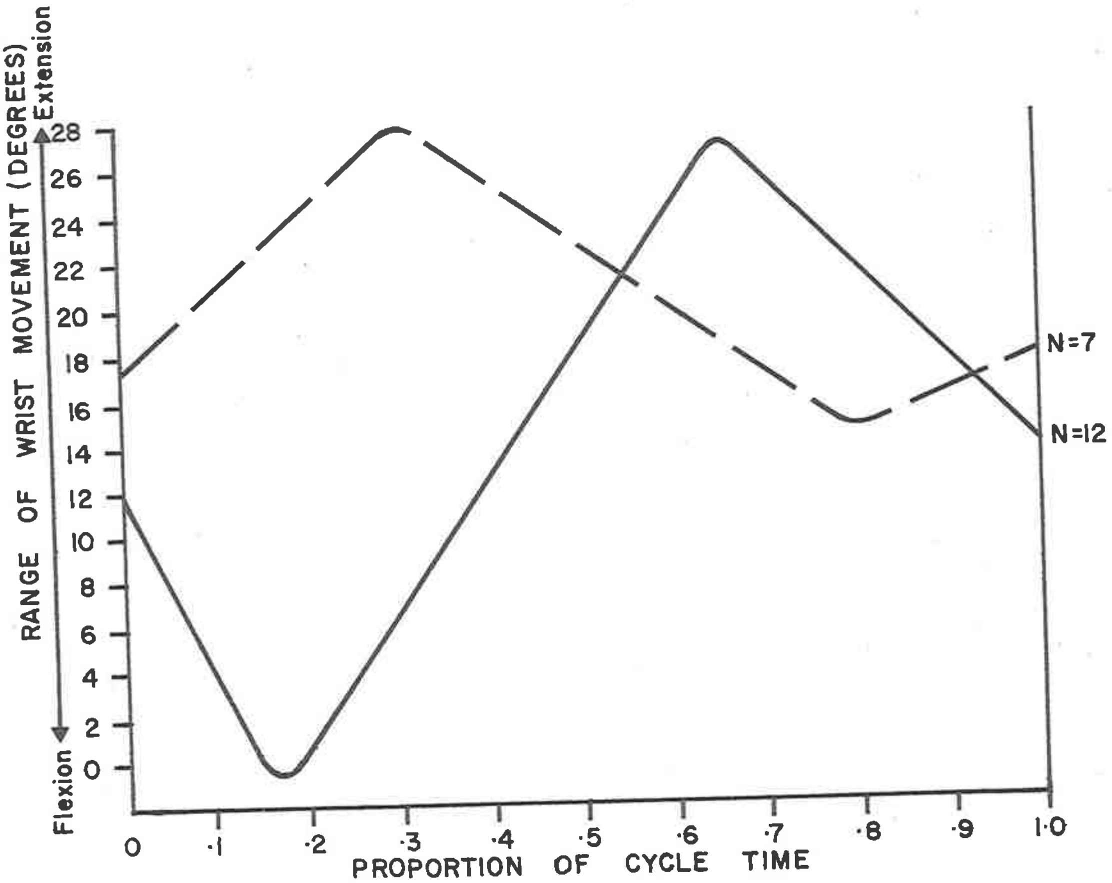

FIGURE III : 5. TWO PATTERNS OF WRIST MOVEMENT.

influence on overall performance.

In the consideration of sequencing, a further feature worthy of comment is the absence of a distinction between skilled and unskilled subjects. Both fast and slow subjects have significantly common patterns of movement. A second analysis confirmed this finding as no significant relationship was found between the degree of discrepancy from the common sequence and speed of cranking.

It does appear that within limits sequencing is not a significant factor differentiating skilled and unskilled performers. Clearly there is a sequence where some movements must occur in relation to others. But there does appear to exist a margin for variation of individual styles, and yet the same end result may still be achieved. How and why this is so is not clear, but it is obviously a problem of serial organisation that bears further investigation. How can the organisation of a series of response units, attached to a moving handle, be of different, yet apparently equally effective patterns? Why is it that individuals differ in the way in which they order or sequence a common set of events? Are some response units or some response sequences preferred to others? Why do some subjects wind with the shoulder markedly abducted, whilst others have little or no shoulder abduction? Why do some subjects use a wrist movement pattern that is the opposite to the majority of subjects? With the novel skill of backward cranking the subject is required to organise response units and movements that have been used previously in a variety of different tasks and hence in a variety of different combinations. The task requires a new combination of the established movements and muscle actions. Clearly the influence of prior usage will determine to some extent the idiosyncrasies of the serial organisation for the new task. However, it is not clear what aspects of previous experience dictate that the shoulder should be abducted, or the wrist flexes early in the cycle of movement rather than later.

Phasing - Criteria

The consistency of temporal intervals between events was used as a criterion of phasing. It indicates the degree of stability of the temporal pattern organised by the operator.

i. Phasing of Force Records (PF). The variation in the cycle length between the onset of successive principal force peaks over 20 cycles was used as a measure of phasing (see Figure III:6). The variation was expressed as a standard deviation based on actual times (PF_A) or as a standard deviation corrected for differences in cycle length and hence speed of cranking (PF_p).

ii. Phasing of EMG Records (PE). Phasing of the muscle activity was determined in a manner similar to that for the force record (see Figure III:6). The onset of the activity of the biceps brachii was used to measure the successive cycle lengths from which the standard deviation was derived. The standard deviation was based on the actual times (PE_A) or the time as a proportion of the cycle length (PE_p).

Phasing - Results

Table III:4 summarises the correlations between the phasing criteria and the speed of cranking. The correlation between the phasing of the force peaks (PF_A) and speed of cranking is $r = -0.630$ ($R = 0.732$), and that between speed and the muscle criterion (PE_A) is $r = -0.703$.[9] Both of

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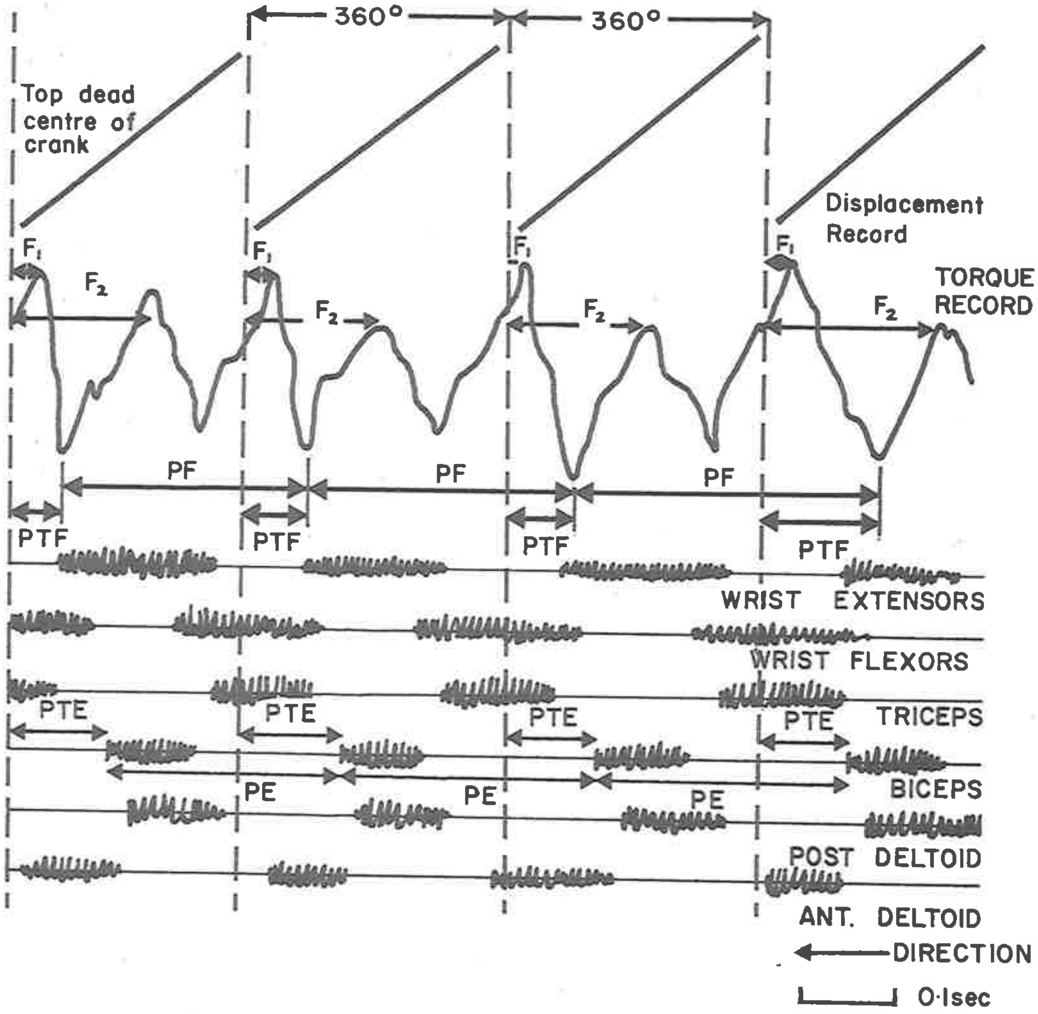
[9] Speed is measured in cycles per second and consistency as a standard deviation, hence the negative correlations.



PF	Phasing Force	PTF	Positional Timing Force - ONSET
PE	Phasing EMG	PTE	Positional Timing EMG - ONSET
F_1	Positional Timing-FORCE EXERTED	F_2	Positional Timing - FORCE EXERTED

ANALYSIS OVER 20 CYCLES

FIGURE III : 6. DIAGRAM OF CRANKING RECORD WITH DETAILS OF ANALYSIS.

Table III:4

Correlations between Phasing Criteria and Speed of Cranking

	Phasing	
	Force Data	E.M.G. Data
Actual Time	PF_A	PE_A
'r' with speed	-.630** (.732)[a]	-.703**
Mean (mm)	1.11	1.17
S.D.	.93	.84
Proportional Time	PF_P	PE_P
'r' with speed	-.510*	-.584**
Mean	4.81	5.10
S.D.	3.16	2.82

* Significant $p < 0.05$

** Significant $p < 0.01$

[a] Correlation in parenthesis is a multiple correlation for a quadratic or second-degree trend, see Appendix B, p. 264.

these correlations were based on real or actual times and were significant ($p < 0.01$). Thus the fastest subjects have the smallest variation in cycle length based on the temporal interval between the initiation of successive force peak and the temporal interval between the commencement of activity of the biceps muscle in successive cycles. The real time measures indicate that in fact the faster subjects show less actual time variation in the occurrence of successive similar events in the cycle of movement.

Expressing these two criteria of phasing as proportions of the cycle length the correlations with speed are still significant, although the one based on the force data, PF_p, $r = -0.510$ is only significant at the 0.05 level of confidence. Both correlations are however somewhat depressed in value compared to the corresponding correlations based on the real times. This finding suggests that some confounding influence does exist in that because fast subjects have correspondingly faster cycle times, there is possibly less chance of variation. Conversely, slow subjects with relatively long cycle times have more opportunity to vary within this cycle length. Whether this is a real effect or a spurious effect because of the recording procedure cannot be differentiated.

However the basic finding is not altered, that is the fast subjects on this task are also the most consistent or least variable in the phasing of significant events in the cycle of movement.

The greater variation in the cycle length as indicated by the correlations between speed and the phasing criteria could result from a gradual slowing down or speed up by some of the subjects. A related samples 't' test was conducted on the force data to test the significance of the difference between the means of the first trial and the means of the last trial for the 19 subjects. A 't'(18) = 2.06 $(p > 0.05)$ is not significant, indicating that there is no overall slowing between the first and last trial.

A second 't' test was used to compare the fast and slow subjects on the actual size of the difference between the first and last cycle of the 20 cycles analysed. This is not significant, 't'(18) = 1.29 $(p > 0.05)$. This finding suggests that the phasing measures based on the standard deviation of cycle length over 20 cycles are not influenced by any differential fatiguing or slowing effects in some of the subjects and not others.

Phasing - Discussion

It appears from the foregoing results that the phasing of events placed in sequence is an important aspect of skilled performance.

At the 'macroscopic' level the force analysis indicates the whole response is phased so that the observable outcome, viz., movement sequences, are precisely temporally structured. The onset of the force peak used as a criterion of phasing may be regarded as the resultant of a number of serially organised response units temporally integrated to occur at some particular time in the sequence of movements.

Considering the similar pattern of results derived with the second phasing criteria, the initiation of activity in biceps brachii, a corresponding pattern of temporal structuring takes place at the 'microscopic' level. Even though only one muscle was used as a criterion of phasing, the significant correlation with speed of cranking lends support to the importance of phasing the actual response units, that go to make up the response as a whole. The effector organisation process involves not only placing the response units in sequence, but more importantly, once in order they must be spaced accurately in time, that is, phased.

Positional Timing

Positional Timing - Criteria

i. Positional timing (PTF) was determined as that point in the cycle of movement when the principal force was initiated as indicated by the torque record. The distance from top dead centre of the crank to the onset of the principal force peak was measured and expressed as a proportion of the cycle length (see Figure III:6, p. 82).

ii. A second criterion of positional timing was based on the onset of the E.M.G. activity of the biceps muscle (PTE). The distance from top dead centre of the crank to the commencement of activity in the biceps muscle was measured and expressed as a proportion of the cycle length.

iii. The points in the cycle of movement where the two principal force peaks occurred (F_1 and F_2) were located in a similar manner, and these two positions were expressed as proportions of the cycle length.

Positional Timing - Results

The correlations between the speed of cranking and positional timing criteria are summarised in Table III:5.

Table III:5

Correlations between Positional Timing Criteria and

Speed of Cranking (c.p.s.)

	Positional Timing	
	Force Data PTF	E.M.G. Data PTE
'r' with speed	0.497*	-0.348
Mean	18.86	39.76
S.D.	2.80	17.16

* Significant $p < 0.05$

Correlating the speed of cranking with the position in the cycle where the principal force was initiated, PTF, a significant value of 0.497 was obtained ($p < 0.05$).[10]

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[10] A replication of this relationship was obtained using the point in the cycle that the force was actually exerted, F_1. A significant correlation of 0.554 ($p \quad 0.05$) was obtained.

This correlation indicates that the faster subjects exerted the force later in the cycle of movement than the slower subjects.

A non significant correlation of -0.348 ($p > 0.05$) was obtained between the speed of cranking and the positional timing criterion based on the onset of EMG activity in the biceps muscle.[11] The negative correlation indicates that the fast subjects initiate the activity of the bicep (and anterior deltoid) earlier in the cycle of movement than the slower subjects. All of these reported relationships between the positional timing criteria and speed are linear.

Figure III:7 summarises the temporal organisation of the activity of the six muscles analysed for the 5 fastest subjects and the 5 slowest subjects. In each case the fastest subjects initiate the activity of the muscles earlier in the cycle of movement than the slowest subjects. This pattern of organisation is consistent with the correlational evidence reported above.

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11. A replication of the speed of cranking and positional timing of muscle activity relationship was obtained using the anterior deltoid. A correlation of -0.517 ($p < 0.05$) was found.

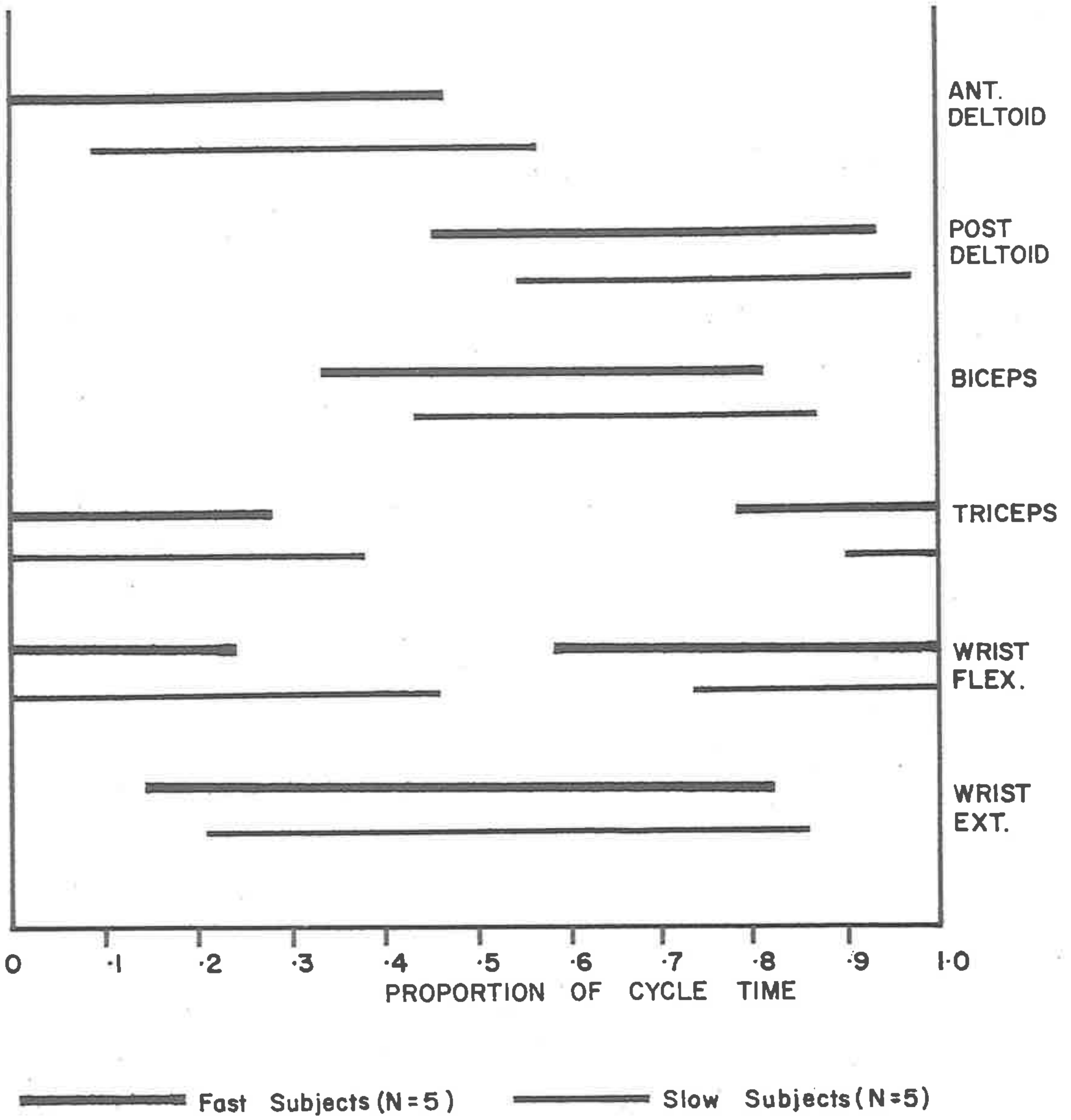


FIGURE III : 7. MEAN TEMPORAL ORGANISATION OF MUSCLE ACTIVITY FOR FAST AND SLOW SUBJECTS

Consistency of Positional Timing

Consistency of positional timing concerns the degree of stability or variability of the occurrence of a particular event at a particular point in the cycle of movement. It was expressed as the standard deviation of each subject's measures used to determine the positional timing criteria.

i. The consistency of positional timing was determined as the standard deviation of the measured distances between top dead centre and the force onset over 20 cycles. This standard deviation was based either on real or actual times ($CPTF_A$), or alternatively derived from the distances expressed as proportions of the cycle length ($CPTF_p$).

ii. A second criterion of consistency was based on the initiation of E.M.G. activity of the biceps. The standard deviations were again based on actual time values ($CPTE_A$), or proportionate values ($CPTE_p$).

The correlations between the consistency of positional timing criteria and speed of cranking are summarised in Table III:6.

The correlations based on the actual time measures are

Table III:6

Correlations between Consistency of Positional Timing and Speed of Cranking

	Consistency of Positional Timing	
	Force Data	E.M.G. Data
Actual Time	$CPTF_A$	$CPTE_A$
'r' with speed	$-.524^{*}$	$-.583^{**}$
Mean (mm)	.43	.94
S.D.	.36	.70
Proportional Time	$CPTF_P$	$CPTE_P$
'r' with speed	-.240	-.436
Mean	1.94	4.14
S.D.	1.02	2.36

* Significant $p<0.05$

** Significant $p<0.01$

both significant. These values are -0.524 for $CPTF_A$ ($p<0.05$) and -0.583 for $CPTE_A$ ($p< 0.01$). Negative values indicate that the fastest subjects have the smallest standard deviations and hence are more consistent.

The correlations based on the criteria derived from proportionate measures fail to reach significance although they are both in the hypothesised direction. Correlations of -0.240 for $CPTF_p$ $(p > 0.05)$ and -0.436 for $CPTE_p$ $(p > 0.05)$ were obtained with speed of cranking.

Positional Timing - Discussion

The positional timing evidence shows that the faster subjects tend to structure their response so that significant events occur at particular times in the cycle of movement. However, structuring in this sense does not seem to be as important as the temporal organisation in phasing. This conclusion is supported by the results of the pilot investigation.

The finding that the relationship between the positional timing criteria and speed is linear, and in general, significant, indicates that the better subjects do tend to position an event differently from the slower subjects. It is conceivable that fast subjects may have adopted a central position whilst the slower subjects positioned the event either side of the mean position of the skilled subjects. However the statistical analysis suggests that this does not occur.

Positional timing may be likened to coincident timing

(Grose, 1967a) in that the subject is attempting to synchronise a particular response (force exertion, muscle activity) with a particular signal (position in the cycle). Unlike other coincident response tasks (Conrad, 1956; Grose, 1967a) the signal in the cranking task of the present study is not directly observable. It exists most certainly in the form of some point in the cycle of action where a principal effort must be exerted on the crank handle. The present results together with those of the pilot investigation indicate that even though such a 'coincident point' does exist, a certain latitude about this point is permissable without too much effect on the resultant speed of cranking.

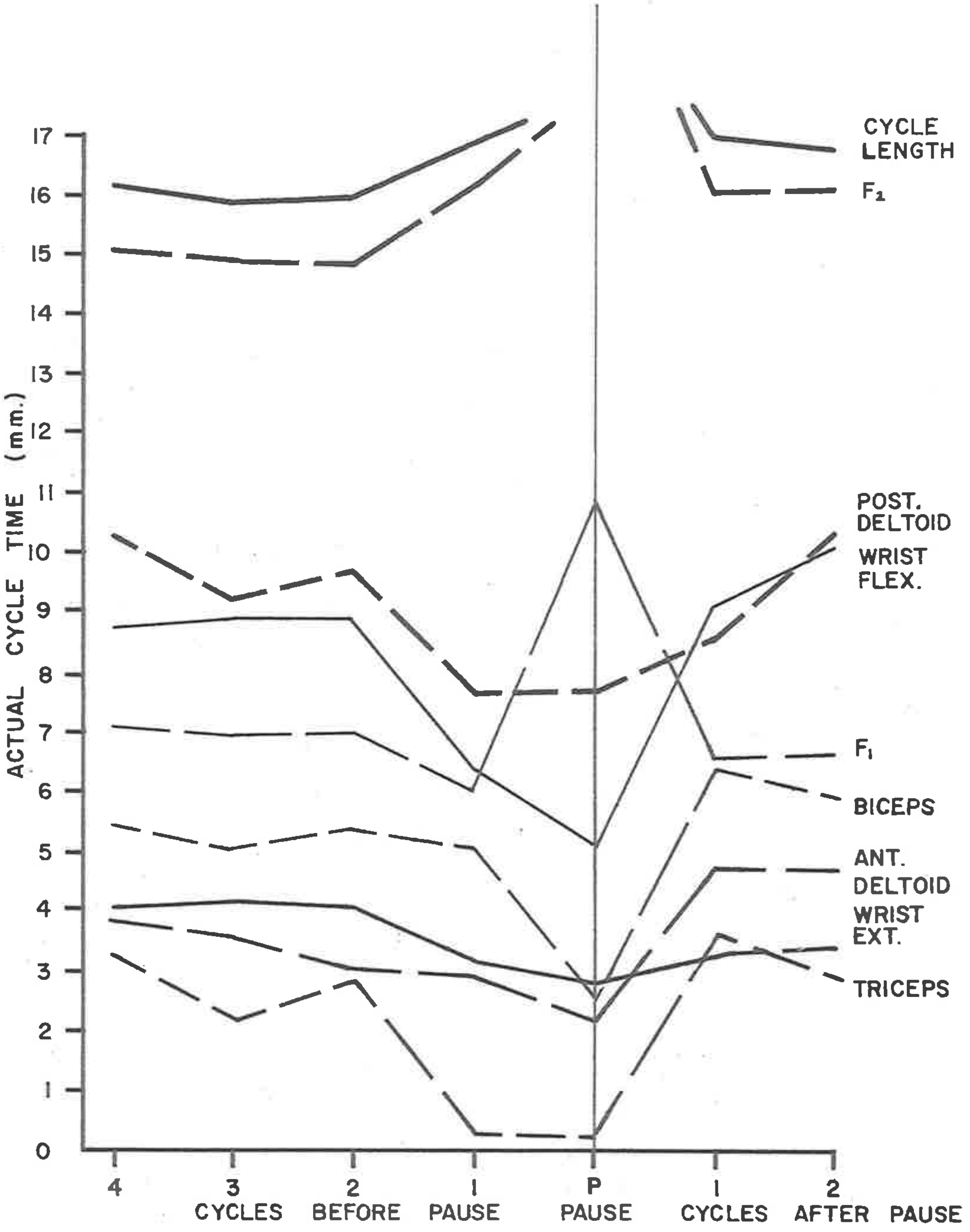
The consistency of positional timing results support this interpretation, although there is an obvious trend whereby the faster subjects show greater consistency in relating the response to an external event. However, a comparison of the correlations based on the actual, with those on the proportionate scores, suggests that this finding is in part due to the difference in time in which variability can occur in fast and slow subjects.

Further Evidence on Temporal Organisation

i. Pauses in Cranking

Further evidence on the significance of the temporal aspect of serial organisation in cranking was provided from an analysis of the pauses or halts that occurred occasionally. An investigation into the nature of these pauses on 5 subjects suggests that they resulted from a change in the temporal position of the muscles analysed.

Figure III:8 presents the temporal organisation of the muscles and the position of the two force peaks prior to and after the pause for 4 subjects. This figure shows that there are real time changes when the muscle's activity commences prior to the pause. For each muscle the activity commences earlier during the cycles just prior to and during the pause. A significant $F(4,12) = 10.662$ ($p < 0.01$) (see summary table in Statistical Appendix B), indicates that the earlier firing is a significant change. Although there are considerable individual differences, those muscles showing the most change in their time of firing are posterior deltoid, bicep and tricep. Immediately



(N = 4)

FIGURE III: 8. MEAN TEMPORAL ORGANISATION OF MUSCLE ACTIVITY AND FORCE EXERTED BEFORE AND AFTER A PAUSE.

prior to the pause there is no significant change in the time of force exertion F_1 and F_2 or any change in the cycle length $F(3, 9) = 0.899$ ($p > 0.05$) (see Appendix B). The remaining subject has the opposite pattern, with the muscle activity occurring later in the cycle prior to the pause (see Figure III:9).

