N86-32997

THE ROLE OF IMPULSE PARAMETERS IN FORCE VARIABILITY

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One of the principle limitations of the human motor system is the ability to produce consistent motor responses. When asked to repeatedly make the same movement, performance outcomes are characterized by a considerable amount of variability. This is especially true for rapid actions or when salient feedback cues are not available, requiring the performer or operator to function in an open-loop manner. This occurs whether variability is expressed in terms of kinetics or kinematics. Variability in performance is of considerable importance because for tasks requiring accuracy it is a critical variable in determining the skill of the performer. In addition, understanding the factors affecting response variability will provide important insights necessary for explaining Fitt's Law (Fitts, 1954) and speed accuracy tradeoffs in general.

What has long been sought is a description of the parameter or parameters that determine the degree of variability. Two general experimental protocals have been used. One protocal is to use dynamic actions and record variability in kinematic parameters such as spatial or temporal error. A second strategy has been to use isometric actions and record kinetic variables such as peak force produced. While a number of hypotheses have been put forward, there are two models which suggest that force parameters determine the amount of variability in a variety of tasks.

Most recently, Schmidt, Zelaznik, Hawkins, Frank & Quinn (1979) presented an impulse variability model which predicts a linear and proportional relationship between the impulse produced and impulse variability. As the level of force required to complete a response increases, the variability in producing that force also increases. Based upon this relationship, Schmidt et al. demonstrated that speed-accuracy tradeoffs could be accounted for by variability in force production. This work provided important advancements for providing the link between variability at kinetic levels and variability in kinematic variables consistent with speed-accuracy relationships.

A second model, which we label an impulse-ratio model, is an extrapolation of the work by Bahrick, Bennett, and Fitts in 1955. They were interested in the control of a spring loaded control stick and how changes of force characteristics affected tracking performance. The model proposed that amplitude, terminal torque and the change of torque from initial to final torque levels influenced accuracy. Extrapolating to isometric tasks, the impulse-ratio model would predict that force variability is proportional to the ratio of the change in force from initial force to peak force, divided by peak force.

Unfortunately, there has been little empirical support for either of these models. For example, there is a large body of evidence which supports a non-proportional relationship between force and force variability in both isometric (Fullerton & Cattell, 1892; Jenkins, 1947; Newell & Carlton, in press; Noble & Bahrick, 1956) and for dynamic movements (Newell, Carlton, & Carlton, 1982). In addition, previous examinations of force variability have confounded a number of force variables. For example, variations in isometric peak force have co-varied with changes in impulse and rate of force production.

The major purpose of this paper is to examine what might be the important force related factors affecting variability and to provide an experimental approach to examine the influence of each of these variables. The models previously presented have implicated peak force, impulse, and change of force. But when we consider that a motor response requires the generation of force over time, it is noted that peak force is a function of the rate of force production and the amount of time that the rate is generated. Thus, the rate of force production and its time of application may be more fundamental than consideration of peak force or impulse alone. Each of these variables are depicted on a typical force-time curve generated in an isometric force production task (Figure 1).

