University of Windsor
Scholarship at UWindsor

Electronic Theses and Dissertations

1982

Theories of acceleration specific exercise and design of a training device.

James J. Dowling
University of Windsor

Follow this and additional works at: http://scholar.uwindsor.ca/etd

Recommended Citation

Dowling, James J., "Theories of acceleration specific exercise and design of a training device." (1982). *Electronic Theses and Dissertations.* Paper 4370.

CANADIAN THESES ON MICROFICHE

I.S.B.N.

THESES CANADIENNES SUR MICROFICHE

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

THIS DISSERTATION HAS BEEN MICROFILMED EXACTLY AS RECEIVED

LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS REÇUE

Canada

THEORIES OF ACCELERATION SPECIFIC EXERCISE

AND DESIGN OF A TRAINING DEVICE

by

(C) James J. Dowling

A Thesis
submitted to the Faculty of Graduate Studies
through the Faculty of
Human Kinetics in Partial Fulfillment
of the requirements for the degree
of Master of Human Kinetics at
The University of Windsor

Windsor, Ontario, Canada

1982

778095

ABSTRACT

The purposes of this study were to determine the optimal accelera-
tion path for ballistic movements and to design a training device that
performs according to that acceleration path.

The optimal acceleration path was determined from a mathematical
modeling study that employed three different methods of acceleration path
manipulation. The results revealed that the optimal acceleration path
for ballistic movement is one in which the initial acceleration is equal
to the maximum acceleration and is maintained throughout the entire range
of motion.

Three different approaches were taken to design an acceleration
specific training device that would provide overload to the muscles and
follow the optimal acceleration path for ballistic movement regardless
of the applied force by the user.

It was concluded that the cost of building an acceleration specific
training device utilizing an electrical stepping motor controlled by a
microprocessor, was not high when compared with the cost of velocity
-specific training devices such as the Cybex and that acceleration speci-
fic training may possibly have a greater transfer of strength gain from
the training program to the performance of the skill than other training
programs.

DEDICATION

Five years ago I would never have believed that I would
be in a position to write this thesis and so I would like to
dedicate it to all of those who have influenced my opinions
and attitudes, given me confidence and helped me to develop a
personal philosophy that has allowed me to understand myself
and given me a direction in which to apply myself.

This thesis is also dedicated to Arlene Tompkins whose
unselfishness and patience is exceeded only by her charm and
her love.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

In sport events such as the high jump or shotput, the velocity of the object being moved changes from an initial value which is zero to a final value (maximum velocity) which is considerably greater than zero. In the high jump, the object being moved is the jumper's center of gravity and when for simplicity, only vertical velocity is considered, the initial velocity will be the vertical velocity of the jumper's mass center at the low point of the take-off phase. In the shot put, the initial velocity can be considered to be the velocity of the shot prior to the thrust or push-off phase. This change in velocity from initial to final, indicates a positive acceleration and a positive change in momentum (Hay, 1973).

$$\text{MOMENTUM} = \text{mass} \times \text{velocity} \qquad (1)$$

The amount of lift that the jumper gets is governed totally by the final vertical velocity (Hay, 1975) and similarly the distance that the shot will travel (provided the proper angle of trajectory) is governed totally by its final velocity. Therefore the greater the change in momentum (change in velocity since mass is constant), the greater the success in the event.

The change in momentum is produced by impulse. The greater the change in velocity when mass is constant, the greater the impulsiveness of the applied force. Thus the objective of these sport skills is to

1

attain the greatest impulse possible. Impulse is the product of force and time.

$$IMPULSE = force \ X \ time \qquad (2)$$

It would appear logical that impulse would be maximized in these skills by maximizing both force and time.

It is well known from the physiology of human skeletal muscle con-tractile properties and fatigue factors (Hill, 1938; Wilkie, 1950; Gordon, 1966; Huxley, 1974) that in vivo a maximal force can be developed for only a short period of time and cannot be maintained for the entire duration of the movement. Therefore there are limits to which the time of force application can be maximized.

Studies comparing elite and experienced performers with proficient performers, and studies comparing good and poor performances, have found that the maximization of time of force application is neither possible nor desireable (Hay, 1975; Ecker, 1976; Ariel, 1977; Dowling, 1980). These studies have found that the better performers achieve greater final velocities while requiring less time for the execution of the movement. Thus a characteristic of a good performance would involve the minimization of movement time rather than maximization.