There appears to be no major change in the temporal organisation of the two principal force peaks, or duration of the cycle of movement, prior to the pause. Pauses appear to be a result of change in the temporal structure of at least one of the response units (muscles). The pause itself is apparently precipitated by a muscle out of phase, eventually 'getting out of sequence'. The muscle that changed sequence now commences earlier in the cycle, except in the case of one subject.

The data concerning the change of temporal structuring with pauses, suggests that corrections are made only every 2 or 3 cycles. It is as if the operator can tolerate minor variations in phasing, but when such variations become more significant some modification and new decision is required to prevent the

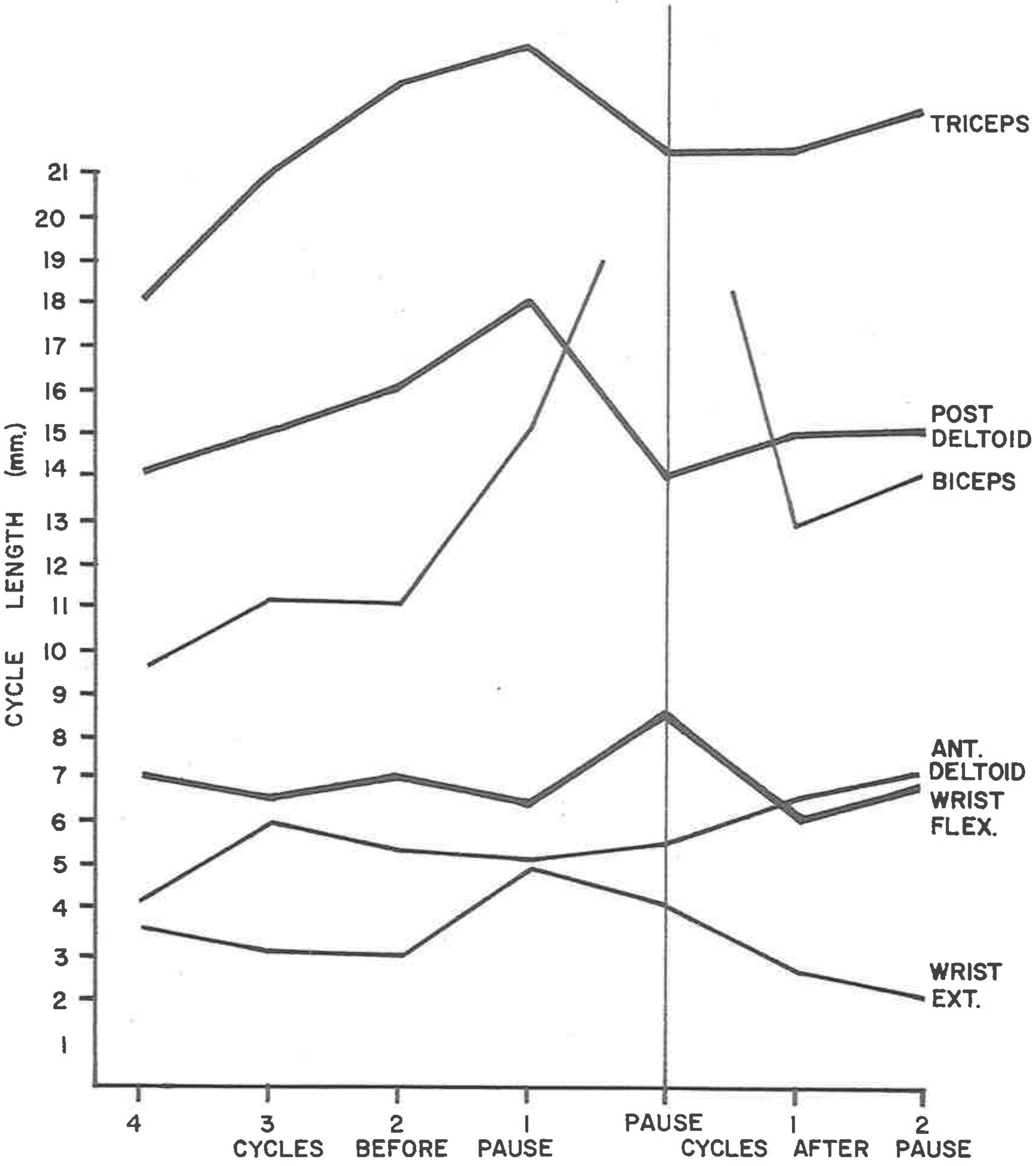


FIGURE III :9. TEMPORAL ORGANISATION OF MUSCLE ACTIVITY BEFORE AND AFTER A PAUSE FOR ONE SUBJECT.

action from breaking down.

ii. Mean Duration of Muscle Activity

A second aspect of the temporal organisation investigated was the duration of the period when each muscle was active in the cycle of movement. This period, determined as that proportion of the cycle time between the onset and cessation of activity for each muscle, was correlated with the speed of cranking. These values are reported in Table III:7. No significant correlations were found. Speed of performance does not seem to be related to the duration of muscle activity.

The muscle groups about the wrist are active for a greater proportion of the cycle time than the remaining 4 muscles recorded. This probably indicates their fixator-synergistic as well as their agonist function.

iii. Replicability of Movement Pattern

Because of the difficulty of assessing the overall serial organisation, resort has frequently been made to the use of graphic records of the performance. The replicability of the movement record or torque record

Table III:7

Correlations between Duration of Muscle Activity and Speed of Cranking

Muscle	Mean Duration of Activity (proportion of cycle time)	S.D.	Correlation with Speed
Anterior Deltoid	0.51	0.07	-0.039
Posterior Deltoid	0.46	0.06	0.279
Bicep	0.46	0.07	0.184
Tricep	0.49	0.11	0.083
Wrist Flexor	0.72	0.14	0.020
Wrist Extensor	0.65	0.13	0.203

$p > 0.05$

from one trial to the next was used to demonstrate the degree of overall stability or consistency.

Figure III:10 presents the torque traces for some of the fast and slow subjects. A certain amount of consistency is evident from visual inspection. In

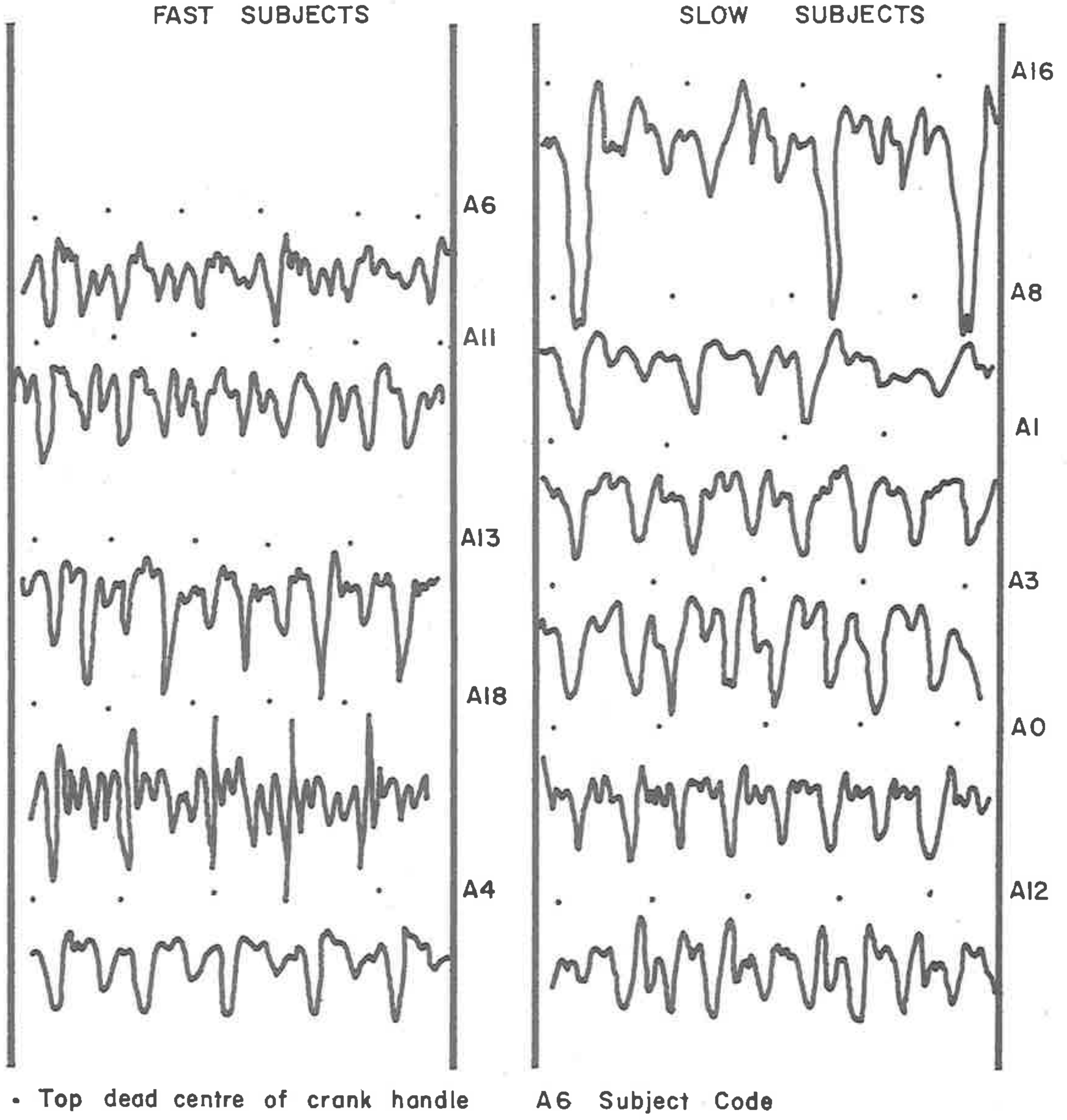


FIGURE III : 10. TRACINGS OF TORQUE RECORD FOR FAST AND SLOW SUBJECTS particular, associated with each cycle, are two general broad force peaks. For each general force peak there are a number of 'spikes', indicating supplementary superimposed adjustments. The same individual generally retains a characteristic pattern of two broad peaks and a number of superimposed 'finer' peaks. However, over successive cycles certain minor changes may occur and may after 4 or 5 cycles be incorporated as part of the generalised pattern. The second aspect of this evidence is the wide variety of individual differences in the force patterns. Each person is characterised by his own individual trace.

Although it is difficult to make comparisons between subjects, it does appear as if both fast and slow subjects show similar degrees of consistency. There are some fast subjects who have a very consistent, regular pattern (for example, A4, A11), and also some slow subjects who show the same degree of consistency (for example, A0, A3). On the other hand, some fast and slow subjects have a less regular pattern (for example, A6, A18, A16, A8).

Relating the evidence on replicability of the movement pattern to the results on phasing and positional timing, it appears that it is only the principal response components that need to be temporally integrated and patterned with some precision. Minor details can vary within limits without having an appreciable effect on the speed of performance.

Gradation

Gradation - Criteria

Several indices of the amount of effort exerted in cranking were employed, firstly using the torque record and secondly, the E.M.G. records.

Gradation - Force Exerted

i. The Amplitude[12] of the two principal force peaks F_1 and F_2 in each cycle was measured from the base

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[12] Use of the torque record to indicate the amount of force exerted has an important restriction. The torque record may not be a valid record of the actual force exerted on the handle by the subject, for no information is available as to whether the force applied was at right angles or oblique to the handle. This limitation should be kept in mind, see Appendix A, p. 244.

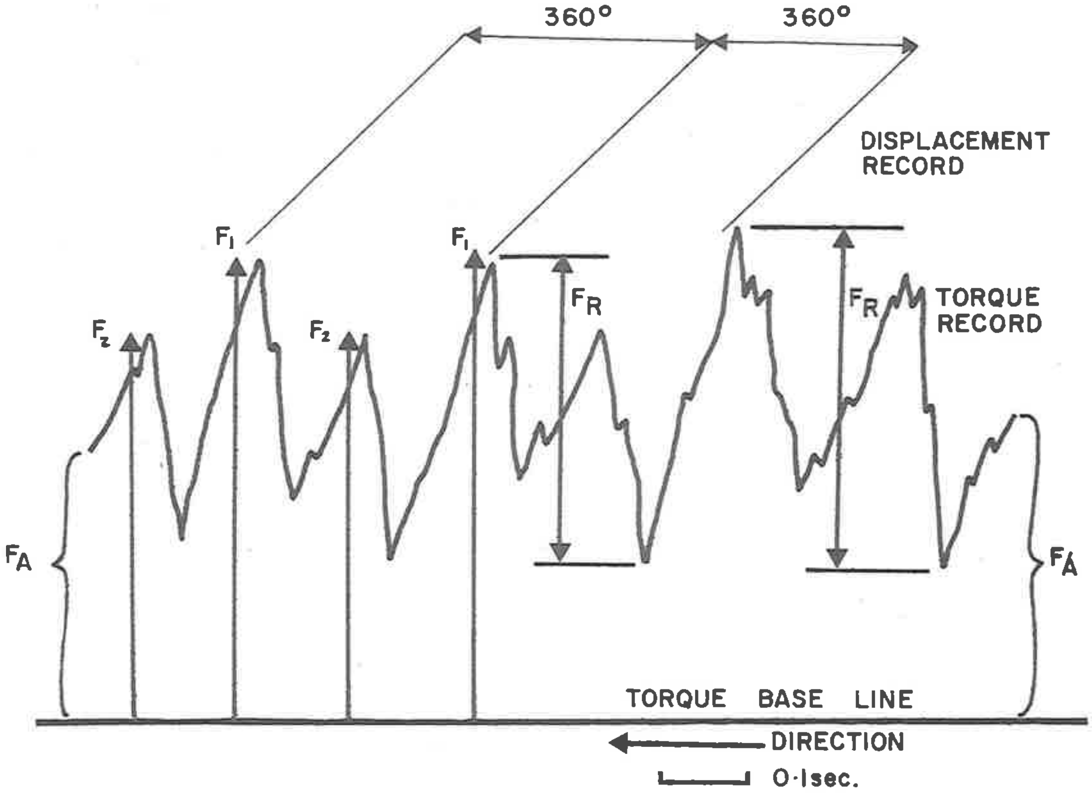
line of the torque record to the two highest peaks of the record. This may be regarded as an index of the total force exerted at a particular instant in the cycle of movement (see Figure III:11).

ii. Area under the Torque Curve, F_A, was used as an overall index of the work done per unit of time. The area was calculated by the rectangles method, for a period of 2 seconds in the middle of the 20 cycles being used for the analysis.

Two measures of the organisation of the force were used:-

i. Force range (F_R) was the range between the highest and lowest force peaks and was used as an index, the degree to which the subject exerted a constant effort or had periods of marked effort followed by a relaxation.

ii. The consistency of the force range, F_C, was used as a criterion of the stability of the effort exerted from cycle to cycle. This measure was the standard deviation of the force range values over the 20 cycles analysed (see Figure III:11).



F_1 ; F_2	FORCE AMPLITUDE – the 2 principal force peaks
F_A	AREA UNDER TORQUE CURVE
F_R	FORCE RANGE between highest and lowest peaks
F_C	CONSISTENCY of the Force Range measure

ANALYSIS OVER 20 CYCLES

FIGURE III :11. DIAGRAM OF TORQUE RECORD WITH DETAILS OF ANALYSIS

Force Exerted - Results

Correlating the two force amplitude measures F_1 and F_2 with speed, values of -0.246 and 0.144 were obtained respectively, see Table III:8. Neither of these values is significant ($p > 0.05$). A non significant correlation of 0.339 ($p > 0.05$) was obtained between speed and area under the Torque Curve, F_A. F_1 and F_2 are not correlated with this latter measure, F_A, $r = -0.006$ and $r = 0.049$ ($p > 0.05$) respectively. However, F_1 and F_2 are significantly correlated, $r = 0.619$ ($p < 0.01$).

Table III:8

Correlations between Speed of Cranking

and Force Criteria

Force Criteria	Mean (mm)	S.D.	'r' (with Speed)
Force Peak (F_1)	26.20	2.45	-0.247
Force Peak (F_2)	28.47	3.13	0.146
Force Area (F_A)	456.19	48.82	0.339
Force Range (F_R)	21.34	7.61	-0.312
Consistency of Force Range (F_C)	5.43	3.45	-0.343

$p > 0.05$

A correlation of -0.312 was obtained between the force range F_R index and speed of cranking. Although not significant ($p > 0.05$) it does suggest that the faster subjects have a smaller range between the periods of effort and relaxation during the cycle. A similar result, $r = -0.343$, was found between speed and the consistency of the force range criterion F_C. Although this correlation is not significant ($p > 0.05$), the trend indicates that the faster subjects are more consistent in the application of the force.

An interesting finding summarised in Table III:9 is that the correlations between the consistency of force range measure (F_C) and the other consistency measured discussed earlier in this chapter (phasing and consistency of positional timing) are significant at the 0.01 level of confidence, except in two cases, $CPTE_A$ and $CPTE_P$.

Gradation - Muscle Activity

i. The degree of muscle activity during each cycle was determined from the E.M.G. records. In the analysis of the E.M.G. records, a four point scale - no activity, slight activity, moderate activity and marked activity, was based on the number of

Table III:9

Correlations between Timing Criteria and Consistency of Force Range (F_C)

Timing Criterion	Correlation with F_C
PF_A[a]	0.663**
PF_p	0.666**
PE_A	0.759**
PE_p	0.775**
$CPTF_A$	0.836**
$CPTF_p$	0.767**
$CPTE_A$	0.569*
$CPTE_p$	0.550*

* Significant $p < 0.05$

** Significant $p < 0.01$

[a] See details of these criteria on p. 80 and p. 90.

spikes, the degree of summation and the mean amplitude of pen deflection. Similar procedures have been used by Basmajian (1967) and Kamon and

Gormley (1968), (see Appendix A, p. 241).

ii. A second measure of muscle activity derived from the E.M.G. records was based on the mean pen deflection measured in millimetres. Although such a criterion is not based directly on the frequency and summation of the action potentials, it has been used as an index of the degree of muscle activity (Kamon & Gormley, 1968; Kitzman, 1964). With these restrictions in mind it has been used in the present study to permit a limited statistical analysis of the data. Further details of the E.M.G. analyses are outlined in Appendix A.

Muscle Activity - Results

Figure III:12 presents the histograms of the degree of activity for each of the six muscles investigated. All of the muscles are active at some stage in the cycle of action. The anterior deltoid, posterior deltoid and bicep appear to have the highest level of activity in most subjects. There is a significantly higher proportion of subjects with 'marked' activity of the anterior and posterior deltoid and bicep than for the other three muscles, $Z = 6.272$ ($p < 0.01$).

Three of the muscles, triceps, wrist flexors and

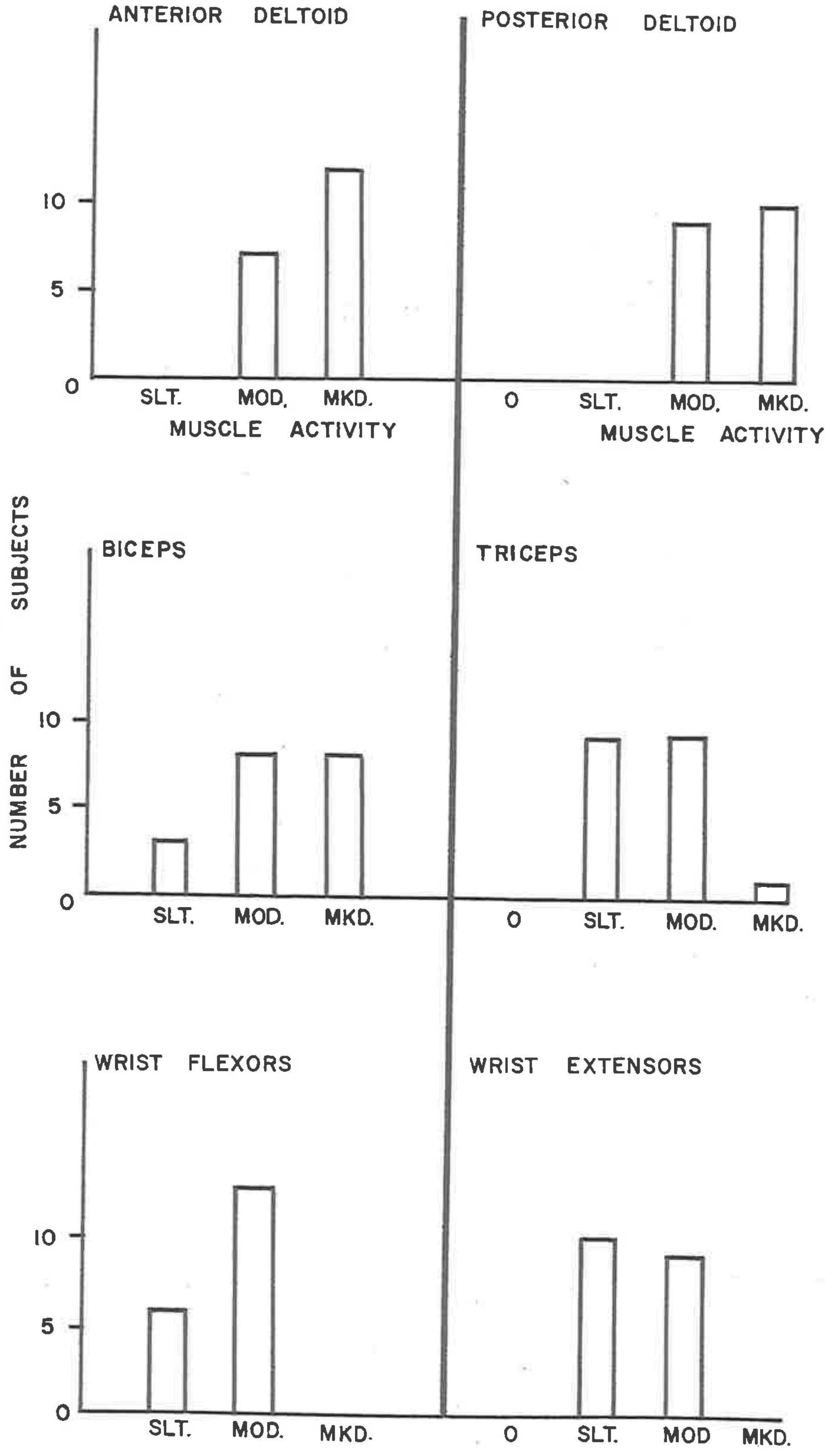


FIGURE III : 12. HISTOGRAMS OF DEGREE OF MUSCLE ACTIVITY extensors appear to be less active in that there is a significantly larger proportion of subjects who show slight activity on these muscles, than the proportion of subjects showing slight activity on the remaining three muscles, $Z = 4.372$ ($p < 0.01$).

The mean pen deflection values support the histogram finding that the three most active muscles are the anterior and posterior deltoid and the biceps, $F(1,32) = 48.38$, $p < 0.001$ (for summary table see Appendix B). The tricep is the most active of the remaining 3 muscles analysed (see Table III:10).

Comparing the fast group of subjects with the slow group of subjects (based on speed of cranking), no significant differences were found in the overall degree of muscle activity, $F(1,32) = 0.11$, $p > 0.05$ (see Appendix B). Further in support of this finding, a Kendall's rank order correlation (Tau) between speed of cranking and the composite sum of the E.M.G. activity (based on pen deflection) of the 6 muscles, is not significant, Tau = -0.173 ($p > 0.05$).

Gradation - Discussion

The most obvious finding from the gradation analysis is that none of the criteria of the amount of effort involved,

Table III:10

Means and Ranges of Degree of Muscle Activity

Muscle	Pen Deflection	
	Mean (mm)	Range (mm)
Anterior Deltoid	9.2	5 - 13
Posterior Deltoid	8.2	5 - 13
Bicep	7.5	3 - 10
Tricep	5.1	2 - 13
Wrist Flexors	4.6	3 - 6
Wrist Extensors	4.4	3 - 6

are significantly related to speed of performance. This is particularly so with the maximum force exerted at a particular point F_1 and F_2, and the degree of muscle activity. Although not significant, the index of work done per unit time, F_A, showed a slight positive relationship with speed.

Considering the organisation of the force, there is a noticeable tendency for the faster subjects to be more consistent in the degree of effort and amount of relaxation during the cycle, as indicated by the torque record. This may be interpreted as an indication of the degree of smoothness in the application of the force. The significant correlations between consistency of force range (F_C) and the phasing and consistency of positional timing criteria, lend support to the notion that the more skilled subjects are able to construct and use a more stable temporal pattern of action. Not only is this pattern stable in terms of the phasing of the response units, but also stable in the degree of effort or the gradation of the response.

General Discussion

The effector organisation in the present task involves the combination and integration of a familiar set of response units (movements and muscles of the right arm) into a novel pattern of action.

A fine grain analysis of the response reveals the extreme complexity of the organisation in the relatively simple skill of backward hand cranking. In the first instance, a variety of postural adjustments place the individual in what he considers to be the most appropriate position. Such adjustments, as leaning forward (within the restrictions of the shoulder strap) and abduction of the shoulder to varying degrees, are the main preparatory movements. This orientation response, apparently is a procedure used to facilitate the organisation of the response, through a series of synergistic postural adjustments.

The complexity of the organisation is also evident from the temporal pattern of muscle and joint activity. For example, the agonists and antagonists about the shoulder and elbow joints show considerable activity, prior to the limb segment each muscle controls, actually moves. In other words the activity of the muscle must commence in anticipation of the movement of the limb. This mode of organisation permits the muscle to act firstly as an antagonist and then, because of the cyclic nature of the movement, as an agonist, without any pause in the cycle of events. Such integrated activity is further complicated by the fact that the biceps and long head of the triceps are bi-articular muscles (Molbech, 1965), and thus can influence the movement of both the shoulder and elbow joints.

Even though hand cranking may be regarded as a closed-kinetic chain (Steindler, 1955) and hence is restricted in the range of possible movements, a wide range of individual styles are evident, both from the film and torque records.

Such differences occur, for example, in the sequencing of events and the postural adjustments. Thus, even though the arm is restricted in movement, differences occurred both in the order in which the joints moved and changed direction, and also in the sequence of activity of the muscles about these joints. However, none of the differences in style of organisation are related to speed of performance. Apparently the same end result can be achieved in a variety of ways by different patterns of effector organisation.

Those aspects of serial organisation which appear, from the results, to be most important to speed of cranking are the phasing of principal events and the consistency with which these events occur in the temporal sequence. Secondary importance appears to be attached to the relationship between the response and the 'external' signal, that is positional timing. However this conclusion must be considered only in terms of the present study, in which there was no separate external event. Usually the task in coincident timing studies (Conrad, 1951; Grose, 1967a) requires the subject to synchronise a response with a clearly observable external event or signal. But with hand cranking a point does exist in the cycle of movement when the subject must exert a particular effort, substantially greater than the on-going constant or steady effort.

The gradation analysis indicates that some general amplification control is influenced in part by the characteristics of the task and that these are more significant than the individual differences in the amount of effort exerted. It appears that it is not the amount of effort involved that is important in relation to the speed of performance, but rather the organisation and consistency of the effort.