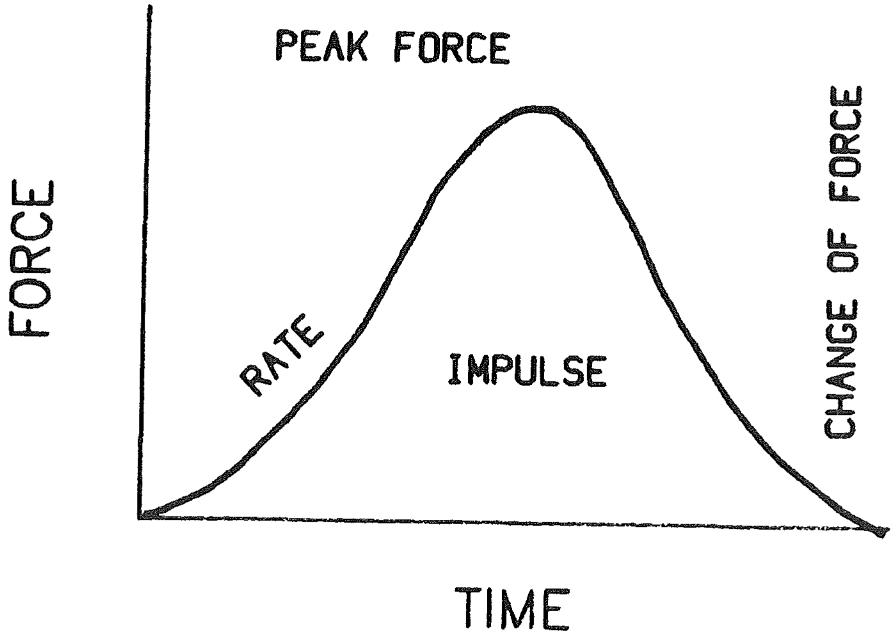

Figure 1. Typical isometric force-time curve.

Research Strategy

We suggest that a reasonable strategy would be to conduct a series of experiments where each of the force parameters would be held constant while allowing others to vary systematically. It is anticipated that synthesis of the experimental findings would lead to an understanding of the contribution of each impulse parameter to response variability. A priori, it was reasoned that the impulse variability and impulse-ratio models had focused on the non-essential variables of force production rather than the essential variables.

Six experiments examining isometric force production are suggested. In each study subjects are required to produce multiple discrete trials in order to evaluate response variability. The subjects are provided a force-time template which should be matched, and feedback after each trial regarding the discrepancy between the template and actual response. The first three experiments (Figure 2) manipulate the initial preload or steady force exerted before each trial.

The Experiments

Figure 1A represents four conditions which have equal peak force but allow for changes in the rate of force production as well as impulse size and change of force. The triangulated force-time curves provide approximations to the force-time manipulations for each experiment. Thus, as preload increases the rate of force production and the change of force decreases.

The experiment outlined in Figure 1B keeps the change of force constant across 4 conditions but allows the impulse size and peak force to vary systematically. The rate of force production also remains constant. A test of the impulse-ratio model is provided in Figure 1C. In each of the four conditions the ratio descibed by the change of force divided by peak force remains constant. The impulse size, rate of force production, and peak force varies with conditions.

The second set of experiments (Figure 3) vary the time to peak force in order to manipulate the desired force parameters. A test of the impulse variability model is provided in Figure 3A. The size of the impulse remains constant by increasing the time to peak force and reducing the peak force attained. As a result, the rate of force production changes for each condition. As far as we know this is the first strong test of the impulse variability model. Figure 3B represents conditions with equal peak force and different rates of force production as well as different impulse. In Figure 3C the rate of force production is held constant while peak force and impulse vary.