If, in equation (2), the time component were to decrease, the force component must increase an equal amount just to maintain the same impulse and thus the same final velocity but the power of the movement will have been increased.

$$POWER = force \ X \ distance \ / \ time \qquad (3)$$

If impulse is to be increased, then the force component must increase at

a greater rate than the time component decreases. From equation (3) it
can be seen that in both of these cases the power of the movement is in-
creased. Therefore it is possible to increase the power of a movement
without increasing the impulsiveness of the movement and thus without
increasing performance in the skill. Therefore neither equation (2) or
(3) is totally suitable for explaining good performances in ballistic
movements since power can be increased without increasing performance and
impulse must be increased in such a manner as to decrease time in order
to reflect the characteristics of a good performance. For this reason,
skills with the criteria of maximum final velocity and minimum movement
time will be reffered to as ballistic movements rather than power move-
ments or impulsive movements.

Ballistics is the study of projectiles. While baseballs, hockey
pucks, and badminton birds are all good examples of projectiles in sport,
the human body itself can also be considered to be a projectile.
Obvious examples of this are evident in such sports as diving, or long
jumping but even skills as simple as the basic running stride contain
ballistic movement. A ballistic movement is any movement which is in-
itiated by a strong muscular contraction and is then carried on by its
own momentum. Most, if not all, sporting events contain some ballistic
movement while many sports are predominated by it. Despite the wide use
of this type of motion, there are no athletic training devices that are
designed to specifically increase the performance of these movements.

Statement of the Problem

The purposes of this study were to determine the optimal accelera-

tion path for ballistic movements and to design a training device that performs according to that acceleration path.

Definition of Terms

TRAINING DEVICE - An exercise apparatus that simulates athletic movement and is adjustable to allow for progressive increases in the user's performance over the training period.

OPTIMAL ACCELERATION PATH - The acceleration-time curve that achieves the maximum final velocity in a minimal time for a given maximum force.

BALLISTIC MOVEMENT - A movement in which the motion is initiated by a strong muscular contraction and is then carried on by its own momentum.

MATHEMATICAL MODELING - The manipulation of equations according to a prescribed criterion.

ACCELERATION-TIME CURVE - The resulting line through the orthogonally plotted cartesian coordinates of acceleration and time values.

Limitations

The major limitation of this study was the prohibitive cost of the equipment necessary to build a training device that performed according to the optimal acceleration path for ballistic movements regardless of the applied force by the user. Three attempts were made to design the device as economically as possible using available equipment but in each instance the available equipment did not have the capabilities to

either attain the high velocity values of ballistic movements, withstand

the high force values required in simulating athletic performance, or

measure the constant acceleration required by the optimal acceleration

path. The cost of purchasing such equipment was beyond the budget of

this project and thus the device could not be completed or tested to

see if training according to the optimal acceleration path increases

performance in ballistic movements better than either conventional

training programs or simply practicing the skill.

Since the training device built for the proposed study did not func-

tion according to the required standards, the remainder of the thesis

will focus on the theoretical bases of acceleration specific training

adaptations and suggest alternate methods of equipment design that could

be used to develop an acceleration specific training device.

CHAPTER II

REVIEW OF LITERATURE

Physiology of Strength and Ballistic Movement

Recent scientific evidence has shown that strength training exer-
cises should simulate the sport movement as closely as possible in terms
of anatomical movement pattern, velocity, acceleration, contraction type
and contraction force (Sale and MacDougall, 1981; Costill, 1980).

Movement pattern specificity studies (Thorstenson et al, 1976;
MacDougall et al, 1977, 1979, 1980; Rash and Morehouse, 1957) have shown
that despite large strength gains achieved in one exercise program, im-
provement in strength tests is considerably less when a different move-
ment pattern or body position is used despite the fact that the same
muscle groups are involved in both tests. Rash and Morehouse concluded
that strength training is to a large extent an aquisition of skill.
Lindh (1979) has shown that training is specific to the joint angle and
contraction type.