Because of the speed of cranking, (mean = 4.7 c.p.s., a cycle of movement taking about 0.21 seconds), the general strategies of effector organisation must involve some form of open-loop control (Pew, 1966). Specifically this involves a number of muscles crossing the joints of the arm and shoulder which must be contracted and relaxed in a relatively stable temporal sequence. At a gross level, in the same period of time, the wrist, elbow and shoulder joints each reverse direction twice, the hand is gripping the crank handle isometrically, and the resultant is a general force applied to overcome the frictional resistance of the system, as well as a variable force, which is exerted several times in the cycle and keeps the crank moving at speed. This sequence of events and hence a series of decisions or instructions by the effector mechanism takes place in about a fifth of a second. Clearly these instructions and the control of at least one cycle of movement must be beyond sensory control. Here is an example of a 'motor programme' (Keele, 1968), in which the instructions to initiate the response units are placed in sequence, appropriately phased and graded. Such a process may be considered to be a fundamental form of anticipatory behaviour, and in particular an aspect of effector anticipation (Poulton, 1957).

The significance of the temporal structuring of the responses has been emphasised by most workers in this field; Conrad (1956), Michon (1967), Naylor et al. (1963), Trumbo et al. (1965). Conrad (1955b) has suggested that the subject structures the situation to create the most favourable temporal conditions for the response. In the present study, as in the pilot investigation, the notion of temporal structuring seems to be supported, particularly in the form of a pre-prepared motor programme. It is suggested that the skilled performer established a relatively stable programme in which the instructions initiating the principal events are ordered into a well defined temporal sequence. Less skilled subjects on the other hand have not been able to stabilise the temporal pattern of events, to the same extent, although as pointed out earlier the sequence of events is structured satisfactorily. Thus what appears to be of central importance is not only the temporal structuring, but also the stability or consistency of the structure. In the present study all of the consistency measures used are correlated with performance on the cranking task. Studies reporting a reduction in variability of performance with practice (for example, Ghiselli, 1936; Grose, 1967b; Provins, 1956) may be considered to be demonstrating the gradual formation of more stable programmes, and larger and larger units of action under open-loop control.

The effector organisation involved in a repetitive speed skill seems to require an open-loop mode of control. It is proposed that the strategy used by the operator concerns the structuring of a motor programme. The programme consists of a series of instructions, placed in order and finely adjusted into a temporal pattern. Speed of performance is dependent not only on the formation of such a motor programme, but also upon the consistency or stability of the series of instructions. However, it is not clear how the motor programme is formed and controlled in a repetitive skill. Again of what significance is the stability of the structure? Can it be altered or modified to account for changes in the task, or do all task variations require the formation of new, specific motor programmes? These questions will be investigated in the following chapters.

CHAPTER IV

THE EFFECT OF CHANGING CRANKING LOAD AND AMPLITUDE ON EFFECTOR ORGANISATION

Abstract

The modifications in effector organisation in backward hand cranking due to changes in the load and amplitude of the crank were investigated. Effector organisation was assessed principally in terms of the serial timing (sequencing and phasing), positional timing and gradation of the response on each of four cranking conditions - small radius, light load; small radius, heavy load; large radius, light load; large radius, heavy load. The results replicated the findings for the AB analysis. Phasing is central in the process of effector organisation, and although positional timing is of some importance, it is the consistency or stability of the temporal structure that is more significant to speed of cranking. Minor modifications in positional timing occur with a change in the amplitude of the crank handle. However, the effect of a heavy load or resistance to cranking is to cause changes both in the temporal structure and gradation of the response. It is proposed that

> the effector organisation involves only one basic motor programme which is modified to meet changes in the task. Further, in view of the generally high intercorrelations between the criteria used on the four cranking conditions, it is suggested that a general organisational strategy in the form of a general plan or executive programme, controls the operation of the motor programme.

In the second part of the present study, the changes in effector organisation, necessitated by modifications to the task of hand cranking, were investigated. Firstly the load or resistance to cranking was changed and secondly the amplitude or excursion of movement was varied by altering the radius of the crank handle, see Table IV:1.

Procedure

<u>The Effect of Load</u>

The same experimental arrangement and procedure as for the first treatment condition, AB, was used, with the same 19 male subjects. The effect of load was investigated under two conditions:-

1. Small Amplitude Condition: Using a 5 cm. radius, the effect of a 5 kg. load was compared with a 10 kg. load suspended from the friction belt (AB

Table IV:1

Summary of the Four Backward Cranking Conditions

Load Comparison

	Light Load				Heavy Load			
	Cranking Condition				Cranking Condition			
		Radius	Load	Effective Resistance		Radius	Load	Effective Resistance
Small Amplitude	AB	5 cms.	5 kg.	2.4 kg.	BB	5 cms,	10 kg.	4.8 kg.
Large Amplitude	CB	10 cms.	5 kg.	1.2 kg.	DB	10 cms,	10 kg.	2.4 kg.

Amplitude Comparison

	Small Amplitude				Large Amplitude			
	Cranking Condition				Cranking Condition			
		Radius	Load	Effective Resistance		Radius	Load	Effective Resistance
Same Effective Resistance	AB	5 cms.	5 kg.	2.4 kg.	DB	10 cms.	10 kg.	2.4 kg.

compared with BB).[1]

2. Large Radius Condition: Using a 10 cm. radius, the effect of a 5 kg. load was compared with a 10 kg. load (CB compared with DB).

The Effect of Amplitude

The effect of amplitude was investigated by doubling the radius of the crank handle from 5 cms. to 10 cms. and keeping the effective resistance the same. This was achieved by using a 5 kg. load with the 5 cms. radius, and comparing it with a 10 kg. load with the 10 cms. radius (AB compared with DB).[2]

Subjects were required to crank as fast as possible (backwards) and in so doing wind up a pulley a distance of 9 feet. The experimental conditions were conducted in accordance with the 4 x 4 Latin square as outlined earlier (see p. 46).

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[1] The effect of doubling the weight is to double the effective resistance. This was verified by calibrating the strain-gauges. See Appendix A, p. 226.

[2] That the effective resistance remained the same under these two conditions was checked by calibrating the strain-gauges. See Appendix A, p. 226.

Results

The analysis of the records and criteria of effector organisation were the same as reported in Chapter III, although some of the criteria that duplicated findings in the analysis of the basic condition (AB) were not included in the comparison of load and amplitude changes.

Speed of Cranking

Table IV:2 summarises the mean speed of cranking for the four treatment conditions, as well as the intercorrelations based on speed.

All of the intercorrelations are positive and only two fail to reach significance at the 0.01 level of confidence. The two load comparisons AB and BB (0.751) and CB and DB (0.884) are both highly significant ($p < 0.01$). Similarly there is a highly significant correlation between the two amplitude conditions AB v DB, 0.805 ($p < 0.01$). These findings indicate that fast subjects on one condition are also the fastest on the other task combinations.

The effect of load and amplitude on speed of cranking were analysed using analysis of variance techniques. A very significant $F(1,126) = 48.989$, $p < 0.001$, indicates

Table IV:2

Means, Standard Deviations and Intercorrelations for Backward Cranking Conditions

		Cranking Condition			
		AB	BB	CB	DB
	Radius	5 cms.	5 cms.	10 cms.	10 cms.
	Load	5 kg.	10 kg.	5 kg.	10 kg.
AB			.751**	.766**	.805**
BB				.435	.528*
CB					.884**
Mean (c.p.s.)		4.71	3.88	4.48	4.39
S.D.		.71	.79	.59	.47

* Significant $p < 0.05$

** Significant $p < 0.01$

a real difference in speed between the heavy and light load conditions.[3] A significant load x amplitude interaction

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[3] The summary tables of all analyses of variance are listed in the Statistical Appendix B, pp. 246-263.

$F(1,126) = 25.968$ ($p < .001$) however suggests some confounding influence of the amplitude or radius of the crank. Testing for simple effects a 't' value (Lindquist, 1956, p. 243) of 6.787 ($p < 0.01$) indicates a significant difference between AB (small radius, light load) and BB (small radius, heavy load), the former being faster. Thus the effect of increasing the load, when using a small radius is to decrease the speed of cranking. On the other hand, no significant difference was found between the light load (CB) and heavy load (DB) conditions using the larger 10 cms. radius, $t = 0.688$ ($p > 0.05$).

Considering the effect of amplitude on speed an $F(1,126) = 0.035$ is not significant ($p > 0.05$), although once again the significant load x amplitude interaction indicates a difference may exist between individual treatment conditions. A significant 't' value of 2.623 ($p < 0.05$) between the means of AB (small radius, light load) and DB (large radius, heavy load) indicates a faster speed of cranking for the former, small radius condition. This difference is only significant at the 0.05 level of confidence in spite of the fact that the handle moves twice as far in the large radius condition compared with the small radius condition.

Speed of Cranking - Discussion

The effect of load is to slow down the speed of cranking, particularly with the small radius condition BB. A non significant slowing effect resulted with an increased load, using a large radius. The effective resistance in condition BB is twice that in conditions AB and DB and four times that in condition CB. The finding that cranking in CB is not significantly faster than in DB, although the resistance to cranking is half as much, indicates that the subject is unable to organise the movement sequences any more effectively. That is, the limitation to speed of movement is the time required to organise and control the movement, supporting similar conclusions by Fitts (1954), Peters and Wenbourne (1936) and Taylor and Birmingham (1948).

The positive and generally significant intercorrelations between the four different cranking conditions suggest a general organisational ability or strategy on this task. This notion is further supported by the finding that the largest correlations are between the similar amplitude conditions, that is AB with BB and CB with DB. However, the correlations of BB with the two large amplitude conditions are the lowest suggesting some change in organisational strategy. As this is not the case with AB, for the correlations with CB and DB are both high, the change is due to the heavy resistance of the BB condition. Thus the heavy resistance condition BB does appear to necessitate a greater reorganisation of the response than the other conditions.

Serial Timing

Sequencing - Results

The sequencing evidence was based on the order of occurrence of the six muscles analysed. All four cranking conditions had the same mean sequence or order, this is, wrist extensors, biceps, posterior deltoid and wrist flexors, triceps and anterior deltoid. Thus a change in load or amplitude has no effect on the mean sequence in which the muscles were fired.

The coefficients of concordance based on the biceps as the first event in the cycle are all significant, see Table IV:3.

Thus with each cranking condition a significant order of events does exist. However, even though the mean pattern is the same, there are some individual variations between

Table IV:3

Coefficients of Concordance (W) for the Sequence of Muscle Activity in the Four Backward Cranking Conditions

	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
W	.427	.607	.491	.355
S	1540**	2190**	1774**	1282**

** Significant $p < 0.01$

conditions. 8 subjects have no change in sequence over the four cranking combinations. There is no pattern of sequencing changes between fast and slow subjects however.

The effect of changing load or amplitude is to cause some minor change in the sequence in which the muscle's activity is initiated, although no consistent trend is noticeable between individuals. The mean sequence remains the same for all four treatment conditions.

Phasing - Results

Phasing criteria, based on the consistency of the cycle length for the torque and muscle activity records, expressed as actual scores (PF_A and PE_A) in proportionate terms (PF_p and PE_p) were used.

The correlations between speed of cranking and the phasing criteria are summarised in Table IV:4.

In general, the correlations show that subjects who are fast at cranking also have the smallest variation as assessed by the phasing criteria. The lowest correlations occur on the BB condition. The non-linear correlations are still consistent with the hypothesis, but it is interesting to note that with the very light resistance condition CB, all but one of the correlations is non-linear. The regression lines are all quadratic, but still support the hypothesis. However, there is some indication that there is a limit to the degree of consistency that fast subjects can achieve.

Table IV:4

Correlations Between Speed of Cranking and the Phasing Criteria (PF_A, PF_p, PE_A, PE_p) on Backward Cranking

Phasing Criterion	Cranking Condition AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
Force Data (Actual time) (PF_A)				
'r' with speed	$-.630^{**}$ $(.732)^{a}$	$-.723^{**}$	$-.681^{**}$ (.791)	$-.659^{**}$
Mean (mm)	1.11	1.63	1.25	.95
S.D.	.93	.93	1.01	.54
Force Data (Proportional) (PF_p)				
'r' with speed	$-.510^{*}$	$-.491^{*}$	$-.587^{**}$ (.706)	$-.546^{*}$
Mean	4.31	5.85	5.21	4.03
S.D.	3.16	2.62	3.45	1.87
EMG Data (Actual time) (PE_A)				
'r' with speed	$-.703^{**}$	$-.592^{**}$	$-.765^{**}$ (.841)	$-.718^{**}$ (.792)
Mean (mm)	1.17	1.92	1.45	1.21
S.D.	.84	1.43	1.08	.65
EMG Data (Proportional) (PE_p)				
'r' with speed	$-.584^{**}$	$-.430$	$-.692^{**}$	$-.607^{**}$
Mean	5.10	6.85	6.01	5.09
S.D.	2.82	4.10	3.64	2.16

[*] Significant $p < 0.05$ [**] Significant $p < 0.01$

[a] Correlations in parentheses are multiple correlations indicating a second order or quadratic trend (see Statistical Appendix B, p. 264).

Tables IV:5 and IV:6 presents the means and the intercorrelations of the phasing criteria for the actual time data and proportional time data respectively, for the four backward cranking conditions.

Table IV:5

Intercorrelations of Phasing Criteria on Backward Cranking Conditions (Actual Time Data)

	Cranking Condition							
	AB (5, 5)		BB (5, 10)		CB (10, 5)		DB (10, 10)	
	Phasing Criteria							
	PF_A	PE_A	PF_A	PE_A	PF_A	PE_A	PF_A	PE_A
AB			.730**	.674**	.828**	.857**	.717**	.624**
BB					.404	.459*	.628**	.798**
CB							.665**	.477*

* Significant $p < 0.05$

** Significant $p < 0.01$

These correlations indicate that subjects who are consistent in their temporal organisation on one condition, tend

Table IV:6

Intercorrelations of Phasing Criteria on Backward Cranking Conditions (Proportional Data)

	Cranking Condition							
	AB (5, 5)		BB (5, 10)		CB (10, 5)		DB (10, 10)	
	Phasing Criteria							
	PF_p	PE_p	PF_p	PE_p	PF_p	PE_p	PF_p	PE_p
AB			$.628^{**}$	$.588^{**}$	$.867^{**}$	$.874^{**}$	$.666^{**}$	$.560^{*}$
BB					.382	$.466^{*}$	$.564^{**}$	$.764^{**}$
CB							$.658^{**}$	.434

* Significant $p < 0.05$

** Significant $p < 0.01$

to be consistent on all conditions. The smallest correlations seem to occur between the two extreme resistance conditions, BB and CB.

A summary of the analyses of variance based on the two phasing criteria, force (PF_p) and muscle activity (PE_p) are presented in the Statistical Appendix, Tables B.6 and B.7. Non significant F values of less than 1 and non significant interactions indicate that no change in phasing occurs with changes in resistance and amplitude in hand cranking.

Phasing - Discussion

The evidence from the phasing analysis reveals that there is no major change with different loads or amplitudes. The criteria used are really variability measures and hence the results indicate that there is no change in overall variability of the cycle length based on force peaks or EMG data. In other words an increase in load or amplitude has no effect on the consistency or stability with which a major event occurs from cycle to cycle. Again the generally high intercorrelations between phasing criteria on the backward cranking conditions provide evidence of some general organisational strategy. The correlations between speed of cranking and the phasing criteria support the earlier conclusion of the significance of phasing in speed of movement and hence its importance in the formation of the motor programme.

Consistent throughout the results reported so far is the change of organisation required for the heavy resistance condition BB. The phasing evidence lends further support to this finding. In particular some of the intercorrelations with BB are low and similar low values are reported between speed and phasing, particularly PF_p and PE_p.

Positional Timing

Positional Timing - Results

The criteria of positional timing used were the onset of the principal force peak PTF and the onset of activity of the biceps muscle PTE. The occurrence of the two principal force peaks F_1 and F_2 were also used as additional evidence to highlight changes in the temporal structure of the response.

Table IV:7 summarises the correlations between the speed of cranking and the positional timing criteria based on force (PTF) and the biceps activity (PTE). A replication of these results based on the force criterion F_1 gave the following correlations for the four conditions, AB, BB, CB and DB: 0.560, 0.635, -0.048 and -0.016 respectively. These results indicate the same trends as those reported for PTF in the Table. The negative correlations indicate that the fast subjects commence the activity earlier in the cycle of movement than the slow subjects.

From Table IV:7 only one correlation reaches significance at the 0.01 level of confidence, that is PTE on the BB con-

Table IV:7

Correlations Between Speed of Cranking and the Positional Timing Criteria (PTF and PTE) on Backward Cranking

Positional Timing Criterion	Cranking Condition AB (5, 5)	 BB (5, 10)	 CB (10, 5)	 DB (10, 10)
PTF				
'r' with speed	.497*	.450*	.110	-.136
Mean	18.86	14.02	20.90	20.27
S.D.	2.80	2.42	3.61	3.81
PTE				
'r' with speed	-.348	-.656**	.014	-.133
Mean	39.76	39.18	32.74	31.91
S.D.	17.16	15.93	25.14	16.14

* Significant $p < 0.05$

** Significant $p < 0.01$

dition. There does appear to be an amplitude effect in that with the large radius conditions CB and DB all of the correlations are very low and not significant. In general however, these results confirm the earlier finding that positional timing as assessed by the criteria in this study is not of major importance to speed of performance. There is an indication that with the small amplitude conditions AB and BB, positional timing becomes more important. The intercorrelations of the positional timing criteria (PTF and PTE) are summarised in Table IV:8.

Table IV:8

Intercorrelations of Positional Timing Criteria (PTF and PTE) on Backward Cranking Conditions

	Cranking Condition							
	AB (5, 5)		BB (5, 10)		CB (10, 5)		DB (10, 10)	
	Positional Timing Criteria							
	PTF	PTE	PTF	PTE	PTF	PTE	PTF	PTE
AB			.596**	.579**	.817**	.744**	.638**	.700**
BB					.548*	.365	.610**	.299
CB							.669**	.758**

* Significant $p < 0.05$

** Significant $p < 0.01$

All of the intercorrelations based on PTF data except that between BB and CB are highly significant ($p < 0.01$). The heavy resistance condition BB in general has the lowest intercorrelations. All the load comparisons AB with BB and CB with DB are significant ($p < 0.01$) as is the amplitude comparison AB with DB ($p < 0.01$). The intercorrelations based on PTE show a remarkably similar pattern to the PTF data.

The position of occurrence of the two principal force peaks F_1 and F_2 are illustrated in Figure IV:1. An analysis of variance of the position of F_1 and F_2 in the cycle indicates that there is a significant change in position of both force peaks with a change in amplitude, $F(1,126) = 80.67$, $p < 0.001$ and $F(1,126) = 14.68$, $p < 0.001$ respectively. The F tests based on load are not significant. There is no amplitude x load interaction effect.

Figure IV:2 summarises the mean position of muscle activity for all 4 backward cranking conditions. Individual muscles show different patterns of organisation, for example, the anterior deltoid shows little difference between the condition, whilst with the biceps, triceps and two wrist groups in the large amplitude conditions CB and DB, the

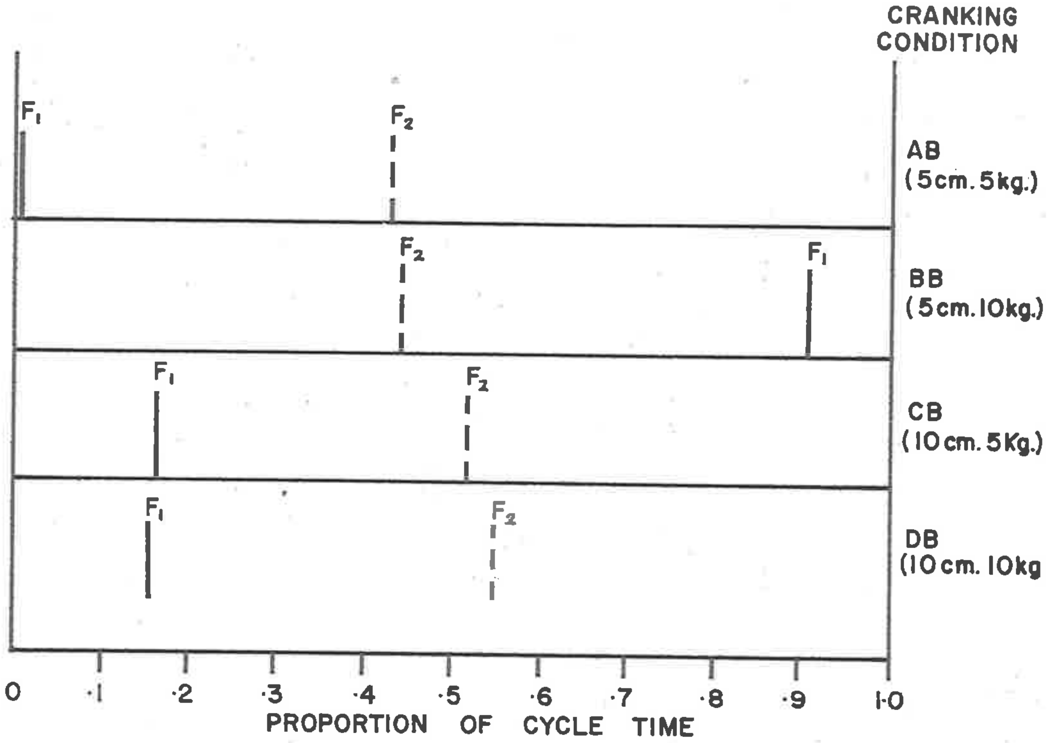


FIGURE IV : 1. THE MEAN TEMPORAL POSITION OF THE TWO PRINCIPAL FORCE PEAKS (F_1 and F_2) IN EACH OF THE FOUR BACKWARD CRANKING CONDITIONS.

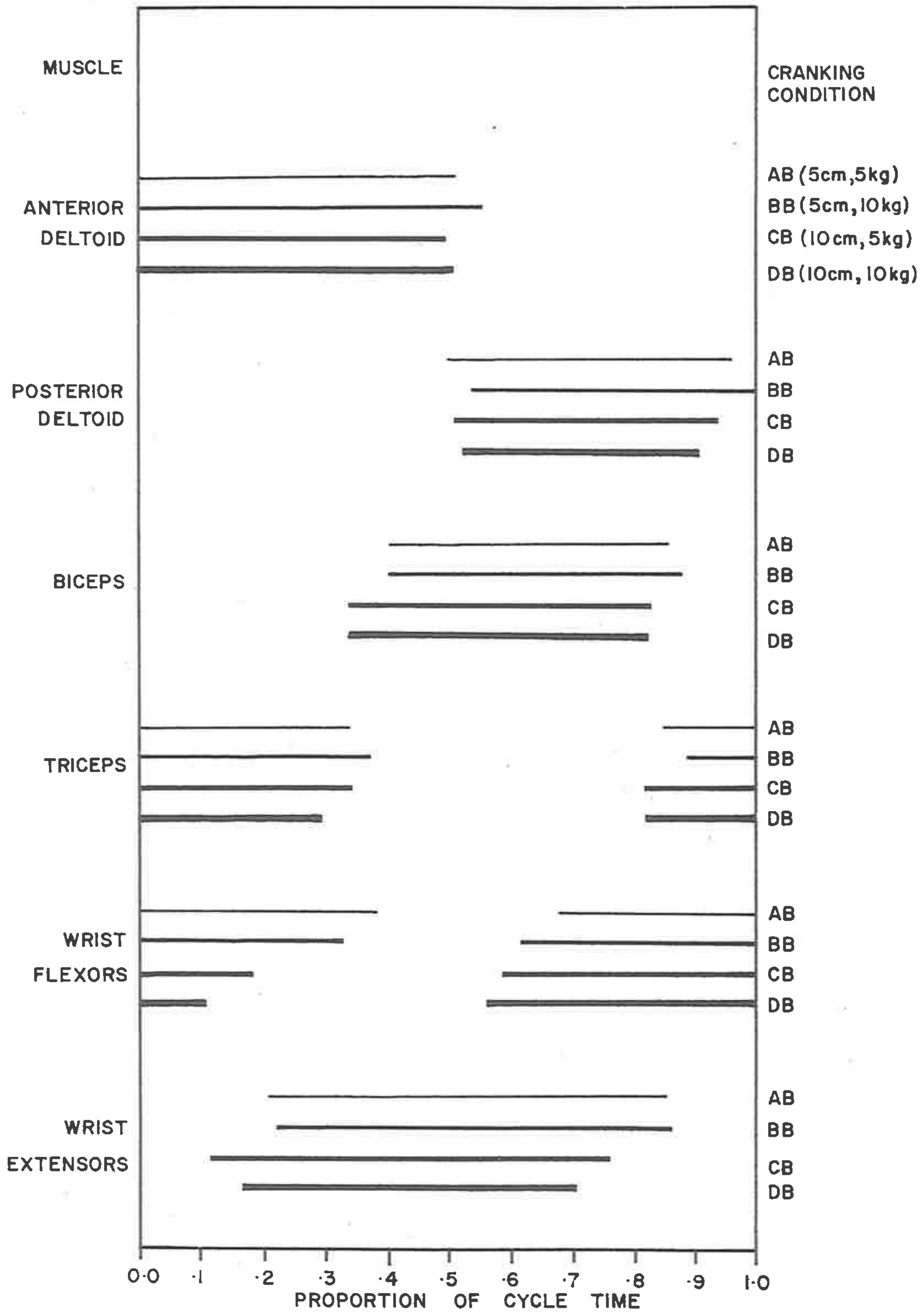


FIGURE IV : 2. THE MEAN DURATION OF ACTIVITY FOR EACH MUSCLE IN EACH OF THE FOUR BACKWARD CRANKING CONDITIONS.

activity appears to occur earlier in the cycle.

In the comparison of the amplitude change (AB v DB), all of the muscles, except anterior and posterior deltoid, are active earlier in the cycle of movement on the large amplitude condition (DB). An F test based on the onset of bicep activity is significant, $F(1,126) = 13.04$, $p < 0.01$, indicating for this muscle at least, that with an increase in amplitude the muscle action occurs earlier in the cycle. A non-significant $F(1,126) = 1.54$, $p > 0.05$, for the change in position of bicep activity for different load conditions, shows that no major reorganisation is involved. There are no significant interaction effects.

Consistency of Positional Timing

Consistency of positional timing was based on the variability of the positional timing criteria. All of the correlations with speed are in the hypothesised direction (see Table IV:9). That is, the fast subjects are more consistent in relating an event to an external position in the cycle of movement. A reduction in the size of the correlations based on the proportionate data suggests that consistency is slightly confounded with speed. With condition CB, all of the relation-

Table IV:9

Correlations Between Speed of Cranking and Consistency of Positional Timing Criteria ($CPTF_A$, $CPTF_p$, $CPTE_A$, $CPTE_p$)

Consistency of Positional Timing Criterion	Cranking Condition AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
Force Data (Actual) ($CPTF_A$)				
'r' with speed	-.524*	-.402	-.685** (.889)^{a}	-.660**
Mean (mm)	.43	.50	.51	.50
S.D.	.26	.22	.28	.26
Force Data (Proportional) ($CPTF_p$)				
'r' with speed	-.240	-.024	-.495* (.812)	-.485*
Mean	1.94	1.82	2.16	2.11
S.D.	1.02	.83	.92	.95
EMG Data (Actual) ($CPTE_A$)				
'r' with speed	-.583**	-.665**	-.732** (.829)	-.662** (.753)
Mean (mm)	.94	1.25	.78	.78
S.D.	.70	.81	.43	.49
EMG Data (Proportional) ($CPTE_p$)				
'r' with speed	-.436	-.511*	-.598** (.707)	-.563**
Mean	4.14	4.47	3.33	3.30
S.D.	2.36	2.24	1.35	1.64

* Significant $p < 0.05$ ** Significant $p < 0.01$

[a] Figures in parentheses are multiple correlations indicating a second order or quadratic trend. (See Appendix B, p. 264).

ships are non-linear, the trend being quadratic. However, the slow subjects are still the most variable.