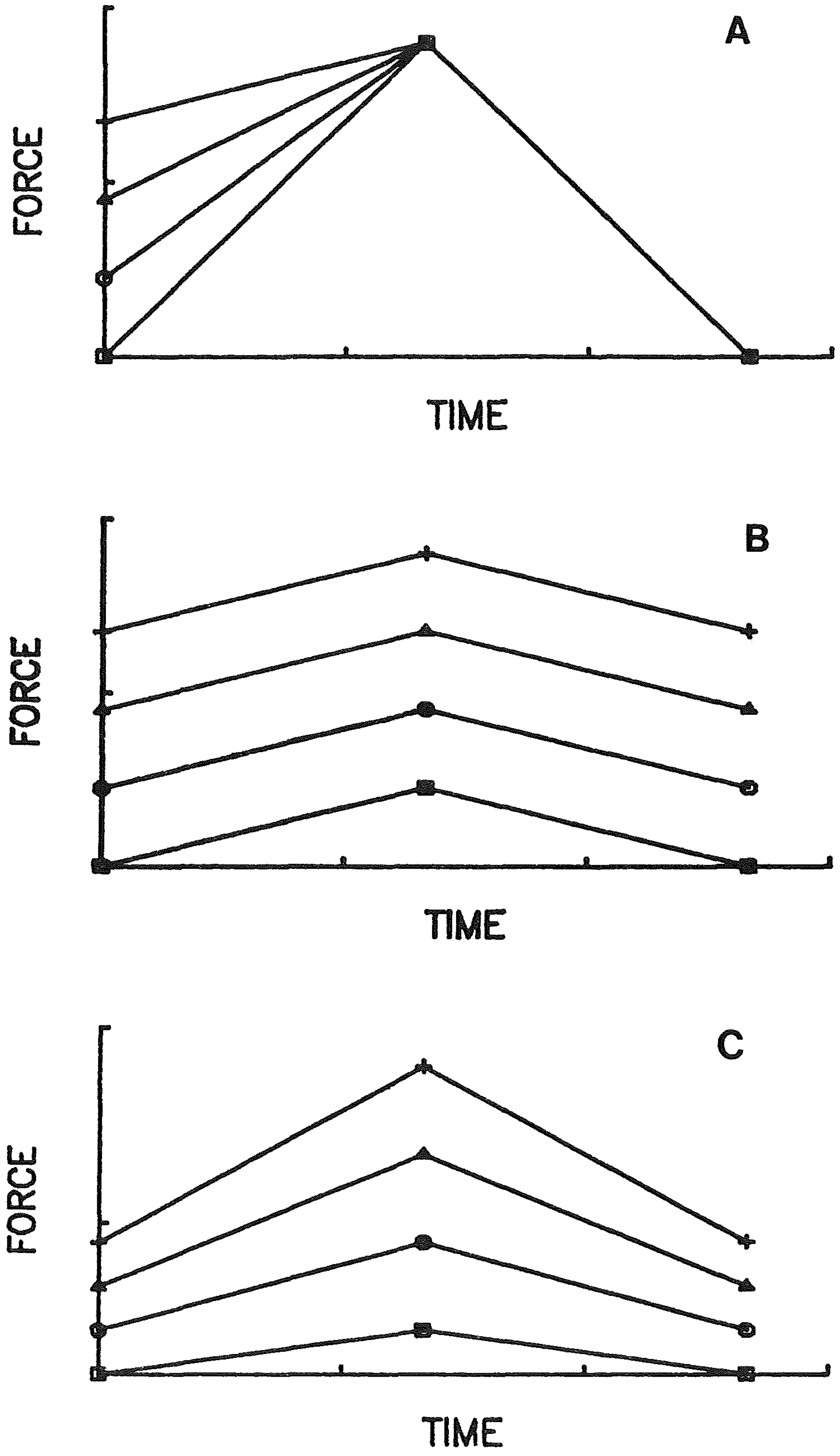

Figure 2. Triangulated force-time curves for experiments 1-3.