Speed specific training studies using the Cybex isokinetic dynamo-
meter (Moffroid and Whipple, 1970; Coyle and Feiring, 1980; Caizzo et al,
1980) found that training at slow speed increases strength when tested
at slow speed but does not increase strength nearly as much when tested
at high speed. Similarly, training at high speed increases strength more
when tested at high speed than when tested at slow speed. A mixed train-
ing program of both fast and slow speeds results in substantial strength

6

gains at both speeds. It was also found that low speed strength gains are easier to achieve than high speed strength gains with speed specific training but the high speed training has a better transfer effect to slow speed than vice versa. Recent neurological evidence suggests that these speed specific effects are due to an adaptation within the nervous system rather than within the muscles themselves and that the brain organizes fast movements differently than slow movements (Desmedt and Godaux, 1977).

Human skeletal muscles are composed of many fibers each of which is innervated by a branch of a motor nerve. All fibers innervated by a single motor nerve have the same metabolic and contractile properties and together make up one motor unit. Unlike most animals, the metabolic and contractile properties of different motor units vary widely within the same muscle in man. The group of motor nerves that innervate a particular muscle form a pool in the ventral horn of the spinal cord. During a muscular contraction, in which the force of contraction is gradually increased, the recruitment order of the single motor units is smallest (slowest) motor unit to largest (fastest) motor unit (Henneman, 1965). The smaller the motor unit, the lower the recruitment threshold. Thus a smaller motor unit is recruited with a smaller force requirement than a larger motor unit. Such movements are carried out through the alpha motor nerves, but also involve the activation of the gamma motor nerves which contract the spindle muscle fibers. Feedback from the spindle through the gamma loop to the alpha motor nerves controls the movement. When man executes movements as quickly as possible, the com-

mands to the alpha motor nerves are preprogrammed in order to produce the required ballistic force and there is no time for any corrective feedback action from the spindle or other afferents. The faster the contraction, the greater the drop in the muscle force threshold at which a motor unit is recruited and in ballistic movements (time to peak of .008 - .14 sec.) the same motor unit fires before the muscle produces any force (Desmedt, 1980). In such contractions therefore, the synaptic input to these motor nerves is different than in the gradual increasing force contraction and therefore the brain organizes fast movements differently than slow movements (Desmedt and Godaux, 1978; Mariani et al, 1978).

.These findings are supported by work done by Costill (1980) who states that even during the greatest muscular efforts, only a fraction of the fibers within a muscle are being stimulated by the nervous system and that a major portion of muscular strength is dependent on the ability to turn on motor units during the maximal contraction. Using a special Biokinetic Training Device to train swimmers, Costill's studies showed that improved fiber recruitment patterns occur early in the strength training program (within one week) and account for a large part of the initial gains. After a four week training period athletes have achieved up to 35% improvements in Biokinetic strength with no measureable increase in body muscle mass. The Biokinetic training device used by lates the arm pull in swimming.

Studies using rats have found that with sprint training, isometric
·Costill allows training according to an acceleration pattern that simu-

twitch contraction time decreases and maximum tetanic tension increases

(Staudt, 1973). These changes are greater in predominantly slow muscle

than in fast. Exercise can cause slow twitch fibers to take on charac-

teristics of fast twitch fibers without hypertrophy by increasing the

ATPase activity (Baldwin et al, 1974) which is in keeping with the con-

cept that ATP hydrolysis by actomyosin is the rate limiting reaction for

muscle shortening. This may be the mechanism that causes changes within

the muscles. Studies have also shown that by changing the frequency

of nerve impulses, fast twitch fibers can take on characteristics of

slow twitch fibers and vice versa (Solmons and Sréter, 1976).

Motor Learning and Ballistic Movement

It has been proposed (although not proven conclusively) that motor

programs are developed somewhere in the central nervous system during

the learning of motor skills (Taub and Berman, 1968; Cratty, 1973; and

Marteniuk, 1976). The motor program is a fixed plan of action stored in

the memory that can send a number of motor commands that control the

entire movement independently of sensory feedback. Such a phenomenon

has already been observed in very fast movements (about 100 milliseconds)

which are completed in less than a reaction time and thus enable no feed-

back.