Positional Timing - Discussion

The positional timing evidence demonstrates changes in effector organisation to account for the variation in the resistance to cranking and the amplitude of the crank handle.

The effect of load is only obvious on the BB condition which offers a substantial resistance to cranking. The reorganisation by the effector mechanism is to cause the principal force peak to occur much earlier, in fact just before top dead centre. These adjustments are not evident with DB, which offers only half the resistance to cranking that BB does.

The amplitude effect (AB v DB) is to cause the muscle activity to occur earlier in the cycle with the large radius. The overall effect results in both force peaks being exerted later in the cycle.

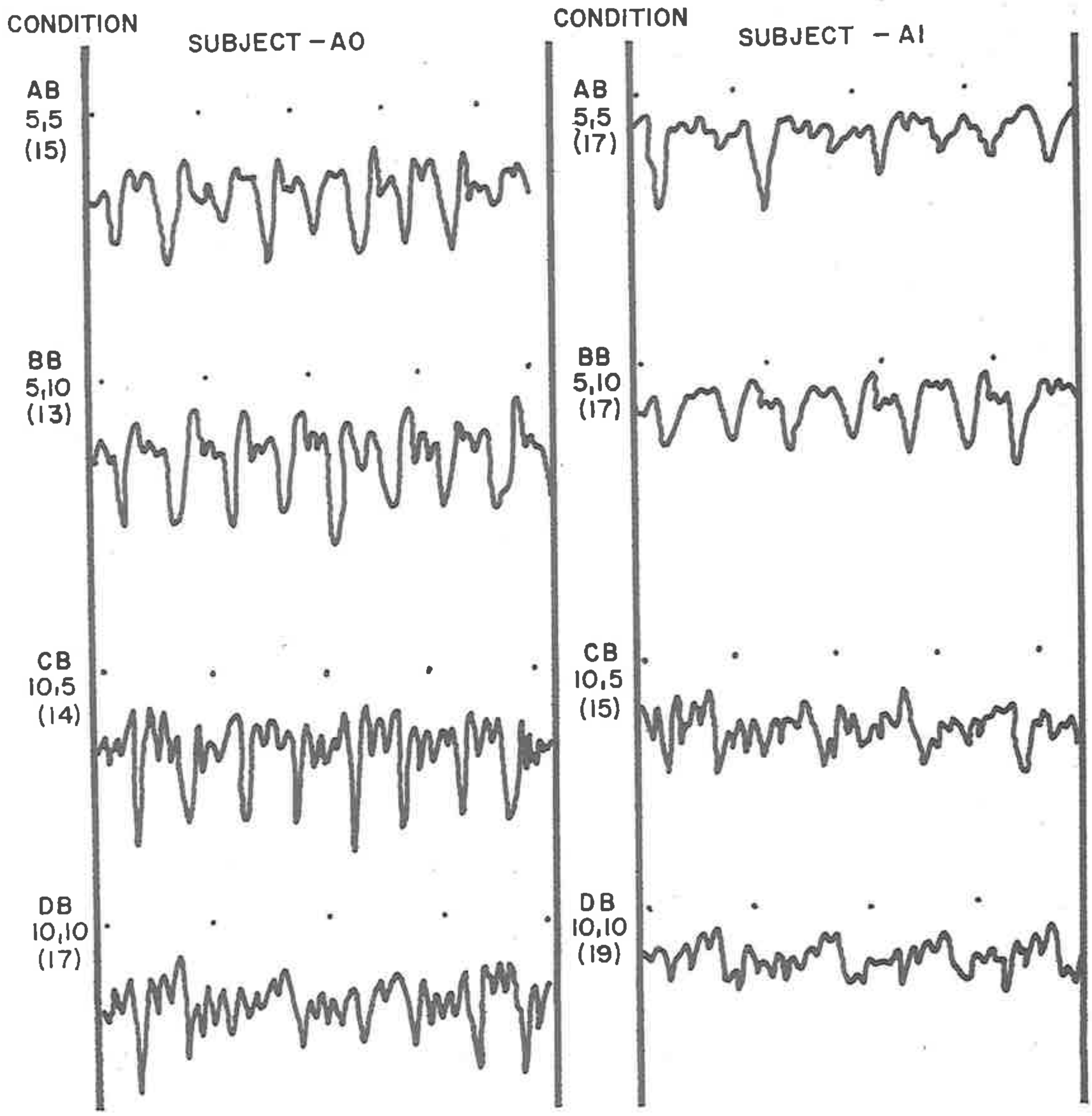
The significant intercorrelations of the positional timing measures suggest some general organisational strategy is used in each condition. However the low intercorrelations with BB support the conclusion that this heavy resistance condition causes considerable reorganisation. There does appear to exist a 'threshold' above which adjustments need to be made to cope with increased load, for the lighter load condition DB did not parallel the changes of BB. This correlational evidence indicates that the change of amplitude does not disrupt the organisational strategy to any marked extent.

Finally, the generally low correlations between speed of cranking and the positional timing criteria support the finding in Chapter III that on this task positional timing is not vital to speed of cranking. There is some evidence, however, that with a small amplitude crank handle, the positional timing becomes more important. However, the consistency of positional timing evidence indicates that the fast subjects have greater stability in relating the response to the 'external' event.

Further Evidence on Effector Organisation

1. Replicability of Torque Record

There is some evidence that suggests that subjects tend to use the same style or pattern of organisation from one condition to the next. In Figure IV:3 characteristic



• Top dead centre of crank handle (15) Rank of speed of cranking

FIGURE IV : 3. TORQUE RECORDS FOR TWO SLOW SUBJECTS ON BACKWARD CRANKING.

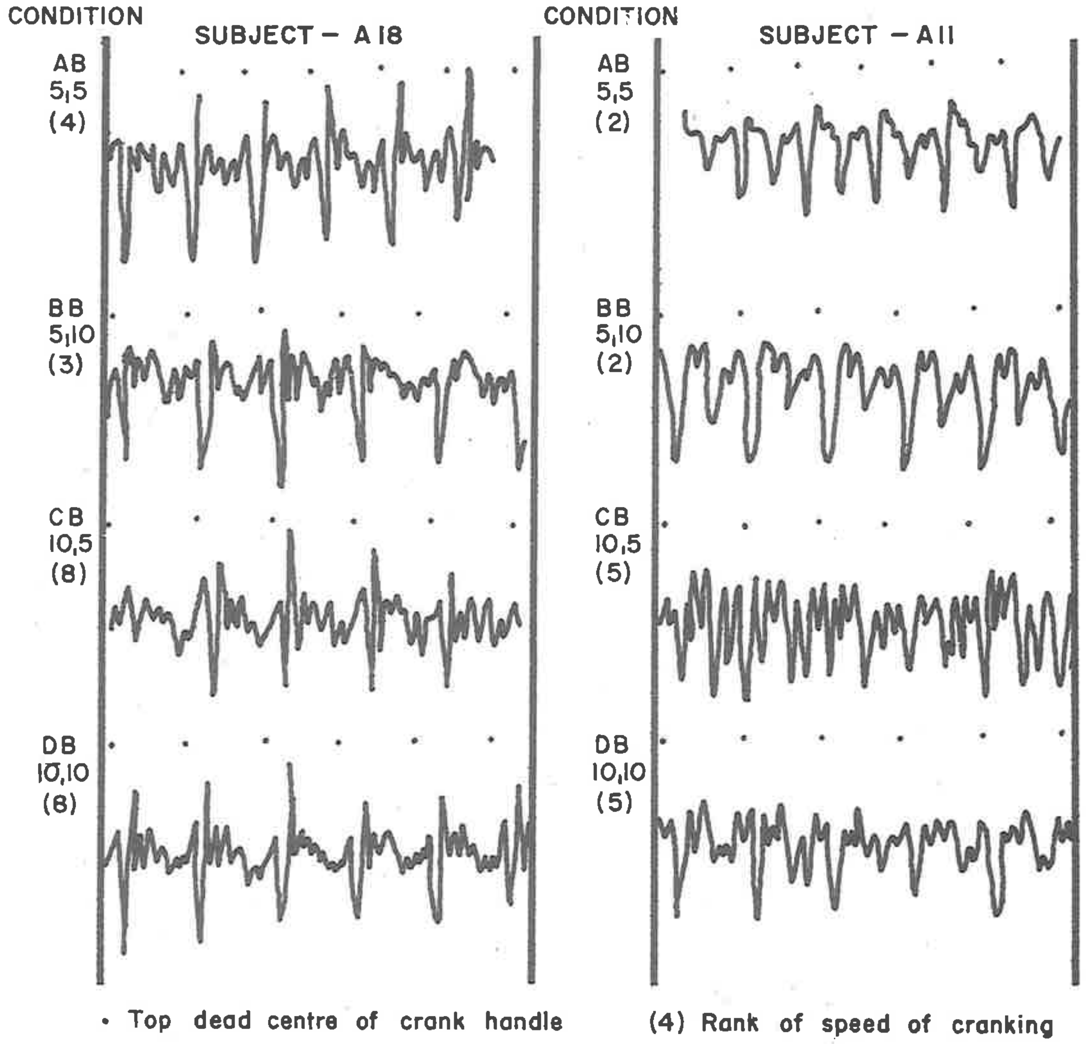


FIGURE IV: 3 (cont.) TORQUE RECORDS FOR TWO FAST SUBJECTS ON THE FOUR BACKWARD CRANKING CONDITIONS individual torque patterns can be seen, particularly in terms of the gross features. Clear examples are the record of subject A18 who shows a characteristic spike in all four records, and A0 and A11 who show two broad peaks per cycle especially in AB and BB. However, there are clearly some changes between conditions as in the case of A1 where AB and BB differ from CB and DB. This is apparently due to the larger amplitude of the latter. However, the limitations of this kind of evidence are obvious, for even though the details of the torque pattern can change, there may still be stability of when the principal events occur in relation to one another. Only by a phasing or positional timing analysis can such stability of the temporal pattern be assessed.

2. Replicability of Movement Pattern

Further replicability evidence is provided in Figure IV:4 in which the spatial displacement of the elbow and shoulder joints is illustrated. The four subjects depicted, A0, A1, A2 and A18 all have individual styles. However each subject tends to be consistent in the arrangement of the movements of the shoulder and elbow joints for the four conditions. Slight modifications do take place in

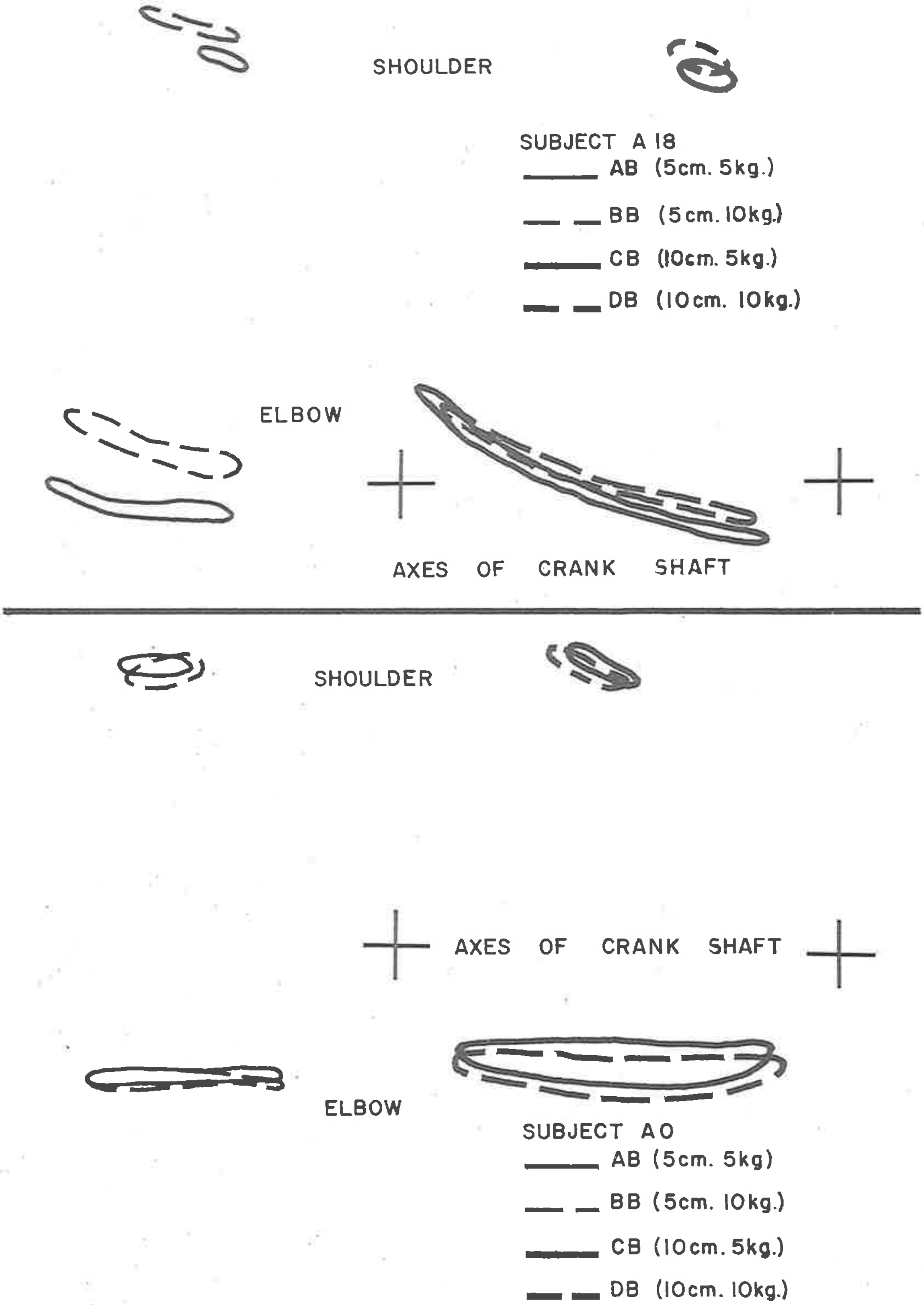


FIGURE IV : 4. MOVEMENT PATTERNS OF ELBOW AND SHOULDER JOINTS FOR TWO SUBJECTS ON BACKWARD CRANKING.

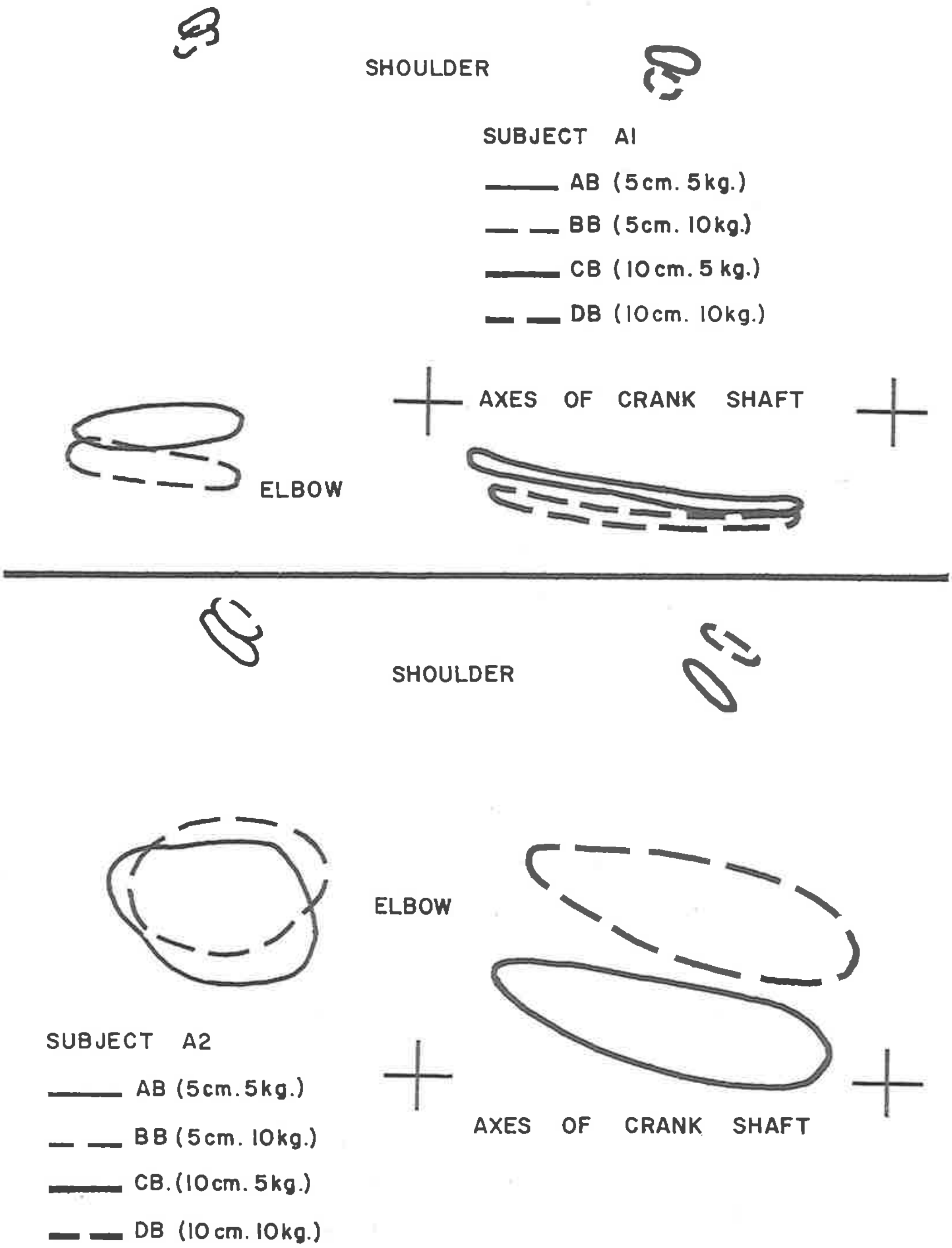


FIGURE IV :4 (cont.) MOVEMENT PATTERNS OF ELBOW AND SHOULDER JOINTS FOR TWO SUBJECTS ON BACKWARD CRANKING.

the change from a small to a large amplitude; in particular the excursion of the elbow joint increases considerably, as would be expected.

Subject A2 is characterised by marked abduction of the shoulder, as indicated by the small vertical distance between the shoulder and elbow markers. This mode of organisation persists on all 4 cranking conditions. Again, subject A18 leans forward so that the shoulder position during cranking is almost in front of the elbow position.

3. Pauses in Cranking

The analysis of the temporal organisation of the muscle activity prior to the occurrence of a pause or halt in cranking reveals that a particular muscle commences activity earlier or later in the sequence of events. A summary of this finding is illustrated in Figure IV:5. These results are consistent with those reported in the AB analysis, and although it appears that in general a muscle is activated earlier in the cycle of movement prior to a pause, in some instances the activity occurs later. Once again there is little or no change in the cycle length and position of force exertion prior to the pause.

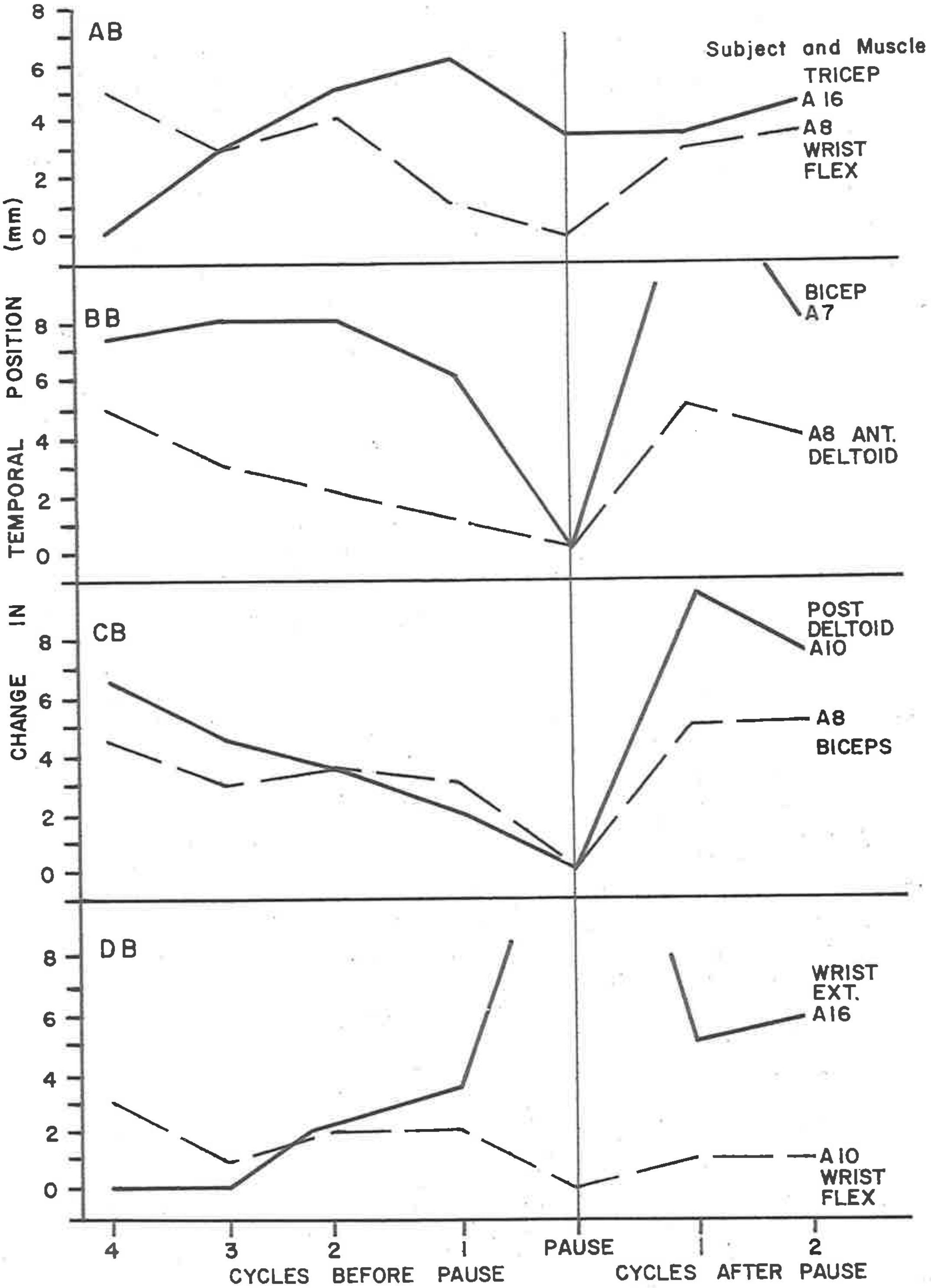


FIGURE IV :5. EXAMPLES OF CHANGE IN TEMPORAL ORGANISATION OF MUSCLE ACTIVITY BEFORE AND AFTER PAUSE ON FOUR BACKWARD CRANKING CONDITIONS.

Gradation

Force Exerted - Results

The amount of force exerted at a particular instant in the cycle of movement was determined as the amplitude of the two principal force peaks, F_1 and F_2. These measures were correlated with the speed of cranking, see Table IV:10.

Table IV:10

Correlations Between Speed of Cranking and the Amplitude of the Two Principal Force Peaks (F_1 and F_2)

Gradation Criterion	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
F_1 'r' with speed	-.247	-.133	.457*	.278
Mean[a] (mm)	26.20	41.28	27.45	43.59
S.D.	2.45	5.90	5.36	6.25
F_2 'r' with speed	.147	.268	.706**	.325
Mean (mm)	28.47	43.21	28.50	45.63
S.D.	3.13	4.63	5.09	5.69

* Significant $p < 0.05$ ** Significant $p < 0.01$

[a] The large differences in the mean values of F_1 and F_2 between AB, CB, and BB, DB, are due principally to the suspended weight on the friction belt and thus comparisons between conditions cannot be made on this criterion.

The only two significant correlations are for the condition CB. The other correlations indicate that there is no significant relationship between speed and force amplitude as measured.

The intercorrelations of F_1 and F_2 on the backward conditions are summarised in Table IV:11. The correlations are all positive, although only three show a significant relationship.

Table IV:11

Intercorrelations of Force Criteria (F_1 and F_2)

on Backward Conditions

	Cranking Condition							
	AB (5, 5)		BB (5, 10)		CB (10, 5)		DB (10, 10)	
	Force Criteria							
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
AB			.430	.681**	.274	.456*	.153	.302
BB					.149	.311	.176	.194
CB							.472*	.317
DB								

* Significant $p < 0.05$ ** Significant $p < 0.01$

Force Organisation - Results

Force range (F_R) was used as a measure of the overall organisation of the effort. The correlations between force range and speed of cranking are summarised in Table IV:12.

Table IV:12

Correlations Between the Speed of Cranking and the Force Range (F_R) Criterion

Force Range	Cranking Condition AB (5, 5)	 BB (5, 10)	 CB (10, 5)	 DB (10, 10)
F_R				
'r' with speed	-.312	-.479*	.264	.454*
Mean (mm)	21.34	27.26	23.38	19.12
S.D.	7.61	13.87	7.76	5.97

* Significant $p < 0.05$

Although only two of the correlations are significant ($p < 0.05$), the correlations with speed show an unusual pattern in that with the small amplitude handle (AB v BB), the fast subjects have the smallest force range. The opposite pattern of results is found on the large amplitude conditions (CB and DB). However there does appear to be a consistent load effect in that the correlations are both significant on the corresponding heavy load condition BB, and DB. Marginally significant triple and simple interaction effects ($p < 0.05$) suggest that the heavy resistance condition BB has a slightly greater mean force range than the other conditions, even though the tests of the main effects are not significant (Amplitude, $F(1,126) = 2.40$, $p > 0.05$; Load, $F(1,126) = < 1$, $p > 0.05$).

The consistency of force range (F_C) criterion, when correlated with speed, showed a trend for the fast subjects to be less variable, except in the case of DB, see Table IV:13.

Non significant F tests (Amplitude, $F(1,126) = 2.31$, $p > 0.05$; Load, $F(1,126) = < 1$, $p > 0.05$) indicate that there are no significant differences on this criterion with changes in load and amplitude of the crank.

Table IV:13

Correlations Between Speed of Cranking and the Consistency of Force Range (F_C) Criterion

Consistency of Force Range	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
F_C				
'r' with speed	$-.343$	$-.611^{**}$	$-.147$	$.623^{**}$
Mean	5.43	7.90	5.12	4.36
S.D.	3.45	7.58	2.31	1.63

** Significant $p < 0.01$

The intercorrelations of the force range, F_R, on the backward conditions are summarised in Table IV:14.