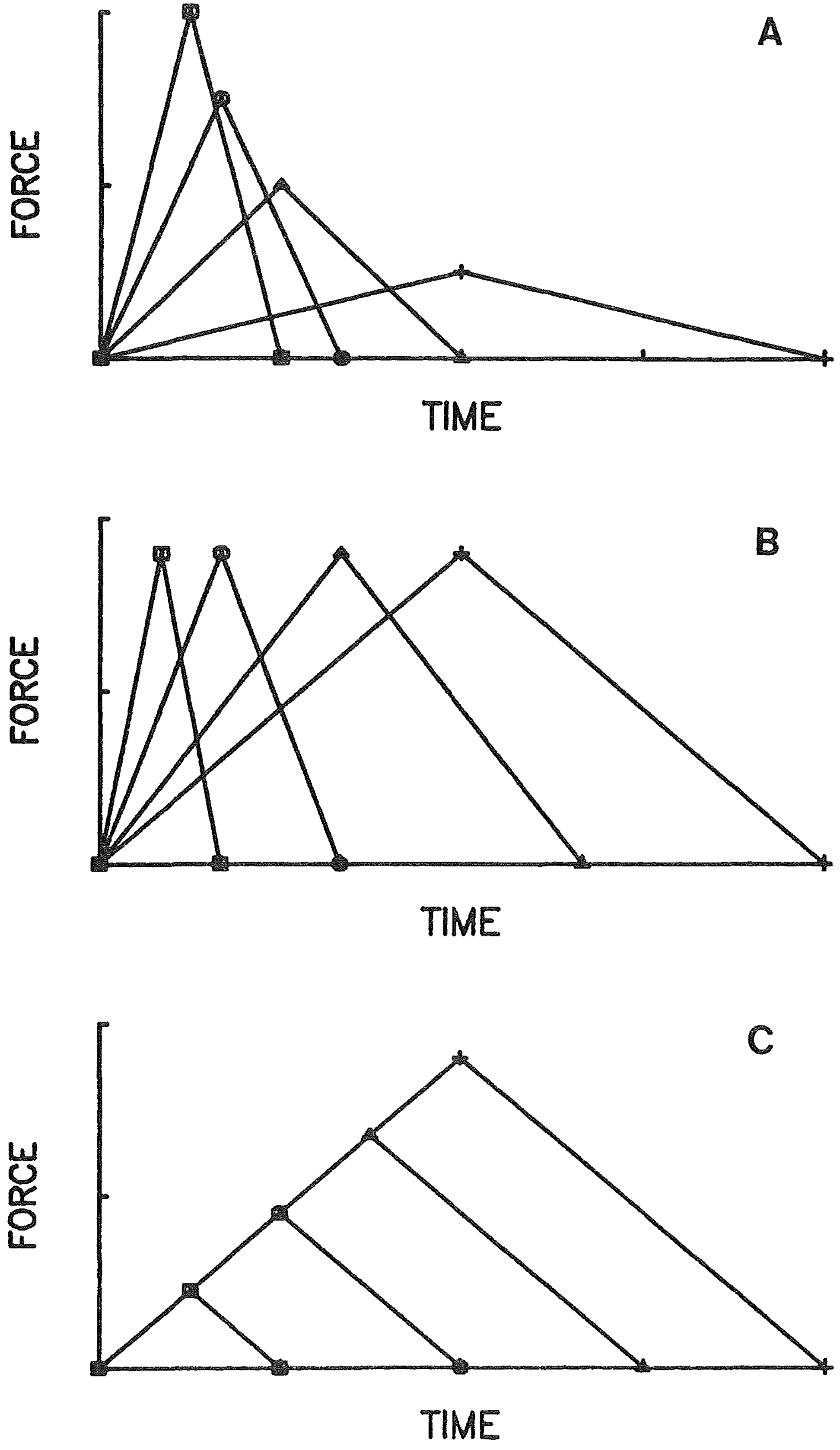

Figure 3. Triangulated force-time curves for experiments 4-6.

DISCUSSION

The pattern of results from the six experiments should provide an indication of the relative importance of each of the force related parameters to force variability. The simplest solution would be provided if variability remained constant as a function of one of the manipulations outlined. For example, if impulse variability remained constant across the four conditions oulined in Figure 3A, evidence would support the contention that impulse size determines variability. Changes in rate of force production and peak force would have no significant effect on variability. Such a finding would provide support for the impulse variability model.

We speculate, based on pilot data and the nature of force production, that no single factor will provide an accurate accounting of the force variability function. However, we believe a physical description is possible when multiple factors are considered. Rate of force production and the time for which that rate is developed would seem to be important features with other factors such as the change of force from initial to final force levels playing some role.

While these experiments have been outlined employing an isometric task, the same manipulations can be produced in dynamic actions. Although these tasks have differing control problems, both require the performer to functionally exert force over time, and hence, generate an impulse (time intergral of force). Newtonian principles of mechanics suggest that kinematic and kinetic approaches to response variability should be congruent and there have been recent attempts at mapping this relationship (Hancock & Newell, in press; Schmidt et al., 1979).

In summary, the results of the experiments should lead to an understanding of the contribution of each impulse parameter to response variability. More important than the relative contribution of these factors is the development of a physical description linking impulse parameters to response variability. The outlined experiments provide a direct test of the impulse-ratio and impulse variability model, but initial indications are that neither model accurately accounts for variability in performance. A model taking into consideration more fundamental properties of the force production mechanisms may provide a better description of response variability and associated phenomena such as Fitt's Law and other speed-accuracy tradeoffs.

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