This concept of motor programs fits quite well with the previously

mentioned work of Desmedt and Godaux (1978) on ballistic movement and

motor unit recruitment (they even referred to these movements as "prepro-

grammed" movements). By training according to a prescribed acceleration

path that more closely simulates the actual movement, a motor program may

be learned that recruits motor units in such a way that improves perform-
ance of the skill. Costill alluded to this exact point when he stated
that for increased force production an athlete must learn to recruit more
motor units since even in a maximal voluntary contraction, not all of
the motor units are recruited

Another major component of motor learning that may help explain the
concept of exercise specificity is the transfer of learned motion.
Transfer is the effect that the practice of one task has on the learning
or performance of a second (Cratty, 1973). Two of the major principles
state that:

1) transfer is greatest when the training conditions

    of two tasks are highly similar.

2) · the greater the amount of practice on the original

    task, the greater the transfer.

Therefore transfer of learned motor programs may explain the find-
ings of the exercise specificity experiments and also adds credence to
the argument that training should simulate the skill as closely as pos-
sible.

It may be possible that training can cause both physiological
as well as neurological adaptations that allow increases in force pro-
duction as well as decreases in movement-time (Schmidtbleicher and
Haralambie, 1981) and thus increased performance in ballistic movements
which are characterized by these two criteria. The question remains as
to the type of training program that will cause these adaptations.

Summary

Good performers of ballistic movements (ie. jumping, throwing, etc.)
attain greater final projectile velocities in shorter periods of time
than do poor performers. Specificity of training effects indicate that
training exercises should simulate the sport movement as closely as pos-
sible in terms of anatomical movement pattern, velocity, acceleration,
contraction type and contraction force. The reasons for the specific
adaptations are primarily due to the way in which the movement is learned
and organized by the central nervous system and to a lesser extent adap-
tations within the muscle. Human skeletal muscle can be trained for
decreased contraction time (whole muscle) as well as increased force ap-
plication (Schmidtbleicher and Haralambie, 1981).

Justification of the Study

In human ballistic movements, there is an acceleration pattern in
which the projectile starts at zero velocity and is accelerated until a
maximum velocity is reached. These movements, depending on the actual
skill, vary in time from 100 msec. to 400 msec. The isokinetic (constant
velocity) exercise has no acceleration and thus the recruitment of motor
units does not parallel the actual movement and the greatest neural adap-
tation will not be achieved.

The Biokinetic training device used in the previously mentioned
studies of Costill (1980) reportedly simulates the acceleration path of
the swimming arm pull but no mention is made of the characteristics of
this path or how the simulated path was developed. Different performers
will have different acceleration paths and there will be variations in

the acceleration paths of the same performer from stroke to stroke. Thus an optimum acceleration path must be developed that meets the criteria of the movement.

Given the optimum acceleration path, an exercise device that will truly train athletes for ballistic movements should permit overload (strength adaptation within the muscle) and be capable of accomodating resistance in such a way that an acceleration pattern which allows for a change in velocity from zero to the maximum for each particular athlete (strength adaptation within the nervous system) is followed. This acceleration path must allow the movement to be completed in the least amount of time that the athlete requires to complete the actual motion. The acceleration path must be adjustable so that the final (maximum) velocity and movement time can be changed to allow the athlete to achieve progressively greater final velocities in progressively shorter time periods. There is a need, therefore, to first determine the optimal acceleration path for ballistic movement and then develop a training device that performs according to this path, permits overload within the muscle, and is adjustable so that both physiological and neurological adaptations can be achieved which will allow for improved performances in ballistic movements.

CHAPTER III

DETERMINATION OF AN OPTIMAL ACCELERATION PATH

FOR BALLISTIC MOVEMENT

In the introduction, it was established that the criteria for good

performances in ballistic movements are a maximal final velocity and a

minimum movement time and these therefore must also be the criteria for

the optimal acceleration path.

FIG. 1 shows two velocity-time curves. In each case the movement

covered the same distance (area A = area B) but the acceleration paths

were different. In case A, the acceleration (slope of the velocity-time

curve) is small at first and in case B, it is small at the end. There

is a greater final velocity in case A but it has required a longer time

to achieve it. Therefore the better path of the acceleration depends

upon the objective of the skill (Hochmuth and Marhold, 1977).