Table IV:14

Intercorrelations of Force Range (F_R) on

Backward Conditions

	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
AB		.609**	.290	.453*
BB			.315	.310
CB				.565**

* Significant $p < 0.05$

** Significant $p < 0.01$

The intercorrelations reveal that similar amplitude conditions are significantly related ($p < 0.01$). However low correlations of AB and BB with CB and DB indicate some significant change in the organisation of the force. A similar pattern of intercorrelations is seen for the consistency of force range data, F_C, although only one correlation is significant, see Table IV:15.

Table IV:15

Intercorrelations of Consistency of Force Range (F_C) on Backward Conditions

	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
AB		.437	.542*	.011
BB			.278	.093
CB				.221

* Significant $p < 0.05$

Muscle Activity - Results

Considering firstly the four point scale of muscle activity (no activity, slight activity, moderate activity and marked activity), graphs based on the frequency of each category for each cranking condition are summarised in Figure IV:6.

In general, similar frequencies are noted for each

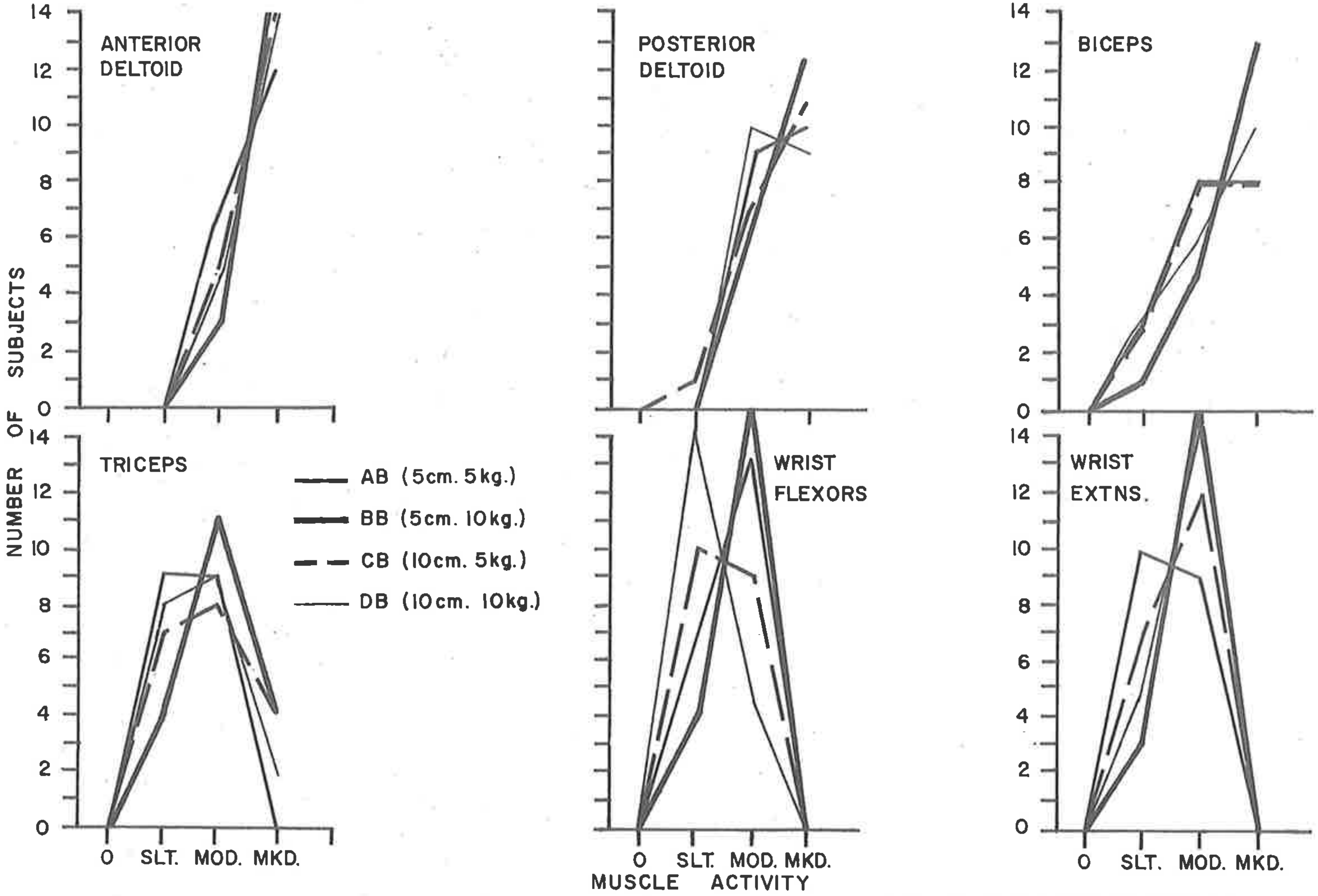


FIGURE IV : 6. DEGREE OF MUSCLE ACTIVITY FOR EACH OF THE SIX MUSCLES IN THE FOUR BACKWARD CRANKING CONDITIONS.

cranking condition, especially with the anterior deltoid, posterior deltoid and bicep. A larger number of subjects appear to have greater muscle activity on the heavy resistance condition, BB.

The second criterion of muscle activity, mean pen deflection, indicates an overall increase in activity only on the heavy resistance condition BB, thus supporting the evidence from the earlier analysis. The mean value for each muscle for each condition is summarised in Table IV:16.

Table IV:16

Mean Pen Deflection (mm) Indicating Muscle Activity in Six Muscles on Backward Conditions

	Cranking Condition			
	AB (5, 5)	BB (5, 10)	CB (10, 5)	DB (10, 10)
Anterior Deltoid (mm)	9.2	10.3	9.6	9.7
Posterior Deltoid (mm)	8.2	9.4	8.7	8.4
Bicep (mm)	7.5	9.1	7.3	7.8
Tricep (mm)	5.1	6.8	5.6	5.3
Wrist Flexors (mm)	4.6	5.4	4.5	4.1
Wrist Extensors (mm)	4.4	5.6	4.8	4.9
Mean (mm)	6.5	7.8	6.8	6.7

Correlating total muscle activity with speed of cranking, using Kendall's Tau, significant relationships ($p < 0.05$) were found only with the two large amplitude conditions, CB and DB, see Table IV:17.

Table IV:17

Correlations Between Speed of Cranking and

Total Muscle Activity

Tau	Cranking Condition AB (5, 5)	 BB (5, 10)	 CB (10, 5)	 DB (10, 10)
Muscle Activity/Speed	-.173	.279	.465*	.479*

* Significant $p < 0.05$

An F test based on the total muscle activity for each condition demonstrates significant load and amplitude effects. However a significant amplitude x load interaction ($F(1,126) = 19.1$, $p < 0.01$) indicates that the difference is due to the heavy load condition with the small radius crank handle (BB).

The activity in the remaining three conditions is remarkably similar.

Gradation - Discussion

The only appreciable change in the gradation of the response appears to occur with the heavy resistance condition BB. On BB, the force range, F_R, measure differs from the other three cranking conditions. The intercorrelational evidence also lends support to a change of organisation on this small radius, large load condition, although there does also appear to be a confounding amplitude effect. The EMG evidence supports that based on the torque records. Firstly, for each muscle, more subjects show the highest level of activity on the BB condition. Secondly, with the pen deflection criterion, each muscle shows the greatest activity on BB. These differences do not exist on the other load comparison, CB v DB, nor with the amplitude comparison, AB v DB.

Finally, in general, the gradation criteria do not appear to be closely related to speed of performance, although with the two large amplitude conditions there is a trend for the faster subjects to exert more force and have a higher level of muscle activity.

General Discussion

The comparison of the four conditions on backward cranking have in general replicated the pattern of findings reported for the AB analysis in Chapter III, and also support and extend the notion of control by means of a motor programme in this skill.

As with the AB analysis, the phasing of the events in sequence is important to speed of performance. This form of temporal structuring is more significant than positional timing, although the consistency or stability of the latter measure again is important. The replication of this evidence is further support for the claim that stability or consistency of the temporal structure of the motor programme is a significant component of effector organisation. Once again the gradation of the response is not closely related to the speed of performance.

Considering further the changes in effector organisation, certain minor adjustments seem to occur with a change in the amplitude of cranking. Again, the effect of a large resistance, as in condition BB, is to cause both modifications in the temporal structure and in the gradation of the response. Subjects appear to make minor adjustments in effector organisation to cope with certain changes in resistance and amplitude in cranking, but only when the effective resistance is increased substantially does the reorganisation become more significant.

The changes in speed of cranking with changes in load and amplitude of movement indicate that only the heavy resistance condition causes marked slowing. Very slight slowing results from doubling the distance that the crank handle moves in the large radius condition. This finding, together with the evidence that CB (light load, large radius) is not significantly faster than DB (heavy load, large radius), indicates that the limits to speed of performance are organisational. That is, the time required to organise and control the components of the response is the limiting factor.

No change in phasing occurs between the four conditions. There is no change in variability of the temporal interval between significant events in spite of changes in load and amplitude. Under each condition the fast subjects are able to construct and maintain a stable programme of events. This evidence points to the significance of phasing as a criterion of skilled performance, and in particular provides some evidence of the stability of the developed motor programme.

The detailed analysis of the response indicates that minor differences do occur in the sequencing of the muscles involved in the response, although the mean sequence is the same for all four backward conditions. However the most obvious changes are in the positional timing of the two force peaks and the muscle activity. In the two large amplitude conditions the force is exerted later in the cycle and the muscle activity tends to occur earlier. Changes in the organisation due to an increased amplitude are further supported from the spatial distribution of the movements of the elbow and shoulder joints.

The effect of an increased load is only noticeable on BB, the heaviest resistance condition, in which one force peak occurs before top dead centre of the cycle of movement. Although there are some changes in the position of muscle activity there is no regular pattern.

The only appreciable change in the gradation of the response is in the degree of muscle activity on the heavy resistance condition, BB, which also has the slowest speed of cranking. On this cranking condition there appears to be an overall increase of activity in all the muscles by some amplification control. No change however is evident in the other load comparison, even though the effective resistance of DB is twice that of CB. It should be remembered that the effective resistance of BB is twice that of DB (and AB). The amplification control only seems to change when the external resistance or load increases beyond a certain level. In the present study this level is located between the effective resistance offered by conditionsAB and BB. With minor variations in load, the amplification remains constant and the increase in load is apparently coped with by alterations in the temporal structure of the programme, in particular the positional timing of the response.

The intercorrelations of the criteria on the four backward conditions indicates a certain stability of performance by each subject. These intercorrelations are particularly significant on measures of speed and the criteria of serial and positional timing. Although positive, the intercorrelations based on the gradation criteria are low. This finding, viz., generally high intercorrelations on the temporal organisation criteria, together with the sequencing evidence and spatial distribution of the movement of the elbow and shoulder, is taken to indicate the existence of some general organisational strategy controlling performance on the four conditions. It is proposed that only one motor programme is formed, and that this programme is slightly modified to cope with variations in load and amplitude. These modifications in large, are in terms of the temporal structure of the events operated by instructions from the programme. Only when changes in the task are considerable (for example, with BB) does the amplification control modify the gradation of the response. Finally, to account for the existence of only one motor programme, which can be modified, it is necessary to hypothesise the existence of some hierarchically-organised control mechanism. It is proposed that such a means of control can be adequately achieved by the operation of some general plan or executive programme for cranking, as described, for example, by Miller, Galanter and Pribram (1960), or Newell, Shaw and Simon (1958).

Further evidence for the existence of a general plan will be presented in the next chapter. The manner in which it can effect the operation of the motor programmes under its control is discussed in the final chapter.

CHAPTER V

THE EFFECT OF CHANGE OF DIRECTION ON EFFECTOR ORGANISATION IN HAND CRANKING

Abstract

The changes in effector organisation due to changing the direction of cranking from backwards to forwards in the sagittal plane, were investigated. There were four forward cranking conditions corresponding in load and handle radius to the four backward cranking conditions reported in Chapter IV. Effector organisation was again evaluated in terms of the serial timing (phasing and sequencing), positional timing and gradation of the response. The results generally replicated the findings reported for the corresponding backward condition. In particular the phasing of the response is of central importance to skilled performance. Performance in forward cranking is not only faster and more consistent than in backward cranking, but also less effort tends to be exerted. Because of the change of direction in cranking, obviously different patterns of organisation are involved. However the generally significant inter-

> correlations on performance between the forward and backward conditions suggest that some common organisational procedure or strategy may be used. The notion of a general plan is developed to account for the common aspects of effector organisation between forward and backward cranking. However the details of the actual response are still under the control of two specific motor programmes, one for forward cranking and one for backward cranking.

In the final section of this study, the changes in effector organisation, due to changing the direction of cranking, were investigated. Forward cranking, under the identical task and procedural conditions, was compared with backward cranking. Forward cranking in the sagittal plane involves the same response units as the backward cranking conditions investigated earlier. However these movements and muscles have to be organised into a different pattern of movement. It is proposed that forward cranking in the sagittal plane is a more familiar skill than backward cranking which involves a novel sequence of movements. The changes in effector organisation necessary to produce the new pattern of movement are the focus of attention of this chapter.

Procedure

The same procedure, with the same 19 subjects was repeated as for the backward treatment conditions. The preparatory procedure, instructions and standardised starting positions were the same. Forward cranking only necessitated changing the weight attached to the friction belt to the other end, and fixing the end that carried the weight during backward cranking. The frictional resistance to cranking, as indicated by the calibration, remained the same as for the corresponding backward condition. The comparisons involved, using the appropriate load and crank radius conditions are summarised in Table V:1.

Table V:1
Comparison of Corresponding Forward and
Backward Cranking Conditions

	Forward Cranking				Backward Cranking	
	Radius of Handle	Load			Radius of Handle	Load
AF	(5 cm.	5 kg.)	compared with	AB	(5 cm.	5 kg.)
BF	(5 cm.	10 kg.)	compared with	BB	(5 cm.	10 kg.)
CF	(10 cm.	5 kg.)	compared with	CB	(10 cm.	5 kg.)
DF	(10 cm.	10 kg.)	compared with	DB	(10 cm.	10 kg.)

Subjects were required to crank as fast as possible (forwards) and in so doing wind up a pulley a distance of 9 feet. The treatment conditions were conducted in accordance with the 4 x 4 Latin square.

Results

Speed of Cranking

A comparison of the corresponding forward and backward cranking conditions on speed of performance is summarised in Table V:2.

Table V:2

Means and Standard Deviations and Intercorrelations of Corresponding Forward and Backward Cranking Conditions

	Cranking Conditions							
Speed	AF	AB	BF	BB	CF	CB	DF	DB
	(5, 5)		(5, 10)		(10, 5)		(10, 10)	
Mean (c.p.s.)	5.11	4.71	4.46	3.88	4.74	4.48	4.60	4.39
S.D.	.53	.71	.54	.79	.40	.59	.38	.47
Intercorrelation 'r'	.704**		.645**		.433		.614**	

** Significant $p < 0.01$

A significant $F(1,126) = 34.59$, $p < 0.01$ indicates that forward cranking is faster than backward cranking. However a small direction x amplitude interaction, $F(1,126) = 4.14$, $p < 0.05$ shows that the differences in speed are greatest on the small amplitude conditions (AF v AB and BF v BB). The forward conditions also show smaller standard deviations than the corresponding backward conditions.

Table V:2 also presents the intercorrelations on speed of cranking between the forward and backward cranking conditions. The correlations are all positive and significant at the 0.01 level of confidence except that between CF and CB, $r = .433$ ($p > 0.05$).

Speed of Cranking - Discussion

The superiority of forward cranking is evident on all conditions, but in particular those with the small radius. The largest difference is between the heavy resistance conditions, BF v BB. It is interesting to note that on the slower backward conditions, there appears to be greater variability in speed as indicated by the larger standard deviation measures.

Forward cranking is a more familiar skill than the novel backward cranking as it is an extension of the movements involved in cranking in the frontal plane. The superiority of commonly used movement patterns over novel patterns is consistent with the evidence of Provins, (1956, 1958) and Provins and Glencross, (1968).

The high intercorrelations show that subjects maintain the same relative performance on the forward as the backward condition. Such a finding suggests that the subjects may be employing some common organisational strategy or technique, although the detailed implementation of the responses change.

Serial Timing

1. Sequencing - Results

The sequencing evidence was derived from the order of occurrence of the six muscles analysed. The coefficients of concordance were based on the biceps activity as the first event in the sequence, see Table V:3.

On all four forward conditions, the mean order of muscle activity is the same: namely, wrist flexors, posterior deltoid, biceps, anterior deltoid, wrist extensors, triceps. For obvious reasons this is clearly different from

Table V:3

Coefficients of Concordance for the Sequence of Muscle Activity in the Four Forward Cranking Conditions

Coefficient of Concordance	Cranking Condition AF (5, 5)	BF (5, 10)	CF (10, 5)	DF (10, 10)
W	.47	.24	.51	.32
S	1686^{**}	872^{**}	1826^{**}	1102^{**}

** Significant $p < 0.01$

the order on backward cranking.

2. Phasing - Results

The analysis of variance based on the two phasing criteria, PF_p and PE_p show a small direction effect with $F = 4.15$ $(p < 0.05)$ and $F = 6.00$ $(p < 0.05)$ respectively. Significant triple interaction effects indicate that the differences are not consistent in any one direction. The means and standard deviations are summarised in Table V:4. By far the largest differences exist on the heavy resistance condition, the forward cranking scores being the smaller and

Table V:4

Means and Standard Deviations of the Phasing Criteria (PF_p and PE_p) for Corresponding Forward and Backward Cranking Conditions (Proportional Data)

Phasing Criterion	Cranking Condition AF (5,	AB 5)	BF (5,	BB 10)	CF (10,	CB 5)	DF (10,	DB 10)
Force Data								
PF_p								
Mean	4.18	4.81	4.02	5.85	4.46	5.21	4.70	4.03
S.D.	1.77	3.16	1.58	2.62	1.80	3.45	1.64	1.87
EMG Data								
PE_p								
Mean	5.26	5.10	4.68	6.85	4.45	6.01	5.17	5.09
S.D.	2.72	2.82	1.51	4.10	1.43	3.64	1.77	2.16

hence less variable. The next most significant difference is for the very light resistance, again the forward condition having the smaller variability scores. Overall, the forward conditions show significantly less variability on the proportional phasing criteria, although with DF/DB small differences in the opposite direction occur.

Only the intercorrelations of the phasing criteria between CF and CB are significant. All other intercorrelations are positive but low and not significant. These values are summarised in Table V:5.

Table V:5

Intercorrelations of Phasing Criteria (PF_A, PF_p, PE_A, PE_p) on Corresponding Forward and Backward Cranking Conditions

	Cranking Conditions			
Phasing Criterion	AF/AB	BF/BB	CF/CB	DF/DB
Force Data				
PF_A	.327	.143	$.507^{*}$	.196
PF_p	.291	.130	$.626^{**}$	.126
EMG Data				
PE_A	.335	.253	$.471^{*}$	.402
PE_p	.242	.240	$.525^{*}$	.410

* Significant $p < 0.05$

** Significant $p < 0.01$

The correlations between speed of cranking and the phasing criteria are summarised in Table V:6.

Table V:6

Correlations Between Speed of Cranking and the Phasing Criteria (PF_A, PF_p, PE_A, PE_p) on Forward Cranking

Phasing Criterion	AF (5, 5)	BF (5, 10)	CF (10, 5)	DF (10, 10)
Force Data				
PF_A				
'r' with speed	$-.662^{**}$	$-.577^{**}$	$-.428$	$-.625^{**}$
PF_p				
'r' with speed	$-.491^{*}$	$-.395$	$-.240$	$-.473^{*}$
EMG Data				
PE_A				
'r' with speed	$-.468^{*}$	$-.502^{*}$	$-.313$	$-.594^{**}$
PE_p				
'r' with speed	$-.279$	$-.190$	$-.051$	$-.426$

* Significant $p < 0.05$

** Significant $p < 0.01$

A very similar pattern of results occurs between the corresponding forward and backward conditions, although there are more significant correlations with the backward data (see Table IV:4, p. 130). On condition CF although the correlations are in the hypothesised direction not one reaches significance, whereas with the corresponding backward condition, CB, all of the correlations are significant ($p < 0.01$). In general, however, the fast subjects have the smallest variability as assessed by the phasing criteria.

Phasing - Discussion

The phasing evidence shows that there is, in general, less variability in temporal structure with forward cranking. This is particularly so with the two extreme resistance conditions, BF/BB and CF/CB. The greater variability of the temporal intervals between events with backward cranking suggests that the programmes of action are less well formed and are subject to larger fluctuations, than on the forward condition. Further evidence of a difference in organisation or temporal structure is provided by the low, but positive, intercorrelations between forward and backward cranking.

The importance of the phasing component of effector organisation is supported by the significant correlations between speed of cranking and the phasing criteria. However, although this evidence replicates that reported for backward cranking, there are fewer significant correlations on the forward data.

Positional Timing

Positional Timing - Results

Figure V:1 illustrates the positions in the cycle of movement when the two principal force peaks F_1 and F_2 are exerted in the corresponding forward and backward cranking conditions. In both forward and backward cranking the organisation of the two force peaks is similar; one occurring near top dead centre and the other occurring about halfway through the cycle. From Figure V:1, it can be seen that with a small amplitude the force tends to be exerted later in the cycle with the forward conditions. The opposite pattern occurs on the large amplitude conditions, that is, the force is exerted earlier in the cycle of movement. These amplitude x direction interaction effects are significant: $F(1,126) = 58.31$, $p < 0.001$ for force peak 'F_1' and $F(1,126) = 8.19$, $p < 0.01$ for force peak 'F_2'. On the former condition a significant direction x load interaction,

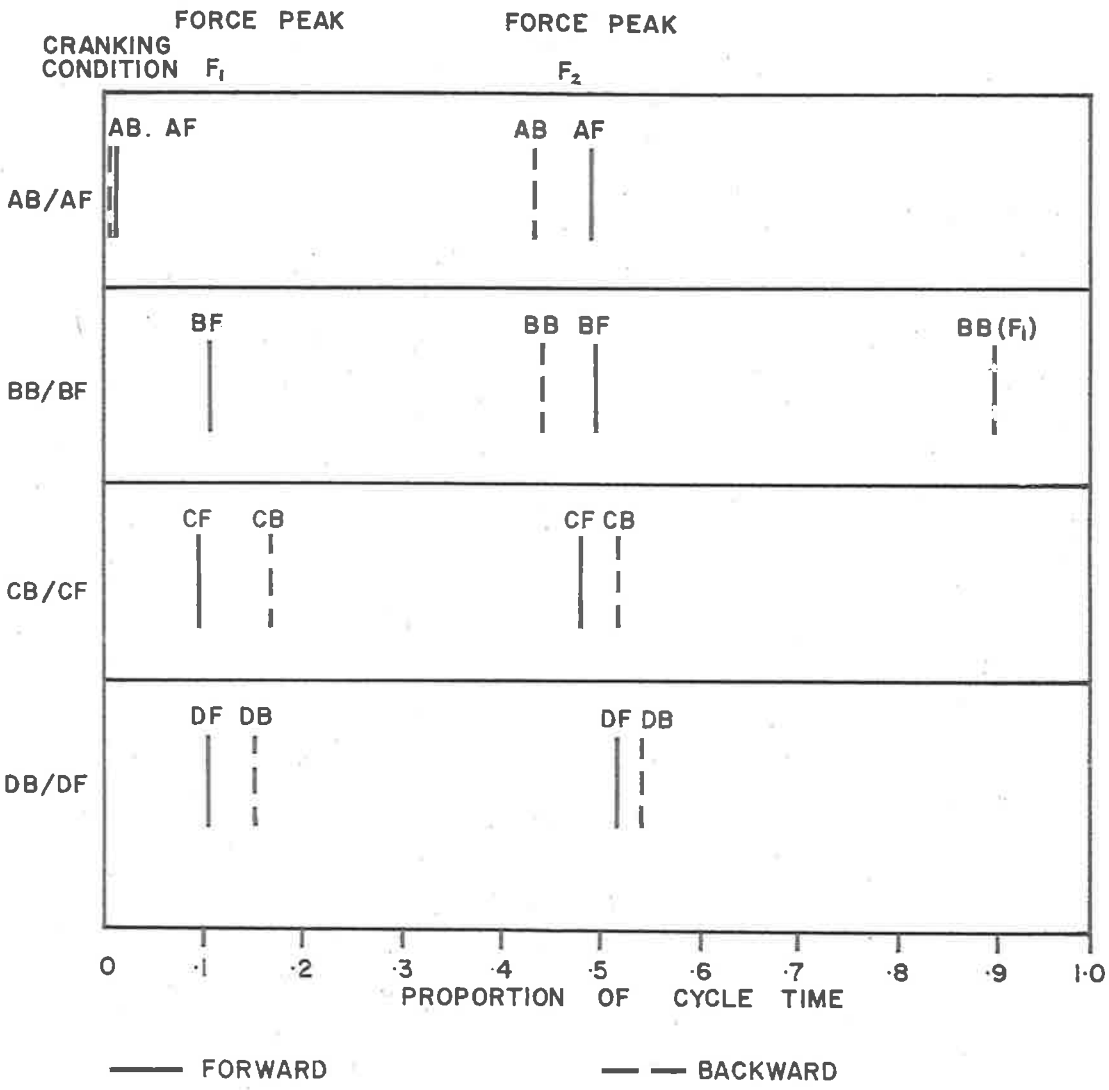


FIGURE V:1. MEAN POSITION OF TWO PRINCIPAL FORCE PEAKS (F_1 and F_2) IN THE CYCLE OF MOVEMENT IN THE CORRESPONDING FORWARD AND BACKWARD CRANKING CONDITIONS

$F(1,126) = 12.08$, $p < 0.01$, explains the positioning of 'F_1' on the heavy resistance conditions BF and BB, where the adjustment is in the opposite direction.

Because of the difference in direction of cranking and hence the difference in movement sequences between forward and backward cranking, the periods of muscle activity are markedly different. Take for example the activity of the posterior deltoid muscle. The onset of muscle activity occurs just after the start of a cycle of movement in forward cranking, but on the other hand, it occurs halfway through the cycle in backward cranking. Differences such as these serve to emphasise the change in organisation required with a change in direction of cranking.

The correlations between positional timing and speed of cranking are summarised in Table V:7. The results replicate those of the backward cranking analysis in that the faster subjects only show a trend towards more effective positional timing. Only one correlation, that for PTE on condition AF reaches significance at the 0.01 level of confidence. As with the backward cranking results, the correlations tend to be larger on the small amplitude conditions (AF and BF). The negative correlations for the EMG data

Table V:7

Correlations Between Speed of Cranking and Positional Timing Criteria (PTF and PTE) on Backward Cranking

Positional Timing Criteria	Cranking Condition AF (5, 5)	BF (5, 10)	CF (10, 5)	DF (10, 10)
Force Data				
PTF				
'r' with speed	.367	.301	.323	-.137
Mean	22.20	20.54	23.57	20.34
S.D.	3.47	4.77	3.19	4.78
EMG Data				
PTE				
'r' with speed	-.632**	-.513*	-.367	-.443
Mean	16.06	15.85	16.07	13.75
S.D.	6.89	6.26	7.71	5.12

* Significant $p < 0.05$

** Significant $p < 0.01$

indicate that the particular event occurs earlier in the cycle of movement for the fast subjects.

The intercorrelations of the positional timing criteria, PTF and PTE, for the corresponding forward and backward conditions are summarised in Table V:8. In general, the correlations are low and not significant. Only one correlation, $r = -.666$, between DF and DB on criterion PTF is significant ($p < 0.01$). The negative correlation indicates that the fast subjects on one condition exerted the force early in the cycle of movement, and later in the cycle relative to the other subjects in the other condition.

Table V:8

Intercorrelation of Positional Timing Criteria (PTF and PTE) for Corresponding Forward and Backward Cranking Conditions

	AF/AB (5, 5)	BF/BB (5, 10)	CF/CB (10, 5)	DF/DB (10, 10)
PTF	.015	.043	-.461*	-.666**
PTE	.533*	.018	.302	.108

* Significant $p < 0.05$

** Significant $p < 0.01$

Consistency of Positional Timing

The correlations between consistency of positional timing and speed are presented in Table V:9. Although all the

Table V:9

Correlations Between Speed of Cranking and the Consistency of Positional Timing Criteria (CPTF$_A$, CPTF$_p$, CPTE$_A$, CPTE$_p$) Cranking Conditions

Consistency of Positional Timing Criterion	Cranking Condition			
	AF (5, 5)	BF (5, 10)	CF (10, 5)	DF (10, 10)
Force Data				
CPTF$_A$				
'r' with speed	-.400	-.330	-.146	-.500*
Mean (mm)	.45	.42	.51	.51
S.D.	.17	.18	.25	.28
CPTF$_p$				
'r' with speed	-.110	-.093	-.011	-.405
Mean	2.27	1.86	2.41	2.16
S.D.	.82	.72	1.17	.92
EMG Data				
CPTE$_A$				
'r' with speed	-.491*	-.390	-.230	-.413
Mean (mm)	.73	.70	.60	.78
S.D.	.22	.26	.20	.43
CPTE$_p$				
'r' with speed	-.114	-.053	-.050	-.122
Mean	3.67	3.06	2.83	3.33
S.D.	.97	.94	.94	1.35

* Significant $p < 0.05$

correlations are negative, indicating that the fast subjects are also the most consistent, only 2 are significant at 0.05 level of confidence. None of the correlations based on the proportionate data are significant. This pattern of results is somewhat similar to that for the backward condition, although there are fewer significant correlations on the forward cranking data.

Positional Timing - Discussion

The positional timing evidence indicates a change in effector organisation for forward cranking. This is most clearly seen from the periods of muscle activity and also from the position in the cycle that the force peaks 'F_1' and 'F_2' occur. These changes however are most significant on the heavy resistance condition, HF. The generally low intercorrelations of the positional timing criteria between the corresponding forward and backward conditions are further evidence of the reorganisation of the temporal aspects of the response.

Finally, the results of the forward analysis, replicate those of the backward analysis, in that positional timing is not a major factor in speed of performance, although it may be more important on the small amplitude conditions.

However, in contrast to backward cranking, consistency of positional timing is not closely related to speed of performance in forward cranking.

Further Evidence on Effector Organisation

Replicability of Movement Pattern

Examples of the patterns of movement of the shoulder and elbow joints in relation to the position of the crank for 4 subjects, A4, A6, A13 and A17 are presented in Figure V:2. From this figure it can be seen that subjects tend to use similar patterns of movement between corresponding forward and backward conditions, although on any one combination of cranking, radius and load, there are marked individual differences as reported in Chapter IV.

However, there are some minor changes in the movement patterns. For example, both subjects A6 and A13 on the small amplitude conditions lift the shoulder and elbow in forward cranking. Subject A4 shows the opposite adjustment on the CB condition.

Clearly then the constraints of the task do not dictate an individual's movement pattern but rather it is a result of effector organisation from a range of possible patterns

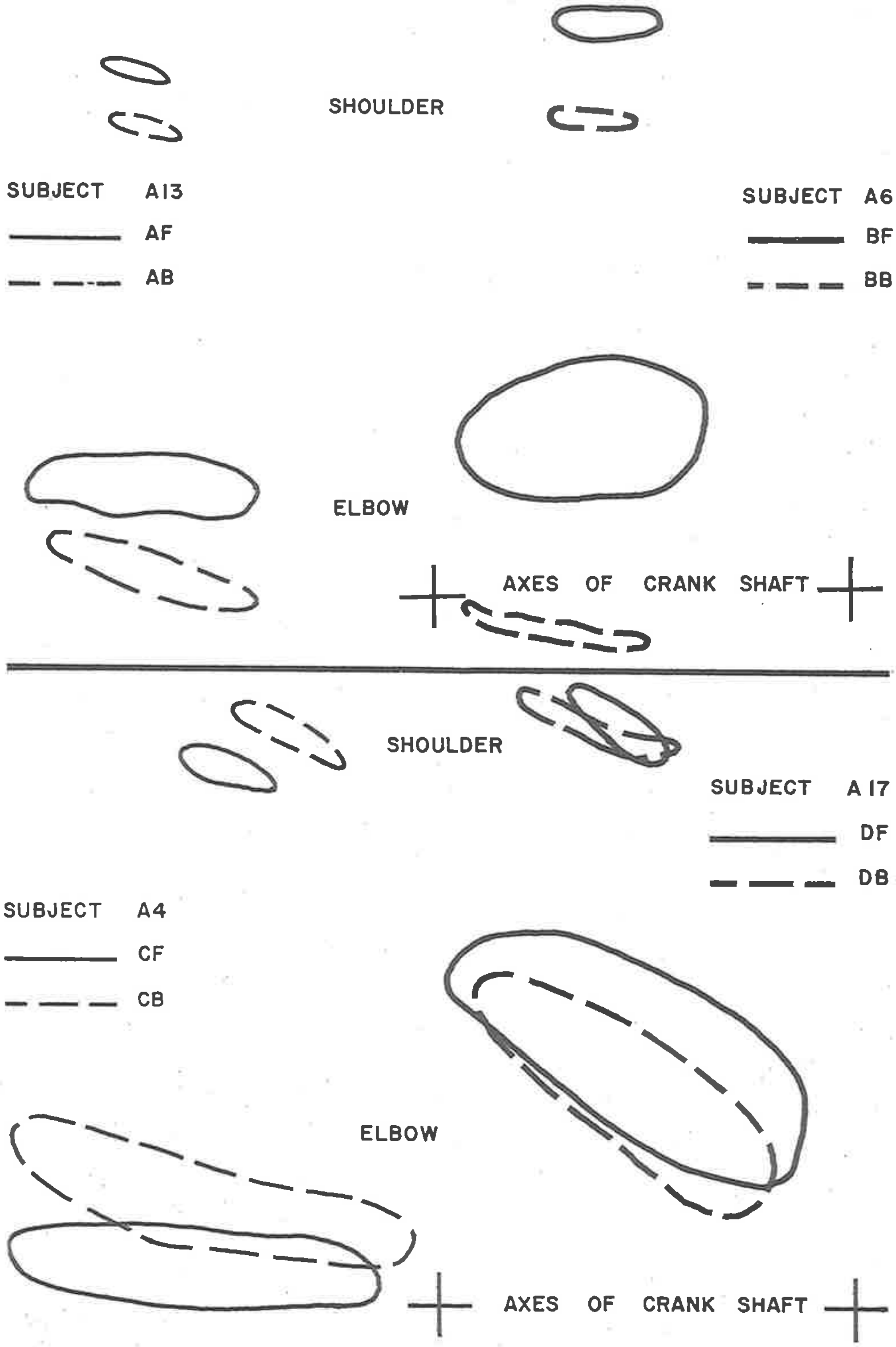


FIGURE V : 2. MOVEMENT PATTERNS OF ELBOW AND SHOULDER JOINTS FOR FOUR SUBJECTS ON CORRESPONDING FORWARD AND BACKWARD CRANKING CONDITIONS within the limits of the apparatus and standardised body position.

Gradation

Force Exerted - Results

Table V:10 presents the correlations between the amplitude of the two force peaks (F_1 and F_2) and speed of cranking, and the intercorrelations of the two force peaks.

Both F_1 and F_2 are significantly larger on the backward conditions, $F(1,126) = 7.01$, $p < 0.01$, and $F(1,126) = 134.73$, $p < 0.001$, respectively.

The intercorrelations between the corresponding forward and backward conditions, based on the two force peaks 'F_1' and 'F_2', are not significant.

Force Organisation - Results

The force range, F_R, criterion when correlated with speed of cranking indicates that on forward cranking the fast subjects have the largest range between highest and lowest force peaks, see Table V:11. Comparing this finding with that on the backward analysis, the small amplitude conditions, AF/AB and BF/BB show the opposite pattern as indicated by the negative correlations between speed and

Table V:10

Correlations Between Speed of Cranking and the Amplitude of the Two Principal Force Peaks (F_1 and F_2)

Gradation Criterion	Cranking Conditions							
	AF	AB	BF	BB	CF	CD	DF	DB
	(5, 5)		(5, 10)		(10, 5)		(10, 10)	
F_1								
'r' with speed	.364	-.247	.140	-.133	.073	$.457^{*}$	.384	.278
Mean (mm)	25.14	26.20	39.31	41.28	25.12	27.45	41.75	43.59
S.D.	2.59	2.45	3.72	5.90	4.17	5.36	4.80	6.25
Intercorrelation 'r'	-.160		.197		.010		.123	
F_2								
'r' with speed	.190	.147	.064	.268	.219	$.706^{**}$	$.633^{**}$	.325
Mean (mm)	21.96	28.47	36.05	43.21	21.89	28.50	37.68	45.63
S.D.	2.45	3.13	3.86	4.63	3.84	5.09	4.94	5.69
Intercorrelation 'r'	.354		.373		-.015		.155	

* Significant $p < 0.05$

** Significant $p < 0.01$

Table V:11

Correlations Between Speed of Cranking and the Force Range (F_R) Criterion

Force Range Criterion	Cranking Conditions							
	AF	AB	BF	BB	CF	CB	DF	DB
	(5, 5)		(5, 10)		(10, 5)		(10, 10)	
F_R								
'r' with speed	.321	-.312	.507*	-.479*	.541*	.264	.714**	.454*
Mean (mm)	18.43	21.34	17.95	27.26	17.98	23.38	17.77	19.12
S.D.	5.78	7.61	6.57	13.87	5.96	7.76	5.11	5.97
Intercorrelations 'r'	-.067		.089		.372		.175	

* Significant $p < 0.05$

** Significant $p < 0.01$

force range on AB and BB. None of the intercorrelations between the corresponding cranking conditions based on force range are significant.

An F value of $F(1,126) = 19.10$, $p < 0.01$ indicates that the force range criterion is significantly larger on the backward conditions. It appears that the greatest difference occurs between the heavy resistance conditions BF and BB.

An irregular pattern of results is seen with the consistency of force range (F_C) measure when correlated with speed of cranking, see Table V:12. None of the correlations based on the forward cranking data are significant. Two of the intercorrelations between the corresponding forward and backward conditions are significant; that between CF/CB = .478 ($p < 0.05$) and DF/DB = .495 ($p < 0.05$).

On the criterion, F_C, forward cranking is significantly more consistent, $F(1,126) = 27.64$, $p < 0.001$.

Muscle Activity - Results

The analysis based on the degree of muscle activity using the four point scale (no activity, slight activity, moderate activity and marked activity) demonstrates that

Table V:12

Correlations Between Speed of Cranking and The Consistency of Force Range (F_C) Criterion

Consistency of Force Range Criteria	Cranking Conditions							
	AF	AB	BF	BB	CF	CB	DF	DB
	(5, 5)		(5, 10)		(10, 5)		(10, 10)	
F_C								
'r' with speed	-.030	-.343	.018	-.611**	.401	-.147	.014	.623**
Mean (mm)	3.47	5.43	2.38	7.90	3.47	5.12	3.28	4.38
S.D.	1.81	3.45	1.15	7.58	1.24	2.31	.91	1.63
Intercorrelations 'r'	.253		.192		.478*		.495*	

* Significant $p < 0.05$

** Significant $p < 0.01$

there tends to be a higher level of activity with backward cranking on the anterior and posterior deltoid muscles, see Table V:13. That is, a larger number of subjects show marked activity for these muscles on most of the backward cranking conditions than is shown on the corresponding forward conditions. With the wrist flexors and to a lesser extent the wrist extensors, more subjects on the forward cranking conditions have a higher level of activity. Thus, overall with the backward cranking conditions, there appears to be a greater range between the most and least active muscles, than with forward cranking.

An analysis of the mean pen deflection criterion of muscle activity reveals that overall there is no difference in degree of activity between the forward and backward conditions $F(1,126) = 0.074$, $p > 0.05$. The mean values are summarised in Table V:14.

However, an interesting interaction exists in that in each of the four comparisons, the backward condition results in greater activity on the anterior deltoid and posterior deltoid muscle. But with the wrist extensor and flexor muscles, the activity is less on the backward condition. That is, the range of degree of muscle activity is

Table V:13

Comparison of Degree of Muscle Activity Between Corresponding Forward and Backward Cranking Conditions

	Muscles Analysed											
	Anterior Deltoid		Posterior Deltoid		Biceps		Triceps		Wrist Flexors		Wrist Extensors	
Degree of Muscle Activity	Cranking Condition											
	AF (5, 5)	BB	AF	BB	AF	BB	AF	BB	AF	BB	AF	BB
None	0	0[a]	0	0	0	0	0	0	0	0	0	0
Slight	**3	0	**3	0	1	3	7	9	6	6	6	10
Moderate	10	7	10	9	10	8	10	9	10	13	13	9
Marked	6	12**	6	10	8	8	2	1	**3	0	0	0
	BF (5, 10)	BB	BF	BB	BF	BB	BF	BB	BF	BB	BF	BB
None	0	0	0	0	0	0	0	0	0	0	0	0
Slight	0	0	1	0	1	1	6	4	3	4	3	3
Moderate	*7	3	8	6	6	5	8	11	15	15	16	15
Marked	12	16*	10	13	12	13	5	4	1	0	0	1

... cont./

Table V:13 (cont.)

Degree of Muscle Activity	Muscles Analysed											
	Anterior Deltoid		Posterior Deltoid		Biceps		Triceps		Wrist Flexors		Wrist Extensors	
	Cranking Condition											
	CF (10,	CB 5)	CF	CB	CF	CB	CF	CB	CF	CB	CF	CB
None	0	0	0	0	0	0	0	0	0	0	0	0
Slight	*2	0	2	1	3	3	9	7	7	10	4	7
Moderate	6	5	9	7	8	8	7	8	10	9	15	12
Marked	11	14	8	11	8	8	3	4	*2	0	0	0
	DF (10,	DB 10)	DF	DB	DF	DB	DF	DB	DF	DB	DF	DB
None	0	0	0	0	0	0	0	0	0	0	0	0
Slight	0	0	1	0	5	3	5	8	6	14**	2	5
Moderate	**10	5	12	10	**12	6	12	9	**13	5	17	14
Marked	9	14**	6	9	2	10**	2	2	0	0	0	0

* Significant $p < 0.05$ ('Z' test between proportions)

** Significant $p < 0.01$

[a] The number in each cell is the number of subjects who showed that particular degree of muscle activity.

Table V:14

Mean E.M.G. Pen Deflection (mm) Indicating Muscle Activity in Six Muscles on Corresponding Forward and Backward Cranking

Muscle	Cranking Condition							
	AF	AB	BF	BB	CF	CB	DF	DB
	(5,	5)	(5,	10)	(10,	5)	(10,	10)
Anterior Deltoid	7.8	9.2	8.8	10.3	8.8	9.6	8.7	9.7
Posterior Deltoid	7.4	8.2	8.8	9.4	7.7	8.7	7.6	8.4
Bicep	7.7	7.5	9.1	9.1	8.2	7.3	8.0	7.8
Tricep	5.4	5.1	6.5	6.8	5.8	5.6	5.6	5.3
Wrist Flexor	5.9	4.6	6.1	5.4	5.7	4.5	5.2	4.1
Wrist Extensor	5.0	4.4	5.9	5.6	5.4	4.8	5.4	4.9
Mean (mm)	6.5	6.5	7.5	7.8	6.9	6.8	6.8	6.7

greater with backward cranking, replicating the finding of the earlier analysis.

Correlating the total muscle activity with speed of cranking using Kendall's Tau, only two correlations are significant, those with the large amplitude crank handle; AF = .143 ($p > 0.05$); BF = −.165 ($p > 0.05$); CF = .480

($p < 0.05$) and DF = .362 ($p < 0.05$). This is the same pattern of correlations as for the backward cranking results.

Gradation - Discussion

Differences do exist in the degree or amount of effort exerted by subjects between forward and backward cranking. This is particularly so in terms of the force exerted, although with the EMG records there is no overall difference in the amount of muscle activity between the two directions of cranking.

The gradation analysis indicates that in forward cranking less force is exerted, the force range is less and the force is exerted more consistently than in backward cranking. The range between the maximum and minimum peaks of effort is smaller and more consistent on forward cranking. Generally, the fast subjects have the larger force range measure, except in the two small amplitude backward cranking conditions, AB and BB. A large force range measure indicates that in applying the effort to the crank handle a period of intense effort is followed by a period of relaxation. This is the pattern of gradation that the fast subjects tend to use. It seems reasonable to assume that such a pattern of gradation is more efficient than a small force range pattern, for it provides a period of relaxation between bouts of intense activity.

In the less familiar backward cranking condition, a wider range of muscle activity occurs than on forward cranking. That is, the most active muscles (anterior and posterior deltoid) have a higher level of activity on the backward condition, whilst the least active muscles (wrist flexors and wrist extensors) have a lower level of activity. With forward cranking, the gradation of activity is more economical in that the effort is distributed more evenly between the six muscles.

In general, there is not a close relationship between the amount of effort exerted and speed of cranking, although there is a tendency for the relationship to be more significant on the large amplitude conditions, where a large excursion of movement is involved. This finding replicates that reported for the backward cranking condition.

General Discussion

The findings from the analysis of the response for the forward cranking conditions replicates those reported for the backward analysis. In particular, the phasing of the response and the consistency of the organisation are central to the effector organisation process. This evidence provides further support for the significance of the stability of the temporal patterning of the response in skilled performance. The gradation of the response is not closely related to speed of performance on both the forward and backward conditions.

In comparing forward and backward cranking it was proposed at the beginning of this study that the former could be considered to be a familar skill, whereas the latter, involving an unfamiliar pattern of movement, is a novel skill. Certainly cranking forwards is significantly faster than cranking backwards. Not only is the speed of cranking faster, but also the performance is more consistent. On almost every criterion used, the forward condition is characterised by less variability of the response, and hence greater consistency and stability. This more effective organisation of the response suggests that the subjects on forward cranking are more skilled, presumably as a result in part at least, of practice or experience in similar types of tasks and movements. Again, the gradation evidence provides further support of the superiority of the organisation involved in forward cranking, for the speed of performance was attained with less effort being exerted more consistently.

Even though forward cranking involves the same 'set' of response units as backward cranking, the organisation of the response is markedly different as evidenced by the sequence of muscle activity. However, it is also apparent that there exist certain components of the effector organisation process, common to both tasks. For example, the intercorrelations on speed of cranking between the corresponding forward and backward conditions are very significant (except in one case), whilst on the phasing and positional timing criteria, the intercorrelations suggest a trend towards communality between the two conditions. However, these correlations are low, indicating that there are considerable changes in organisational detail. Further, the movement patterns of the elbow and shoulder joints show that a certain common 'style' exists between the corresponding conditions.

Because of the speed of cranking it is clear that the means of control is through a motor programme, but this programme is different from that employed in backward cranking. Thus it seems necessary to explain the intercorrelation of performance and hence the effector organisation of the response in forward and backward cranking by some general plan that influences the operation and perhaps formation of two motor programmes - one for forward cranking and one for backward cranking. It is likely that this general plan is the same as that proposed in Chapter IV to explain the modification of the motor programme for backward cranking to incorporate changes in load and amplitude of the crank.

The operation of the general plan and hypotheses as to how it can control the action of the two motor programmes will be discussed in the final chapter.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

This study was concerned with an analysis of the effector organisation in a repetitive speed skill, hand cranking. It has attempted to describe the strategies of effector organisation used by the operator, from a detailed multi-level analysis of the response. The purpose of this final chapter will be to discuss the principal findings of the investigation, to interpret and integrate them with other current views and to explore some of their implications.

The approach used in the present investigation was largely exploratory, but has served to demonstrate the value of a detailed analysis of the response in skill behaviour. It also points to the limitations of using gross overall measures as sole criteria of skilled performance. The use of sophisticated recording analysis techniques offers a methodological breakthrough in an area of research previously restricted by the sheer volume of work and immense detail involved. For clearly, a multilevel analysis of the actual details of the response must provide fuller information about the processes involved and their interaction. In attempting to understand behaviour that is hierarchically organised, involving a shift in level of control, the most useful description of this process will involve an analysis at both 'molar' and 'molecular' levels simultaneously.

In the present study such a multilevel approach has been attempted. The serial organisation of the behaviour has been recorded at three levels; firstly by the use of motion photography to record the movement sequences, secondly by the use of strain-gauge techniques to record the patterns of force exerted, and thirdly electromyography provided details of the activity of selected muscles. There does seem to exist reasonable agreement between the levels of analysis. For example, the sequencing evidence is consistent whether based on the order of the turning points of the joints derived from the photographic records, or on the onset of the muscle activity in the cycle of movement as determined from the electromyography records. Again the findings have been replicated for the phasing and positional timing criteria, by both the torque and the electromyography records. However, the principal advantage of the electromyography and torque analysis over the record of gross patterns of movement is that they represent more directly the strategies of organisation used by the operator. Not only can more precise detailed information be provided, but also it is less likely to be confounded with postural idiosyncrasies and distortions due to the inertia of body segments and movements in several planes.

However such an approach is not without limitations. Apart from the technical difficulties and the unsuitability of complex responses to be recorded in detail, there are certain methodological restrictions. In particular, the use of electromyography does invalidate the use of an extended practice paradigm unless the electrodes can be replaced precisely under the same conditions on each practice trial. It would be useful however to try and replicate the present study using a practice paradigm so that the same subject may be compared in the untrained and trained condition. An additional limitation of the present investigation (as with most skill studies) is that the level of skill attained is not very advanced in comparison with the level of performance attained for example by a skilled typist or pianist.

To describe adequately the processes of effector organisation in repetitive speed skills such as hand cranking used in this study, it appears necessary to postulate a hierarchically organised means of control. Firstly, at the 'higher' level there must exist an overall control, described in Chapters IV and V as a general plan, and secondly at a 'lower' level it is proposed that the actual details of the response are under the control of a motor programme. This distinction is important, because the general plan which operates in a closed-loop fashion (feedback dependent) appears to control the operation and modification of the motor programme or motor programmes which are open-loop in nature. The relationship between the two levels of control is schematically represented in Figure VI:1. The use of the terms open and closed-loop is related to the manner in which the feedback is processed and is consistent with the views of Pew (1966) and Welford (1968, p. 196).

The concept of a general plan is in keeping with that

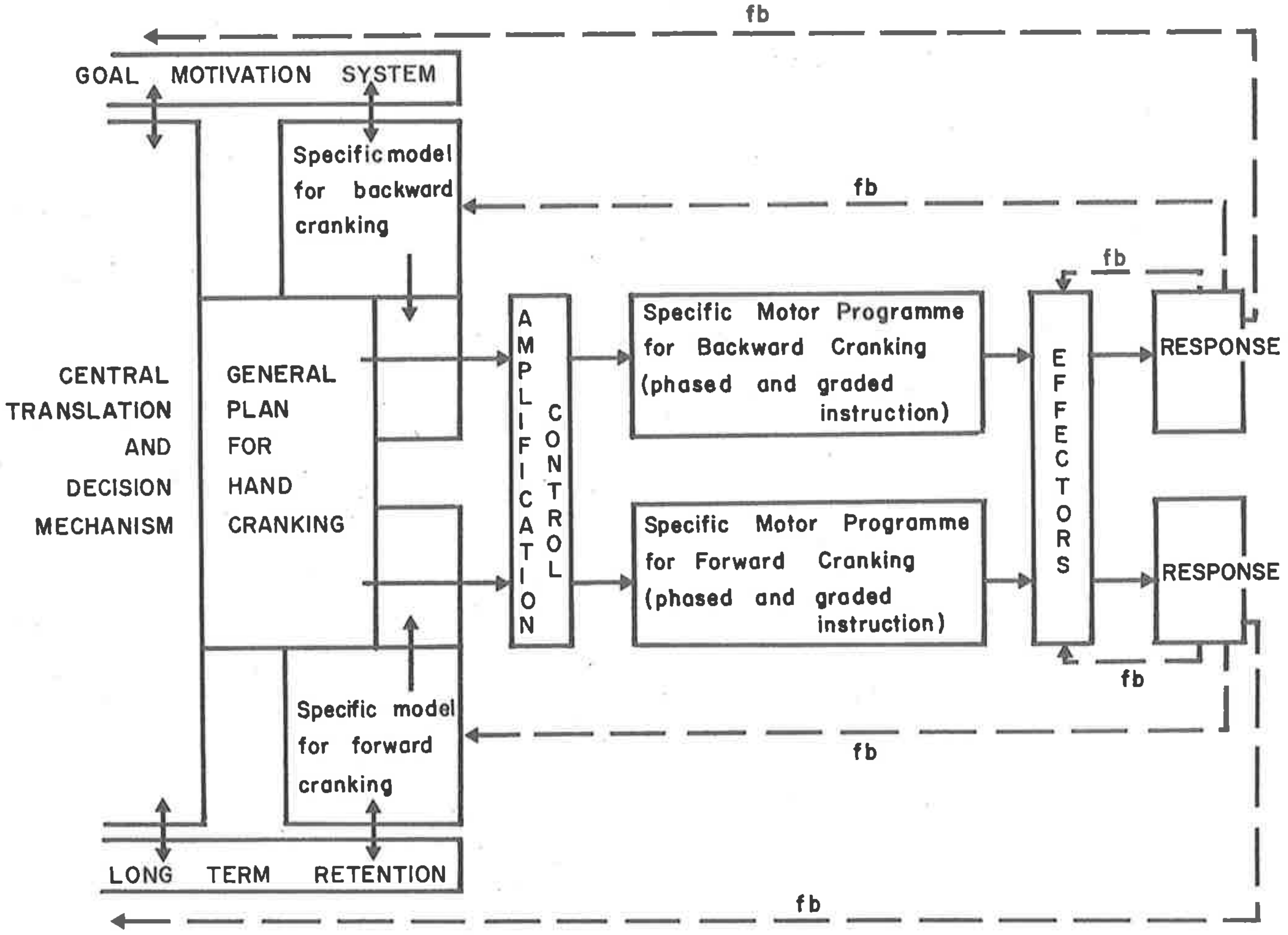


FIGURE VI: I. HYPOTHETICAL FLOW DIAGRAM OF SOME OF THE PROCESSES OF EFFECTOR ORGANISATION IN SKILL BEHAVIOUR.

described by Newell, Shaw and Simon (1958) and Miller, Galanter and Pribram (1960) and incorporates all of the general or common characteristics for the task at hand. In particular, for the task of hand cranking, the general plan will include the rules 'to crank as fast as you can and in so doing wind the light weight up a distance of 9 feet', the restrictions set by the standardised starting position and the restraints of the apparatus. Also included are any previous related experiences in similar tasks and the immediate experience resulting from practice on the hand cranking apparatus. The existence of a general plan is supported principally by the intercorrelational evidence between the four backward cranking conditions and between the corresponding forward and backward condition based on speed of cranking, phasing and positional timing. Further evidence is provided by the replicability of torque patterns and movement patterns of the elbow and shoulder joints from one condition to the next.