Hochmuth and Marhold (1977) simulated linearly increasing and de-

creasing acceleration-time curves over a constant time interval. The

results in each case were consistent with their findings and lead them to

conclude that the most efficient type of acceleration-time dynamics de-

pended on the objective of the skill. If a certain movement must be ex-

ecuted in a minimum time, (ie. the boxing punch) then the maximum force

must be applied at the beginning of the movement (decreasing tendency of

acceleration). If the objective of the skill is to attain a maximum

13
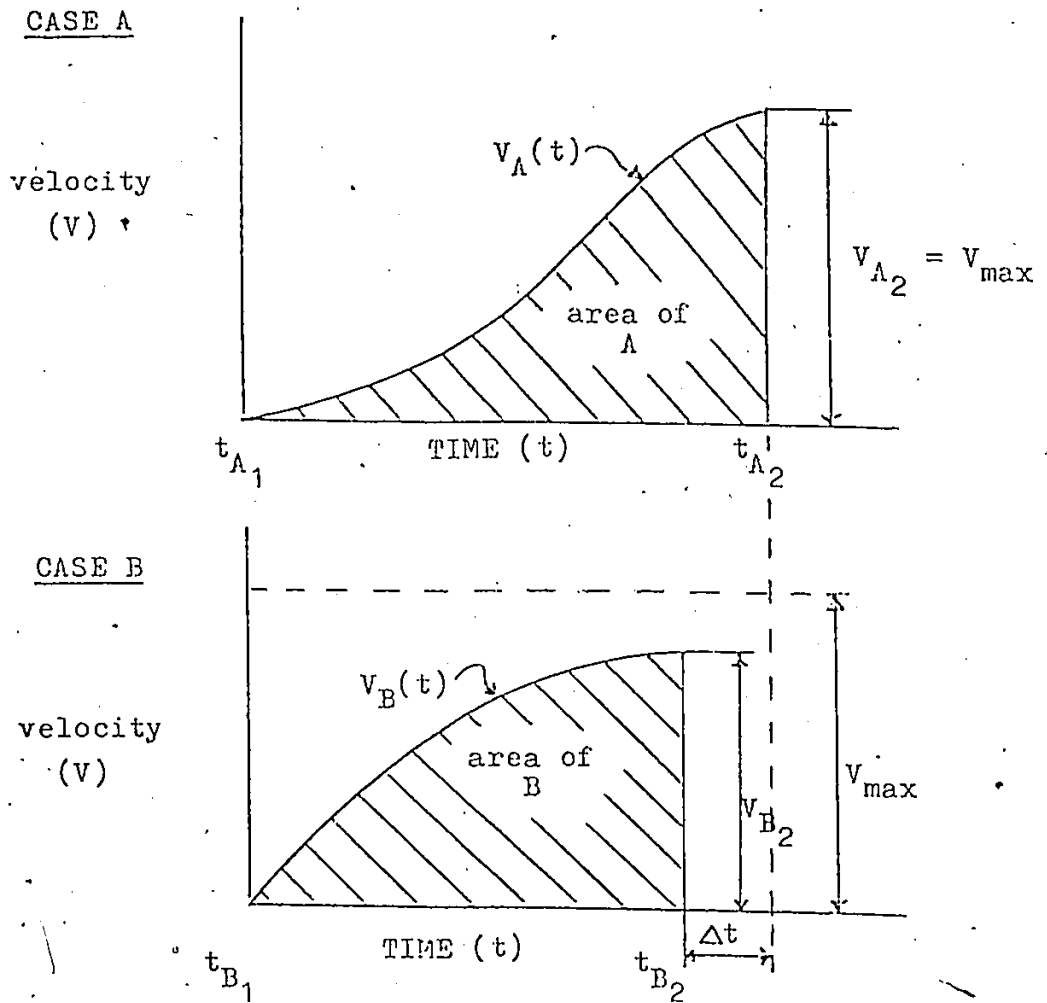
Figure 1: Velocity-time curves from Hochmuth and Marhold (1977).

final velocity, then the greatest force must be applied at the end of the movement (increasing tendency of acceleration).

Thus in a skill where the objective is to attain the greatest final velocity possible, an increasing tendency of acceleration dynamics is desired. As stated earlier, however, this type of acceleration path requires a greater length of time to achieve the greater final velocity. Since it was established earlier that the criteria of ballistic movement while requiring a maximum final velocity, require less time for execution, the desired acceleration path for ballistic movement is still in doubt.

In Hochmuth and Marhold's study (FIG. 4) both time and final velocity were held constant (.25 sec. and 3.68 m/sec. respectively) while the length of the acceleration path was allowed to vary. To get a true cause and effect relationship between path of acceleration and final velocity, both time and final velocity cannot be held constant. One of these two variables must be held constant while the other is allowed to vary.

Since the purpose of this study was to determine the acceleration path that best meets the criteria of ballistic movement, the independent variable must be the acceleration path. As stated earlier, to solve the the problem of maximum velocity and minimum time, one of these variables and only one of these variables must be free to vary and be measured as the dependent variable. All other variables must be held constant so that the effect of the independent variable manipulation can be measured directly by the dependent variable.

In the first method the acceleration paths were expressed as functions of distance (Hochmuth's and Marhold's acceleration paths were expressed in the conventional manner as functions of time). The rather unorthodox method of expressing the acceleration paths of the present study allowed distance, final velocity, and average acceleration in terms of distance to be held constant while time was allowed to vary with the manipulation of the acceleration path. This method was called the distance method and the subsequent process of integration of these functions is considerably more complex than that of the previous study (see FIG. 2).

Line 1 (FIG. 2) shows the acceleration (a) expressed as a function of distance (X). Using the standard differential equations of Line 2, and substituting f(X) for (a) results in the equation of Line 5. When both sides of Line 5 are integrated (Line 6) an expression of velocity (V) in terms of distance is obtained (Line 7). Substituting velocity (V) into the standard differential equation of Line 8, and integrating both sides again (Line 9) gives an expression of time (t) in terms of distance (Line 10). Substitution of the known value for X into Line 10 results in the time value for the acceleration path of Line 1. The acceleration path that yielded the smallest time value was taken as the best of these functions for ballistic movement since it required the shortest period of time without decreasing the final velocity.

The second method used linear acceleration paths expressed as functions of time and held distance and final velocity constant so that changes in the time value were caused by manipulating the initial acceleration value. This process is shown in FIG 3 (pp 18-19).

$$a = f(x) \qquad \text{Line 1}$$

$$\therefore \quad a = \frac{dv}{dt} \quad \text{and} \quad dt = \frac{dx}{v} \qquad \text{Line 2}$$

$$\therefore \quad a = v\frac{dv}{dx} \qquad \text{Line 3}$$

$$vdv = adx \qquad \text{Line 4}$$

$$vdv = f(x)dx \qquad \text{Line 5}$$

$$\text{Integrating,} \quad \int_{V_o}^{V} vdv = \int_{X_o}^{X} f(x)dx \qquad \text{Line 6}$$

$$\left[\frac{1}{2}v^2\right]_{V_o}^{V} = \int_{X_o}^{X} f(x)dx \qquad \text{Line 7}$$

$$\text{Substitute V into } dt = \frac{dx}{v} \qquad \text{Line 8}$$

$$\text{Integrating,} \quad \int_{t_o}^{t} dt = \int_{X_o}^{X} \frac{dx}{v} \qquad \text{Line 9}$$

$$t = \int_{X_o}^{X} \frac{dx}{v} \qquad \text{Line 10}$$

Figure 2:   Integration process of the distance method of acceleration path manipulation.
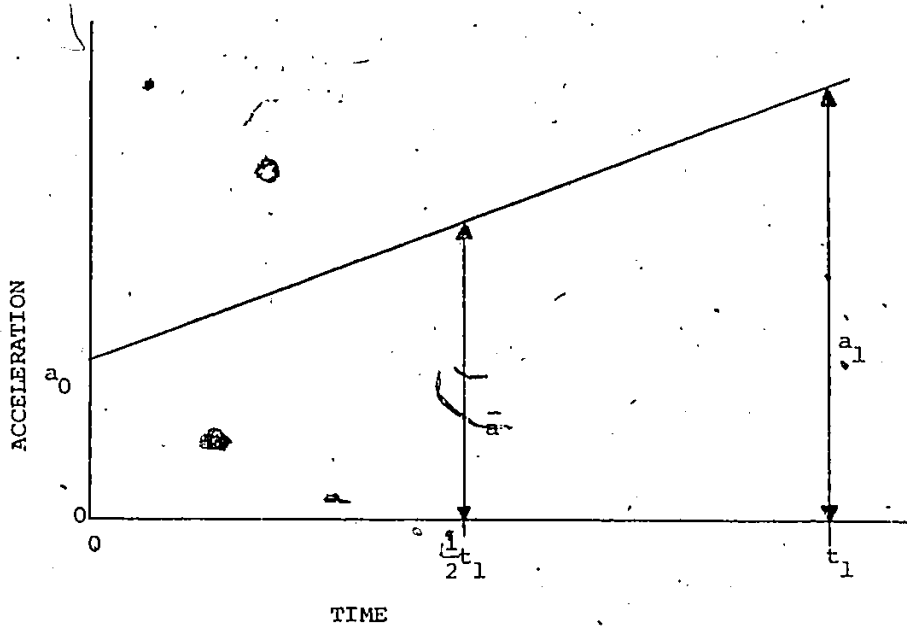
$$a(t) = a_0 + bt$$