Within the framework of the general plan, the operator forms the specific detailed programme of action used to implement the response. This involves the actual serial organisation of the selected response units from the available 'pool' of response units to effect the desired outcome so that there is minimum discrepancy between intent and the action. From the sequencing and positional timing results of the present study it appears that two specific programmes of action are formed, one for forward cranking and one for backward cranking.

Because of the speed of cranking (the mean cycle time is about 0.20 seconds) it is proposed that the basic organisation and control of the response is by means of a motor programme (Keele, 1968) which operates in an open-loop manner because of the insufficient time available for sensory control (Hick, 1948; Vince, 1948b). The effector organisation thus involves two motor programmes for forward and backward cranking, under the control of a general plan for cranking. The details of this organisation will be discussed in the context of this structure.

A motor programme is a sequence of temporally organised instructions which once initiated, runs its full course without further sensory intervention. In the formation of the specific programme for hand cranking, the details consist of a sequence of instructions temporally structured or phased, which initiate specific motor units, muscles or synergistic groups of muscles (Paillard, 1960). At the same level of organisation an amplification control is responsible for the integrated gradation of the whole response. The instructions from the motor programme are manifested as corresponding muscle activity, contracting and relaxing in a temporal pattern, determined in anticipation by the structure of the programme.

In the formation of the motor programme, the sequencing of the specific instructions determines the order in which the response units occur. Often the sequencing of such events is dictated in part by the nature of the task and the anatomical arrangement of the body levers. This is particularly so in closed-kinetic chains, where the body segment is attached to an external control such as a steering wheel, pedal or handle. Such is the case in the present study where the joints of the arm and shoulder move in a predetermined sequence when the crank and arm are moved passively. However in the active situation a surprising range of individual differences occur both in the sequence of joint movements and in the order of activity of the muscles about these joints. These differences contribute to individual styles that are evident both from the force record of cranking and the motion film record. However, there is no relationship between the individual differences in sequencing and speed of performance. Clearly then, the same end result can be achieved in a variety of ways. Such evidence would appear to have important implications in task analysis, teaching and training programmes. Within limits, the focus of training should be around the individual's style and movement pattern, rather than the traditional procedure where details of grip, position and movement patterns are standardised.

The principal finding however is the significant relationship between speed of cranking and the phasing criterion. Thus in the formation of a motor programme the temporal structure of the events placed in sequence is of central importance. The faster subjects on all cranking conditions are characterised by a more stable and consistent temporal pattern. Both the 'macroscopic' analysis of the temporal pattern of the force exerted and the 'microscopic' record of the phasing of the muscle activity support this conclusion. The significance of the latter measure however is that it is more likely to indicate the actual structure of the motor programme, for it is reasonable to assume that in this type of skill, the instructions of the programme initiate directly the activity of groups of muscles.

Positional timing is involved in cranking, for the response must be related to some position of the arm or crank handle. There must exist some point in the cycle of movement where, through the action of the motor programme, a resultant force or effort must be exerted. However the criteria of positional timing used in this study are not highly related to speed of performance. Apparently in repetitive tasks such as hand cranking, positional timing is not as important an organisational process as is the phasing of the response. Again, the correlations between these two criteria of serial organisation are generally low and not significant. Thus it would seem of value to draw a distinction between these two components of temporal structuring, positional timing and phasing, as Schmidt (1968) suggests.

With tasks that have little specific external time structure such as in running, cranking and cycling, positional timing does not appear to be of major importance, whereas phasing seems to be central to the serial organisation of the response. It appears that within the limits suggested by the variability of the positional timing criteria on the cranking task, the actual position of an event in the cycle of movement in relation to an external signal is not important to success in tasks of this type. On the other hand, with tasks that do involve the coincidence of a response with a signal, such as in striking a baseball or tennis ball, ballet dancing or playing an instrument with an orchestra, the external time structure dictates the precision of positional timing demanded of the operator (Conrad, 1951, 1955b, 1956; Michon, 1967). In these situations phasing may also be time structured to the external signal. The apparent independence of the organisational processes structuring positional timing and phasing aspects of the task, seems to relate to two different types of temporal judgement. In the former an assessment is made of the delay before the external signal is expected to occur, so that on the 'psychological signal' (Conrad, 1953), the response can be initiated. Conrad (1956) and Michon (1967) describe how this form of temporal judgement is influenced by prior responses and previous temporal intervals. The temporal judgement involved in phasing concerns the delay in initiating an instruction after the occurrence of the preceding instruction. It is difficult to describe the means by which the operator makes these judgements, particularly in the present task where the temporal intervals are so small, and in view of the "bewildering complexity that confronts us in the patterning of skilled movements" (Paillard, 1960, p. 1684).

The distinction between positional timing and phasing should be further investigated in a more extensive practice situation to provide more information on the development of temporal structuring, and in particular on the extent of variability in highly trained operators. Again these two aspects of serial organisation need to be investigated in a variety of tasks where both the external time structure and the complexity of the response can be varied. Another direction for further investigation is the nature of pauses or breakdowns in performance. It is interesting to speculate that the frequently reported deterioration of positional timing with fatigue may in fact be a result of an increased variability in phasing. The analysis of the pauses in cranking in the present study indicates that this does in fact occur in fast movements under the control of a motor programme.

Such information relates to the general question of the temporal structuring of behaviour and points to the need to distinguish between timing involving external events and timing involving the components of the response or motor programme, that is intra response timing.

Effector organisation also involves the amplification of the instructions so that the response as a whole is appropriately graded in effort. The results from this study based on the torque record and extent of muscle activity serve to emphasise that the gradation of the response cannot be fully appreciated in terms of the physiologically graded muscle activity. In addition to the amount of force exerted at any particular moment and the degree of muscle activity, the temporal organisation and consistency of this organisation must be considered. The fact that in the present study the speed of cranking was largely independent of the amount of force exerted or degree of muscle activity, indicates that perhaps it is the organisational aspects of the gradation that are important, although no consistent pattern of findings emerged from the analysis.

Modifications to the resistance to cranking and the amplitude of the crank handle did not involve a substantial change in the effector organisation of the response. Slight adjustments are made to the temporal structure of the motor programme in particular to the positional timing of the force exerted and the muscle activity. However, the heavy resistance, small amplitude condition involves modifications both in positional timing and in the gradation of the response. On this cranking condition speed of performance is the slowest and the temporal structure of the programme is the most variable. The other effect of the heavy load condition is for the amplification control to increase the overall muscle activity as reported in the EMG analysis. This increase in amplification did not occur on the large amplitude conditions, when the load was increased. Thus in terms of the effective resistance to cranking, no change in the amplification of the response is required up to a certain level or 'threshold'. Beyond this level, changes in both the temporal structure and amplification of the motor programme occur. Such an amplification control has been suggested by Hick and Bates (1950). With the present task this tolerance level or 'threshold' seems to be locates somewhere between the resistance offered by conditions AB (2.4 kg.) and BB (4.8 kg.). Further work needs to be done to elaborate this characteristic of the amplification control.

It thus appears that one basic motor programme can be used for a range of conditions on any particular task. A strategy that enables the operator to use an existing motor programme, rather than the formation of a new programme in every instance, would appear to be a most efficient form of organisation. In this way the skilled operator can accurately and rapidly adjust to variations in task features, such as a typist transferring from a manual to an electric typewriter, or a tennis player changing from a light to a heavy racquet and a change by a toolmaker where the amplitude and resistance of the control handle of a lathe varies from machine to machine. There is some evidence that the human operator can 'by-pass' part of the system and make modifications and adjustments to the response at a rate faster than the usual decision-making process takes (Rabbitt, 1968 ; Vince & Welford, 1967). Indeed the ability of the skilled operator to modify appropriately and rapidly an already existing and possibly on-going programme of action may well be an important but neglected aspect of serial organisation. The plasticity and flexibility of motor programmes could be further investigated by making changes to the task, whilst the response is continuing in a manner similar to that reported by Brebner (1968) and Vince and Welford (1967), but using an approach similar to that in the present study and increasing the response complexity.

It is clear that with a change in direction in cranking a new pattern of organisation is involved. However the pool or set of response units remains the same. The analysis shows that the movement sequences, and periods of muscle activity are different for forward as against backward cranking. The patterns of the torque record are also different. Thus it seems reasonable to regard forward cranking as being under the control of a new or different motor programme. Forward cranking is faster than backward cranking. In general the performance in forward cranking is also more consistent and hence less variable, and less effort tends to be exerted than with backward cranking.

Throughout the analysis of the experimental conditions there has emerged, both with the temporal organisation and gradation criteria, evidence that the faster subjects are more consistent in the serial organisation of the response. A similar pattern of evidence emerges in the comparison of the familiar task, forward cranking with the relatively novel task, backward cranking, and in the comparison of the preferred and non-preferred hands reported in the pilot investigation.

Consistency has frequently been reported as a characteristic of skilled performance (Annett & Kay, 1956, 1957; Carlsöö, 1967; Kay, 1962; Provins, 1958; Slater-Hammel, 1948, 1949). The present study provides evidence that such stability can be associated with the definition of the details of the motor programme. A consistent performance is taken to indicate that the operator has so ordered, phased and graded the details of the programme that the outcome or action results in little discrepancy with the intent or purpose. Hence there is little or no need to modify the programme. Consequently there is thus a reduction in the feedback which has to be processed. The significance of this reduction in feedback with consistency of performance has been emphasised by Kay (1962).

The notion of consistency or stability is central to the understanding of anticipatory behaviour. Anticipation is most effective where events and temporal characteristics are regular and can be predicted (Poulton, 1964). When the input or output to the system can be predicted, there is a reduction in the uncertainty of the situation, or in information terms, a reduction of the load. The significance of such anticipation is that the limitations of the human operator can be overcome or at least reduced. In the present study the consistency of the criteria used indicates the stability of the motor programme, and hence the effectiveness of the anticipation involved in the effector organisation process.

How does the motor programme operate, and in what way does the general plan exert control over the motor programmes incorporated under its structure? In the present study it is assumed that at least one cycle of movement, and probably two or three are under the control of a motor programme, and operate independently of sensory control. If the motor programme is of this extent, how does it continue repetitively for 30 or 40 cycles in the task of hand cranking? There is not sufficient time at the end of each cycle for the feedback to be 'checked' and a 'continue' instruction issued. Nor does this process occur after every second or third cycle, for the torque record shows no regular pause or feature at this frequency. In the analysis of pauses in cranking (Chapters III and IV), it was seen that the motor programme 'broke down' after 3 or 4 cycles when a response unit gradually became out of phase, before the change could be detected and corrected. This evidence would seem to indicate that a more adequate explanation of the repetitive activity of the motor programme is that it is under the direct control of the general plan. It is conceivable that the human operator through the general plan gives the initial instruction to commence and continue the activity of the motor programme and eventually instructs the programme to stop when the target has been reached. During the on-going activity of the motor programme the operator is receiving both intrinsic and extrinsic feedback (Annett, 1969) from the movements of the arm, the apparatus, the passage of the weight being wound up and the knowledge of results from the experimenter. Because of the speed of movement, much of the intrinsic feedback will be out-of-phase with the movement to which it is relevant (Chernikoff & Taylor, 1952). Attending to this out-of-phase feedback may disrupt the task (Posner & Keele, 1968). It is proposed that the general plan receives the feedback and acts as a screen or filter, protecting the active motor programme from any minor or irrelevant feedback that may only disrupt the movement.

In this hierarchically organised system the general plan not only initiates the motor programme but also keeps it operating until the target has been reached. Feedback from the movement, as well as the other forms of feedback associated with the task, is directed to the general plan. Here the feedback is integrated and related to the desired outcome or intent. "If there is a discrepancy between the present feedback and the image, the subject receives an error indication that would be the basis of corrective responding to reduce the error to zero", (Adams, 1968, p. 496). Such corrections or modifications will be effected only after several additional cycles of movement have elapsed.

A second role that the general plan plays in handling the feedback is that it can 'protect' the motor programme from irrelevant feedback that may disrupt performance. The feedback is screened or filtered by the general plan, and only that which is significant, indicating substantial error in the system, will be processed to effect a modification of the motor programme. Thus a certain amount of variability can exist in the response, and only when this results in significant feedback, will any adjustment take place. Certainly in the present study, minor random variations characterised all the records of performance.

It appears that all performance may have some minor variability which can be tolerated by the system. The process of skill learning is seen to involve the gradual reduction of variation in responding, and as indicated in this study, the development of consistent temporal patterns of organisation. However it is interesting to consider that the skilled operator on some continuous tasks, for example, tracking, may tolerate larger degrees of variation than unskilled subjects. That is the skilled operator has a higher tolerance level and can permit more error feedback in the system before any modification to the on-going response is required. Unfortunately no precise information is available from the present study as to this process, although such a strategy has been discussed by Pew (1966) where the operator makes corrections only over groups of responses when a certain error level has been reached.

It is not clear how the general programme and motor programme can integrate in processing the feedback from the movement and task as a whole. However some ideo-motor mechanism, discussed in the recent work of Greenwald (1970), may provide an explanation of the manner in which the motor programme is related to the general plan. Further, the work of Taub and Bergman (1968) and Festinger and Canon (1965) has provided some evidence of the existence of a purely central feedback system.

Whatever the process, it does seem essential to consider the general plan as controlling the specific motor programmes in repetitive speed skills. Only in this way can the programme continue, undistrubed by irrelevant and out-of-phase feedback.

The present study sheds some light on the two central aspects of skilled performance reported in the literature since the classical work of Bryan and Harter (1899). These aspects are firstly the hierarchical organisation of levels of control and secondly the formation of larger units of action. Although the cranking task is largely limited, by design, to the processes of effector organisation, the notion of a hierarchical organisation of a general plan controlling specific motor programmes seems necessary to explain the organisation of the task. Such a system would appear to be essential in all skills where the speed of movement is such that part of the skill at least operates in an open-loop fashion. Secondly the question of grouping or the formation of larger units of action seems to be related to the manner in which the operator processes the feedback. Larger units of action are formed when more and more of the response occurs in open-loop fashion (even though there may be time to operate in a closed-loop manner). By means of the general plan the operator 'protects' the motor programme from the feedback until the discrepancy or error becomes significant. That is, the motor programme becomes more extensive operating in an open-loop manner, whilst the whole task remains under the control of the general plan which operates in a closed-loop fashion. Thus the time relations become important, with regard to the manner in which the general plan controls the operation of the motor programme. If sufficient time is available for sensory control, there may be continual integration and interplay between the two levels. On the other hand where the movement is very rapid (less than about half a second), the motor programme once initiated, continues without further intervention from the general plan, unless significant error occurs. However the operator can through the general plan increase the sequence of actions that occur as a coherent unit of performance, by preventing the feedback from influencing the operation of this motor programme. Further investigations, based on the approach of Pew (1966) and that used in this study would provide a fuller understanding of the development of levels of control and the formation of larger units of action. The changes in organisational strategies need to be studied at all stages, from the untrained, unskilled operator through to the highly skilled performer.

Finally, the elaboration of such a hierarchically structured, effector organisation process does relate to the general question of the means by which cognition or knowledge is translated into action, which has been largely ignored by theorists in this field. The present study has provided an approach and some evidence on one aspect of this question, that is, the process of effector organisation in skill behaviour.

APPENDIX A

DETAILS OF THE APPARATUS AND PROCEDURE

Details of the cranking apparatus and procedures for the use of photography and electromyography are outlined below:

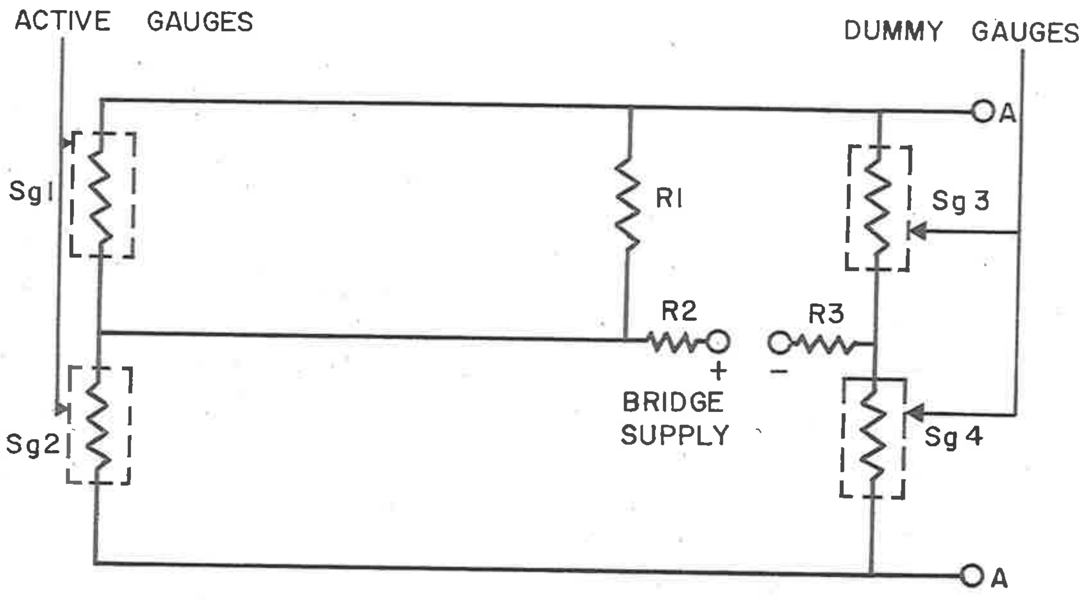
A. Cranking Apparatus

1.	Adjustable Crank Arm	- Total length, 14.5 cms. - Effective adjustment range for the handle grip, 4 cms. to 13 cms.
2.	Friction Drum	- Polished metal drum, placed centrally on the axle, 8.5 cms. diameter.
3.	Handle Grip	- A freely movable tube placed over the fixed grip, 10 cms. in length, 2.5 cms. diameter.
4.	Strain-Gauges	- Two strain-gauges were mounted on a beryllium-copper bar, and the two dummy strain-gauges were placed on a 4 way tag strip on top of the frame of the crank. In order to limit the current through the strain-gauges to 5 mA per gauge it was necessary to put 500 Ω

in series with the supply voltage. The resistance was divided into 2 separate 250Ω resistors placed at the end of the bridge to 'balance' it. The characteristics of the strain-gauges were, 119.4Ω; 2.02 G.F. The circuit diagram, incorporating the strain-gauges is presented in Figure A:1.

5. Calibration - The apparatus was calibrated by cranking the machine at three speeds, slow, medium and fast (approximately 60 to 300 r.p.m.) and noting the torque on a Tinsley spot galvanometer. This calibration was carried out using a 5 cm. and 10 cm. radius crank arm, with 2, 5, 10 and 15 kg. load suspended from the friction belt, and winding in a forwards and backwards direction. The torque at any breaking resistance was found to be constant irrespective of the speed of cranking within the limits used, see Figure A:2.

The apparatus was also calibrated statically by suspending 2, 5, 7, 10, 12 and 15 kg. weights at 5 cm. and 10 cm. radius



Sg1 – 4 — 119·4 Ω STRAIN GAUGES
2·02 GAUGE FACTOR

R1	68 Ω	·5W
R2–3	250 Ω	·5W

BRIDGE SUPPLY 3V DC

A–A OUTPUT TO RECORDER

FIGURE A: 1. CIRCUIT DIAGRAM OF STRAIN-GAUGE SET–UP USED IN MAJOR CRANKING STUDY.

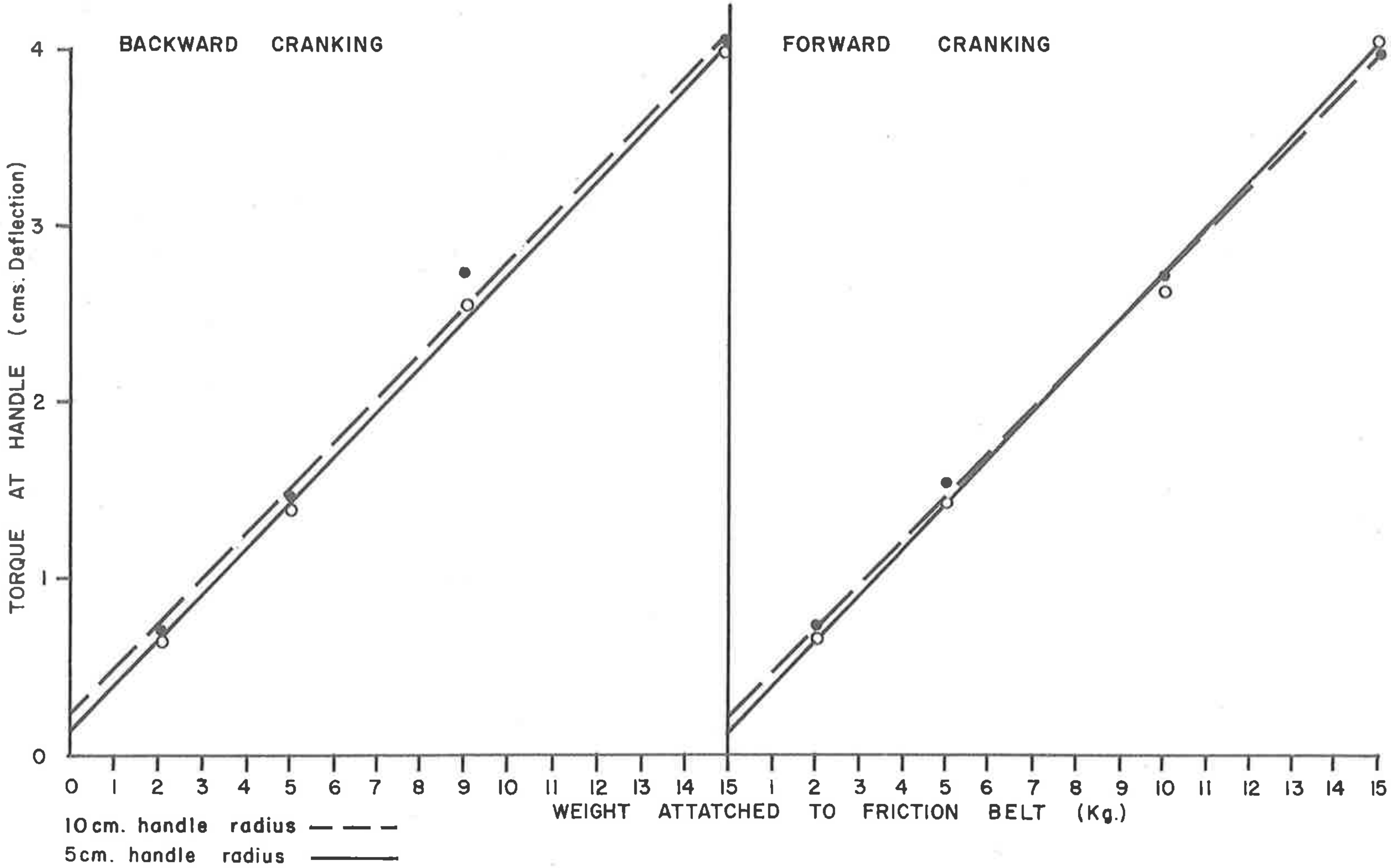


FIGURE A:2. DYNAMIC CALIBRATION FOR CRANKING APPARATUS IN FORWARD AND BACKWARD DIRECTION. (MEAN OF 3 CRANKING SPEEDS) crank arms, see Figure A:3.

6. Displacement - The movement of the crank was recorded by means of a 350° rotary potentiometer fitted to the free end of the axle. A 12 volt D.C. supply was used and the displacement was recorded on the U/V recorder.

B. Photography

1. 16mm motion photography was used to record the motion of the arm and crank handle.

Camera - 16mm Bolex

Film - Ilford F.P.3

Speed - 32 frames per second

Settings - Shutter - 1

f value - 1.4

Distance - 3 metres

Lighting - 2 large batteries, 6 feet from the crank, each at an angle of 30°.

Lens height - 94 cms.

Camera Position - At right angles to the sagittal plane of the subject in the standardised cranking position.

2. Preliminary photographic trials

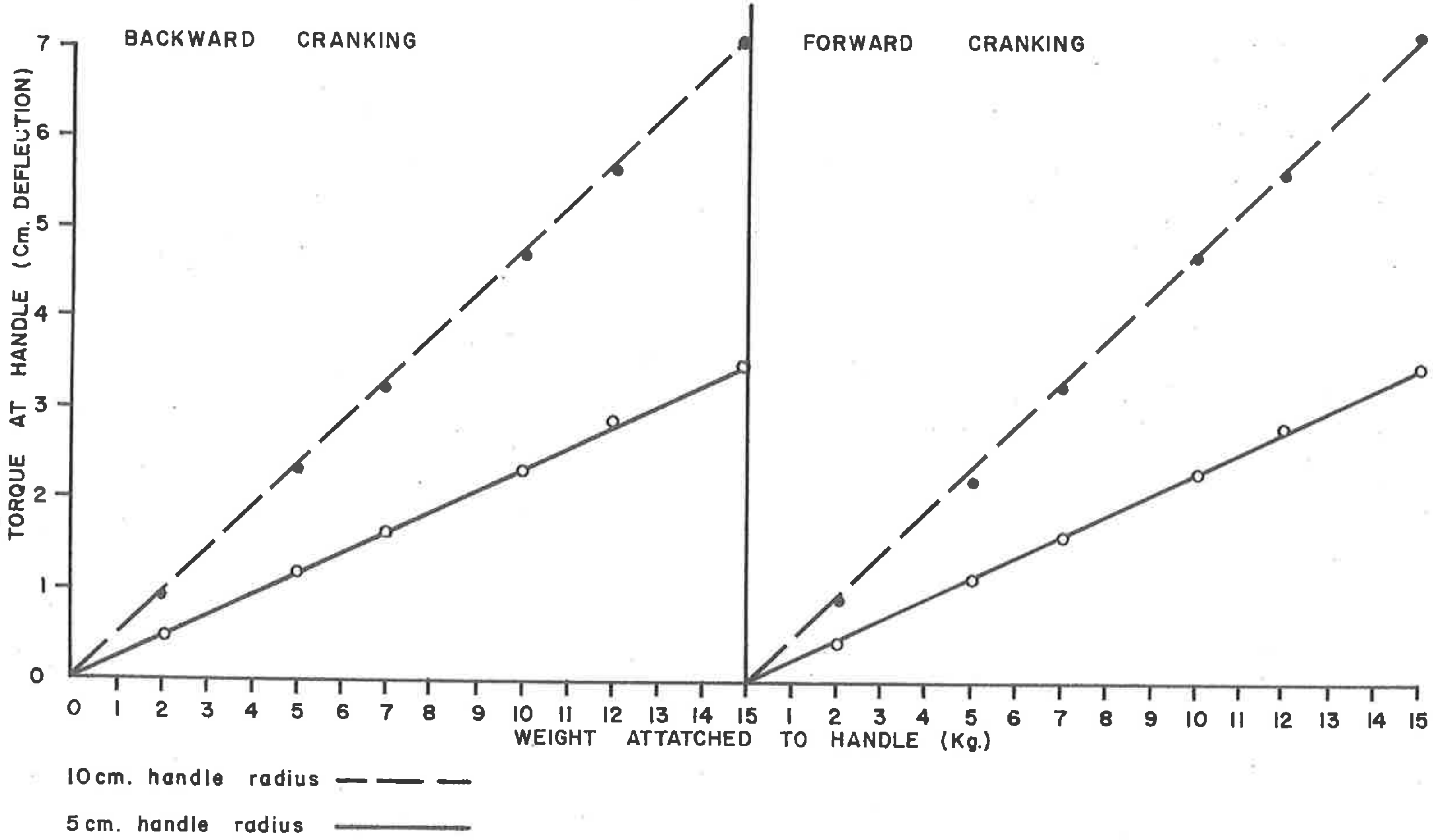


FIGURE A:3. STATIC CALIBRATION OF CRANKING APPARATUS IN FORWARDS AND BACKWARDS DIRECTIONS.

Details of Preliminary Photographic Trials

Speed (Frames per Sec.)	'f'	Shutter	Comment
12	5.6	open	Movement blurred, too dark, too slow, poor detail (3 frames per cycle).
12	4	1/2	Too dark, too slow.
12	4	1	Fair record, not blurred, too slow.
12	2.8	1	Too dark, too slow.
24	4	open	Clear, but slight blurring; more detail (6 frames per cycle).
24	4	1/2	Good.
24	2.8	1	Good, markers very clear.
24	2	1/2	Fair, but blurred.
24	2.8	1/2	Fair, but blurred.
24	1.4	1	Good, clear picture.
24	2	1	Good, a little light.
32	2	1/2	Good, but markers blurred, good detail (8 frames per cycle).
32	2.8	1/2	Good, but markers blurred.
*32	1.4	1	Good, clear picture.
32	2	1	Good, clear picture, slightly lighter.

* Used in the major experiment

3. Body Markers for Photography

Shoulder marker -

Acromium Process - the highest point palpated on the lateral edge of the acromium spine of the scapula.

Elbow marker -

Lateral Epicondyle of the Humerus - located by palpation at the distal extremity of the humerus.

Wrist marker -

Styloid Process of Ulna - located at the distal extremity of ulna.

Hand marker -

Fifth Metacarpal Joint - the lateral border of the knuckle of the small finger.

C. Electromyography

Electromyography was employed to determine the periods and extent of muscle activity during cranking.

1. Preliminary EMG Investigations

Preliminary trials were conducted to determine the procedures for using electromyography. A variety of surface electrodes were investigated. The most effective locations of the electrodes about the joints of the right arm and shoulder were also determined. 3 subjects, not used in the major study, were used for the preliminary investigations.

Details of Preliminary Electromyography Investigations

Electrode	Location	Impedance	EMG Record
Small Grommet (5 mm)	Bicep Belly	10K	Good, slight movement
Large Grommet (1 cm)	Bicep Belly	10K	Good
Large Grommet (1 cm)	Bicep Belly - Lateral border	350 Ω	Good
Large Grommet (1 cm)	Bicep Belly - Medial border	500 Ω	Good, slight movement
Small Grommet (5 mm)	Bicep Belly - Centre	350 Ω	Very good
EEG Electrode - 'Sami'	Bicep Belly	1K	Movement artifact
Large Grommet (1 cm)	Anterior Deltoid	500 Ω	Good
Large Grommet (1 cm)	Posterior Deltoid	800 Ω	Good
ECG 'Stick-On' (1 in.)	Bicep	1.2K	Good
Large Grommet (1 cm)	Tricep	1.8K	Good
Silver ECG Electrode	Wrist Flexors	4K	Poor
Small Grommet (5 mm)	Wrist Extensors	3K	Fair

Joint Movement	Location of Electrodes	EMG Record
Elbow Flexion	Brachioradialis - 2" proximal to elbow crease on lateral border of upper arm	poor
Elbow Extension	Triceps - 3" distal to axilla, on lateral bulge	good
Shoulder Extension	Posterior Deltoid - 3" vertically upwards from posterior axilla crease	good
Shoulder Flexion	Anterior Deltoid - 2" vertically upwards from anterior axilla crease	good
Wrist Extension	Wrist Extensors - 4" distal to lateral elbow crease on posterior surface of forearm	fair
Wrist Flexion	Wrist Flexors - 3" distal to elbow crease of supinated forearm, 1" from medial border	poor
Wrist Flexion	Wrist Flexors - 4" distal to elbow crease of supinated forearm, 1" from medial border	good
Wrist Flexion	Wrist Flexors - 3" distal to elbow crease, on the medial border of the supinated forearm	good
Wrist Extension	Wrist Extensors - 3" distal to elbow crease, 1" from lateral border on pronated forearm	good
Elbow Flexion	Brachioradialis - 1" proximal to elbow crease on lateral border of upper arm	poor
Elbow Extension	Triceps - 3.1/2" distal to posterior axilla, middle of posterior surface of upper arm	fair

Joint Movement	Location of Electrodes	EMG Record
Shoulder Flexion	Shoulder Flexors - 3" vertically upwards from anterior axilla	good
Shoulder Extension	Shoulder Extensors - 2" upwards and 1" medial from posterior axilla	poor
Wrist Flexion	Wrist Flexors - 3" distal to elbow crease on medial border of supinated forearm	good
Wrist Extension	Wrist Extensors - 3" distal to elbow crease, 1" medial to the ulna or pronated forearm	good
Elbow Flexion	Brachioradialis - 2" proximal to elbow crease on lateral border of upper arm	poor
Elbow Extension	Triceps - 3" distal to posterior axilla on lateral bulge	good
Shoulder Flexion	Anterior Deltoid - 1" upwards at 45^0 lateral to anterior axilla	good
Shoulder Extension	Posterior Deltoid - 3" vertically upwards from posterior axilla	good
Elbow Flexion	Biceps - 4.1/2" proximal to elbow crease, middle of biceps belly	good
Elbow Flexion	Brachioradialis - 2" proximal to elbow crease on lateral border of upper arm	poor
Elbow Flexion	Biceps - 3" proximal to elbow crease, middle of biceps belly	good

Joint Movement	Location of Electrodes	EMG Record
Elbow Extension	Triceps - 4" distal to posterior axilla, middle of posterior surface of upper arm	good

In these trials, the large grommets (1 cm. dia.) were used, placed 2 cms. apart and parallel to the underlying muscle fibres.

These electrodes were selected for the major study because of their ease of application, the quality of the records, and the smallest amount of movement artifact occurred under these conditions.

2. Details of Electromyography for Major Study

The surface electrodes were constructed from round rings of rubber 1 cm. in diameter. Silver wire formed a loop inside the rubber ring and then passed in a groove around the outer edge of the ring. This was connected to a screened cable. In preparation for the electrodes, the skin was wiped with acetone, shaved, and abraded with fine emery paper. The electrodes were applied in pairs, 2 cms. apart, and placed along the longitudinal axis of the muscle, parallel to the muscle fibres. The under surface of the rubber ring electrode were coated with Dalmaplast, a non-irritant adhesive plaster glue. The electrode was then applied to the prepared skin area and held in place until it stuck firmly (10 - 20 secs.). A gauze disc of nylon net 1 cm. in diameter was then placed inside the electrode on the skin but beneath the loop of silver wire to prevent it from making direct contact with the skin. Cambridge electrode jelly was then introduced into the hollow of the electrode by means of a syringe and was packed firm with the aid of a toothbrush. A circular adhesive plaster, 4 cms. in diameter, was then placed centrally over the electrode and firmly stuck to the surrounding skin. The leads were then attached to the arm with zinc oxide plaster so that no strain was placed on the actual electrode. Thus the electrode may be regarded as a floating electrode - electrical contact was made via the electrode jelly from the skin to the wire loop. In this way movement artifacts were eliminated or minimised.

The electrodes were positioned so that they recorded the agonistic and antagonistic muscle activity about each of the shoulder, elbow and wrist joints.

Placement of the electrodes was determined by anatomical reference points.

Anterior Deltoid (shoulder flexion) - 1 inch upwards from the anterior axilla point and laterally at 45°.

Posterior Deltoid (shoulder extension) - 3 inches vertically upwards from the posterior axilla.

Bicep (elbow flexion) - mid-bicep belly, electrodes approximately 4 inches proximal to the elbow joint.

Tricep (elbow extension) - lateral and mid-bellies of triceps 3-4 inches distal to posterior axillary crease.

Wrist Flexors - on the supinated forearm, 4 inches distal to the elbow crease on the medial border anterior surface. This electrode represents activity from the flexor carpi radialis, flexor carpi ulnaris and the flexor digitorum sublimis.

Wrist Extensors - on the pronated forearm, approximately 3 inches distal to the elbow crease and on the extensor surface from the border ulna. Activity from the extensor digitorum communis, and possibly extensor carpi ulnaris and extensor carpi radialis brevis was sampled.

The subject ground electrode was placed on the posterior surface of the left hand.

The electrode impedance was measured before and after the experiment. An impedance of 3K was set as the maximum acceptable level of resistance.

Muscle action potentials picked up by the surface electrodes were directed through a pre-amplifier to an A8 amplifier of a Medelec DMSR Electromyograph Unit and recorded on the 16 channel ultra-violet recorder.

The amplification was kept constant for each muscle in all subjects. Calibration of pen deflection was made for each test with a 500µV signal.

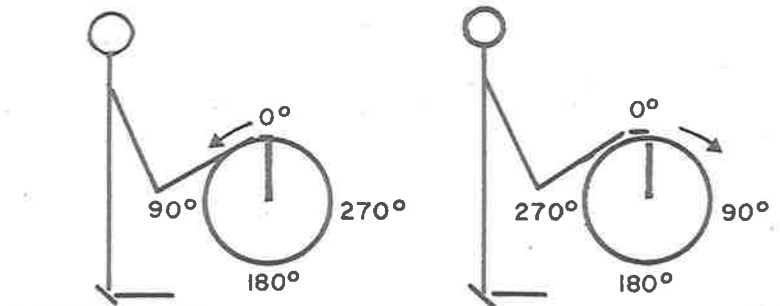
When the electrodes were in position the muscle activity was monitored one channel at a time on an oscilloscope monitor under two conditions, firstly by an isometric contraction in the role of agonist and secondly during slow cranking.

D. Analysis of the Film Record

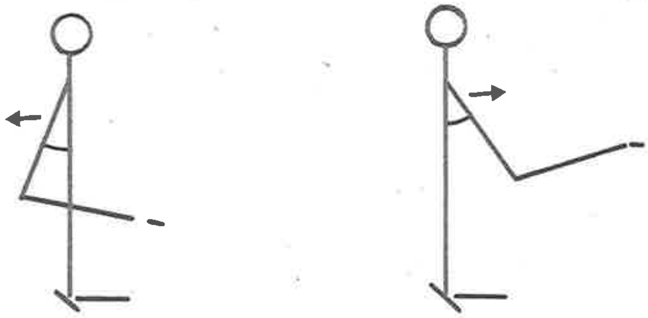
The motion photography records were analysed using a Specto 16mm motion analysis projector. For the purposes of this study it was only necessary to determine the maximum turning point for the shoulder, elbow and wrist joints, and their location in the cycle of movement. The analysis involved the projection of the image onto a screen and marking the positions of the shoulder, elbow, wrist and markers in relation to the position of the crank handle on a large piece of cardboard. From these records the extent of shoulder extension, shoulder flexion, elbow extension, elbow flexion, wrist extension and wrist flexion were determined, see Figure A:4. The maximum extent of flexion and extension for each joint's movement (viz., the turning point for each joint) was related to the position of the crank handle at that instant.

E. Analysis of the EMG Records

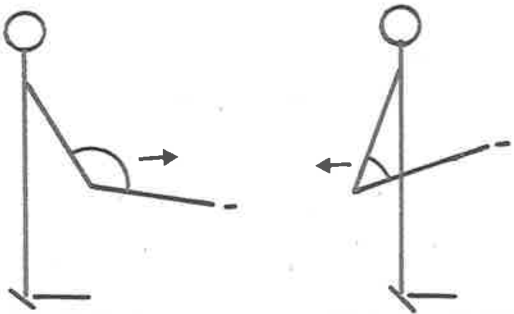
For each of the six muscles recorded, the periods of EMG activity were determined and related to the displacement record and the time of occurrence in the cycle of move-



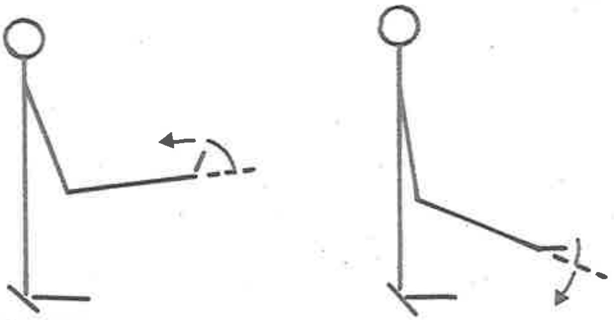
BACKWARD CRANKING FORWARD CRANKING



SHOULDER EXTENSION SHOULDER FLEXION



ELBOW EXTENSION ELBOW FLEXION



WRIST EXTENSION WRIST FLEXION

FIGURE A:4. POSITION OF SUBJECT CRANKING IN SAGITTAL PLANE ILLUSTRATING TURNING POINTS OF SHOULDER, ELBOW AND WRIST JOINTS.

ment (expressed relative to the time for a cycle of movement). The criterion used for the onset of muscle activity was when the pen deflection was greater than 500µV and continuous. Occasional small but isolated bursts of activity were ignored. The cessation of activity was taken as that point where the continuous EMG activity ceased to be greater than 500µV.

A four point scale of no activity, slight activity, moderate activity and marked activity was used to assess the extent of muscle activity from the EMG records. This scale was based on the mean pen deflection of the record and the number of spikes. To facilitate the analysis, a set of typical records characteristic of each degree of activity on the four point scale was used as a basis for comparison. In addition, to permit a limited statistical analysis of this data, mean pen deflection by itself was used as a criterion of the extent or degree of muscle activity. This technique however does not take into account the number of spikes, the rate of firing or the degree of summation (Close, 1964), and this restriction should be kept in mind in interpreting the results.

F. Analysis of the Displacement Record

The movement of the crank handle was determined from the displacement record. The degrees of movement from top dead centre (taken as 0^o) were related to the time scale. The direction of movement of the handle (forwards or backwards) determined the specific angular displacement, see Figure A;4, page 242.

G. Analysis of the Torque Record

The force exerted by the subject on the handle of a particular radius was recorded by the strain-gauges. These torque records were used to indicate when the subject exerted an effort on the crank handle. The point of occurrence of these peaks of effort in the cycle of movement were determined by relating them to the displacement record and the time scale (expressed relative to the cycle time). In a similar fashion the beginning or onset of the principal effort was located in the cycle of movement.

The amount of effort exerted was also determined from the torque record. In particular, the amplitudes of the two principal force peaks (F_1 and F_2) were measured as the vertical distance from the base line of the torque record to the two largest peaks. It should be realised that this index incorporates the force exerted to overcome the frictional resistance of the weighted belt on the drum, as well as the 'additional' force exerted to move the crank handle at speed. For this reason a direct comparison can only be made between subjects on any one condition and between the corresponding forward and backward conditions. A further restriction is that no evidence is available as to whether the force exerted by the subject was at right angles to the handle or not. Only if the force was exerted at right angles will the strain-gauge record be a true indicator of the whole force exerted at that particular instant.

The vertical distance between the largest peak and the lowest deflection of the torque record (force range F_R) was used as a criterion of the organisation of the force effort, providing an estimate of the range between the maximum force exerted and the least force exerted.

APPENDIX B

STATISTICAL APPENDIX

APPENDIX B

STATISTICAL APPENDIX

Table B:1

Summary Tables of Analyses of Variance of Order and Sequence Effects Based on Speed of Cranking

Latin Square I (Subjects 1 to 8)

Source	d.f.	S.S.	M.S.	F	p
Individuals	7	12.6310	1.8044		
Order	7	2.4790	.3542	2.44	N.S.
Treatments	7	7.8542	1.1220		
Error	42	6.0956	.1451		
Total	63	29.0598			

Latin Square II (Subjects 9 to 16)

Source	d.f.	S.S.	M.S.	F	p
Individuals	7	8.0227	1.1461		
Order	7	.1573	.0225	0.15	N.S.
Treatments	7	6.5013	.9288		
Error	42	6.3499	.1512		
Total	63	21.0311			

cont../

Table B:1 (cont.)

Latin Square III (Subjects 4 to 11)

Source	d.f.	S.S.	M.S.	F	p
Individuals	7	7.2970	1.0424		
Order	7	.7986	.1141	0.56	N.S.
Treatments	7	8.6901	1.2415		
Error	42	8.6292	.2055		
Total	63	25.4149			

Latin Square IV (Subjects 12 to 19)

Source	d.f.	S.S.	M.S.	F	p
Individuals	7	10.1915	1.4559		
Order	7	2.7673	.3953	0.73	N.S.
Treatments	7	7.3720	1.0531		
Error	42	22.6325	.5389		
Total	63	42.9632			

Table B:2

Summary Table of Analysis of Variance of Change in Onset of Muscle Activity in Cycles of Movement Prior to a Pause in Backward Cranking Condition (AB)

Source	d.f.	S.S.	M.S.	F	p
A (Muscles)	5	699.070	139.814	1.16	N.S.
B (Cycles)	4	109.780	27.445	10.66	.001
S (Subjects)	3	501.240	167.080		
A v B	20	29.340	1.467	1.36	N.S.
A v S	15	1803.305	120.220	111.52	.001
B v S	12	30.883	2.574	2.39	.05
A v B v S	60	64.677	1.078		
Total	119	2518.295			

Table B:3

Summary Table of Analysis of Variance of Change in Position of Force Exerted (F_1 and F_2) and Cycle Length in Cycles of Movement Prior to a Pause in Backward Cranking Condition (AB)

Source	d.f.	S.S.	M.S.	F	p
A (F_1 F_2 Cycle Length)	2	845.5417	422.771	56.58	.001
B (Cycles)	3	1.8541	0.618	0.90	N.S.
S (Subjects)	3	84.1041	28.035		
A v B	6	3.9578	0.660	0.55	N.S.
A v S	6	44.8328	7.472	6.12	.01
B v S	9	6.1874	0.687	0.56	N.S.
A v B v S	18	21.9990	1.222		
Total	47	1008.4769			

Table B:4

Summary Table of Analysis of Variance of the Degree of Muscle Activity (Pen Deflection) for the Six Muscles for Fast and Slow Subjects on the Backward Cranking Condition (AB)

Source		S.S.	M.S.	F	p
Rows (Slow v Fast) 9 v 9	1	2.77	2.77	0.11	N.S.
Cols. M123 v M456	1	1045.00	1045.00	48.38	.001
Interaction	1	13.90	13.90	0.64	N.S.
Error	32	691.30	21.60		
Total	35	1752.97			

Table B:5

Summary Table of Analysis of Variance of Speed of Cranking

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	28.278			
(Treatments	7	16.3599	2.3371)		
Amplitude	1	0.0050	0.0050	0.04	N.S.
Load	1	6.9760	6.9760	48.99	.001
Direction	1	4.9252	4.9252	34.59	.001
A x L	1	3.6981	3.6981	25.97	.001
A x D	1	0.5901	0.5901	4.14	.05
L x D	1	0.0281	0.0281	< 1	N.S.
A x L x D	1	0.1374	0.1374	< 1	N.S.
Error	126	17.9475	0.1424		
Total	151	62.5862			

Table B:6

Summary Table of Analysis of Variance of Phasing Criterion (PF_p)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	325.7340			
(Treatments	7	53.4290	7.6327)		
Amplitude	1	0.5064	0.5064	<1	N.S.
Load	1	0.0099	0.0099	<1	N.S.
Direction	1	15.2279	15.2279	4.15	.05
A x L	1	7.8412	7.8412	2.14	N.S.
A x D	1	13.4305	13.4305	3.66	N.S.
L x D	1	0.1133	0.1133	<1	N.S.
A x L x D	1	16.2998	16.2998	4.44	.05
Error	126	462.3087	3.6691		
Total	151	841.4718			

Table B:7

Summary Table of Analysis of Variance of Phasing Criterion (PE_p)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	427.7941			
(Treatments	7	77.8396	11.1199)		
Amplitude	1	3.1935	3.1935	<1	N.S.
Load	1	2.2328	2.2328	<1	N.S.
Direction	1	28.9027	28.9027	6.00	.05
A x L	1	4.4673	4.4673	<1	N.S.
A x D	1	0.6709	0.6709	<1	N.S.
L x D	1	1.0786	1.0786	<1	N.S.
A x L x D	1	37.2938	37.2938	7.74	.01
Error	126	607.1940	4.8190		
Total	151	1112.8278			

Table B:8

Summary Table of Analysis of Variance of Positional Timing Criterion (F_1)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	.2237	.0124	2.168	.01
(Treatments	7	.9390	.1341)		
Amplitude	1	.4598	.4598	80.67	.001
Lead	1	.0061	.0061	1.07	N.S.
Direction	1	.0296	.0296	5.18	.05
A x L	1	.0056	.0056	<1	N.S.
A x D	1	.3335	.3335	58.31	.001
L x D	1	.0691	.0691	12.08	.001
A x L x D	1	.0353	.0353	6.19	.05
Error	126	.7206	.0057		
Total	151	1.8833			

Table B:9

Summary Table of Analysis of Variance of Positional Timing Criterion (F_2)

Source	d.f.	S.D.	M.S.	F	p
Individuals	18	.4877	.0271	3.21	.001
(Treatments	7	.2201	.0314)		
Amplitude	1	.1239	.1239	14.68	.001
Load	1	.0152	.0152	1.80	N.S.
Direction	1	.0046	.0046	<1	N.S.
A x L	1	.0056	.0056	<1	N.S.
A x D	1	.0691	.0691	8.19	.01
L x D	1	.0008	.0008	<1	N.S.
A x L x D	1	.0009	.0009	<1	N.S.
Error	126	1.0635	.0084		
Total	151	1.7714			

Table B:10

Summary Table of Analysis of Variance of Onset of Activity of Biceps Muscle

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	.4683			
(Treatments	7	1.2717	.1817)		
Amplitude	1	.0600	.0600	13.04	.001
Load	1	.0071	.0071	1.54	N.S.
Direction	1	1.1955	1.1955	259.89	.001
A x L	1	.0011	.0011	< 1	N.S.
A x D	1	.0051	.0051	1.11	N.S.
L x D	1	.0001	.0001	< 1	N.S.
A x L x D	1	.0028	.0028	< 1	N.S.
Error	126	.5854	.0046		
Total	151	2.3254			

Table B:11

Summary Table of Analysis of Variance of Force Gradation Criterion (Amplitude of F_1)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	824.49	46.08	2.61	.01
(Treatments	7	9386.85	1340.98)		
Amplitude	1	85.05	85.05	4.82	.05
Load	1	9140.35	9140.35	518.23	.001
Direction	1	123.66	123.66	7.01	.01
A x L	1	29.62	29.62	1.68	N.S.
A x D	1	3.04	3.04	<1	N.S.
L x D	1	0.43	0.43	<1	N.S.
A x L x D	1	4.70	4.70	<1	N.S.
Error	126	2222.34	17.64		
Total	151	12433.68			

Table B:12

Summary Table of Analysis of Variance of Force Gradation Criterion (Amplitude of F_2)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	920.08	51.12	3.64	.001
(Treatments	7	11039.73	1577.10)		
Amplitude	1	38.30	38.30	2.73	N.S.
Load	1	9056.80	9056.80	644.86	.001
Direction	1	1892.22	1892.22	134.73	.001
A x L	1	39.92	39.92	2.84	N.S.
A x D	1	1.88	1.88	<1	N.S.
L x D	1	9.45	9.45	<1	N.S.
A x L x D	1	1.16	1.16	<1	N.S.
Error	126	1769.63	14.04		
Total	151	13729.44			

Table B:13

Summary Table of Analysis of Variance of

Force Range Criterion (F_R)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	3076.4520			
(Treatments	8	1541.8272	220.2610)		
Amplitude	1	107.5706	107.5706	2.40	N.S.
Load	1	2.1912	2.1912	<1	N.S.
Direction	1	854.9542	854.9542	19.10	.001
A x L	1	233.2938	233.2938	5.21	.05
A x D	1	71.2537	71.2537	1.59	N.S.
L x D	1	12.9987	12.9987	<1	N.S.
A x L x D	1	259.5650	259.5650	5.80	.05
Error	126	5639.4974	44.7579		
Total	151	10257.7766			

Table B:14

Summary Table of Analysis of Variance of Consistency of Force Range Criterion (F_C)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	387.2178			
(Treatments	7	396.7602	56.6800)		
Amplitude	1	20.6979	20.6979	2.31	N.S.
Load	1	0.4327	0.4327	< 1	N.S.
Direction	1	247.7329	247.7329	27.64	.001
A x L	1	12.4776	12.4776	1.39	N.S.
A x D	1	53.0175	53.0175	5.91	.05
L x D	1	21.8501	21.8501	2.44	N.S.
A x L x D	1	40.5515	40.5515	4.52	.05
Error	126	1129.4756	8.9641		
Total	151	1913.4537			

Table B:15

Summary Table of Analysis of Variance of Total Muscle Activity (Pen Deflection)

Source	d.f.	S.S.	M.S.	F	p
Individuals	18	6812.0658			
(Treatments	7	1047.3092	149.6156)		
Amplitude	1	123.4803	123.4803	6.16	.05
Load	1	382.1118	382.1118	19.07	.001
Direction	1	1.4803	1.4803	< 1	N.S.
A x L	1	512.1118	512.1118	25.56	.001
A x D	1	19.9013	19.9013	< 1	N.S.
L x D	1	8.0592	8.0592	< 1	N.S.
A x L x D	1	0.1645	0.1645	< 1	N.S.
Error	126	2524.5658	20.0362		
Total	151	10383.9408			

Coefficients of Orthogonal Polynomials

(see Hays, 1963)

Backward Cranking

AB - PF_A/Speed, $Y = 19.82 - 7.43X + .72X^2$
CB - PF_A/Speed, $Y = 33.01 - 13.47X + 1.40X^2$
CB - PF_p/Speed, $Y = 108.97 - 44.41X + 4.67X^2$
CB - PE_A/Speed, $Y = 32.24 - 12.77X + 1.29X^2$
DB - PE_A/Speed, $Y = 31.53 - 13.26X + 1.43X^2$

Forward Cranking

CB - $CPTF_p$/Speed, $Y = 44.18 - 18.76X + 2.05X^2$
CB - $CPTE_p$/Speed, $Y = 42.70 - 16.78X + 1.75X^2$
CB - $CPTF_A$/Speed, $Y = 12.44 - 5.18X + .55X^2$
CB - $CPTE_A$/Speed, $Y = 14.09 - 5.60X + .58X^2$
DB - $CPTE_A$/Speed, $Y = 24.79 - 10.61X + 1.16X^2$

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