$$a_1 = a(t_1) = a_0 + bt_1$$

$$\bar{a} = \frac{1}{2}(a_0 + a_1)$$

$$= \frac{1}{2}(a_0 + a_0 + bt_1)$$

$$= a_0 + \frac{1}{2}bt_1$$

$\bar{a}$ — average acceleration
a_1 — final acceleration
a_0 — initial acceleration
t_1 — final time value

Then $v(t) = \displaystyle\int_0^t (a_0 + bt)\,dt = a_0 t + \frac{1}{2}bt^2$

$x(t) = \displaystyle\int_0^t v(t)\,dt = \frac{1}{2}a_0 t^2 + \frac{1}{6}bt^3$

Thus at $t = t_1$

$$v_1 = a_0 t_1 + \frac{1}{2}bt_1^2$$

$$x_1 = \frac{1}{2}a_0 t_1^2 + \frac{1}{6}bt_1^3$$

where v_1 = final velocity

x_1 = final distance

But $\bar{a} = a_0 + \frac{1}{2}bt_1$, hence $v_1 = \bar{a}t_1$

Also $x_1 = \frac{1}{6}t_1^2(3a_0 + bt_1)$

$\qquad = \frac{1}{6}t_1^2(a_0 + 2a_0 + bt_1)$

$\qquad = \frac{1}{6}t_1^2(a_0 + 2\bar{a})$

$\qquad = \frac{1}{6}t_1^2(a_0 + \frac{2v_1}{t_1})$

Therefore $\quad 6x_1 = t_1^2 a_0 + 2v_1 t_1$

Thus $\quad v_1 = \bar{a}t_1 \qquad\qquad$ where $\quad \bar{a} = \dfrac{a_0 + a_1}{2}$.

and $\quad 6x_1 = a_0 t_1^2 + 2v_1 t_1$

Given $\quad v_1$ and x_1,

Then $\quad a_0 t_1^2 + 2v_1 t_1 - 6x_1 = 0$.

Solving the quadratic equation for t,

$$t_1 = \frac{(v_1^2 + 6a_0 x_1)^{\frac{1}{2}} - v_1}{a_0}$$

Take the root that makes t=0 when x=0. -

Figure 3: The acceleration path manipulation process of the initial
acceleration method.

Since v and x are constants, it can be seen that t will change
as initial acceleration (a) changes. As with the first method, the
acceleration path that resulted in the lowest time value was taken as the
best path of this method since it achieves the lowest time value without
decreasing the final velocity which was held constant.

In order to compare the results of this study with those of Hochmuth and Marhold's, a mathematical modeling design was used that was identical to that of their linearly increasing and decreasing acceleration paths (shown in FIG. 4). In the distance method of the present study, the acceleration paths were expressed as functions of distance rather than time and thus in both methods a constant distance of .46 meters was used instead of a constant time of .25 seconds. In both methods of this study and in Hochmuth and Marhold's, the final velocity was 3.68 meters per second for all trials.

Results and Discussion

The results of the distance method revealed that the (-3) acceleration-distance curve required the shortest movement time (.197 sec.) with progressively longer time periods for curves (-2) to (3). The resulting time value for curve (3) was infinite because the initial velocity and acceleration were zero and therefore no distance could be traveled until an acceleration was achieved and since acceleration was expressed as a function of distance, no acceleration could be achieved until a distance was traveled. Therefore the projectile remained stationary and never achieved the final velocity of 3.68 m/sec. All of these curves are shown in FIG. 5 except for curve (3) which would lie along the abscissa.

Each of the curves in FIG. 5 have the same area and thus the same final velocity. Each of the movements occurred over the same distance (.46 meters). The curves with the greatest initial acceleration allow the shortest movement times.

Hochmuth

Dowling
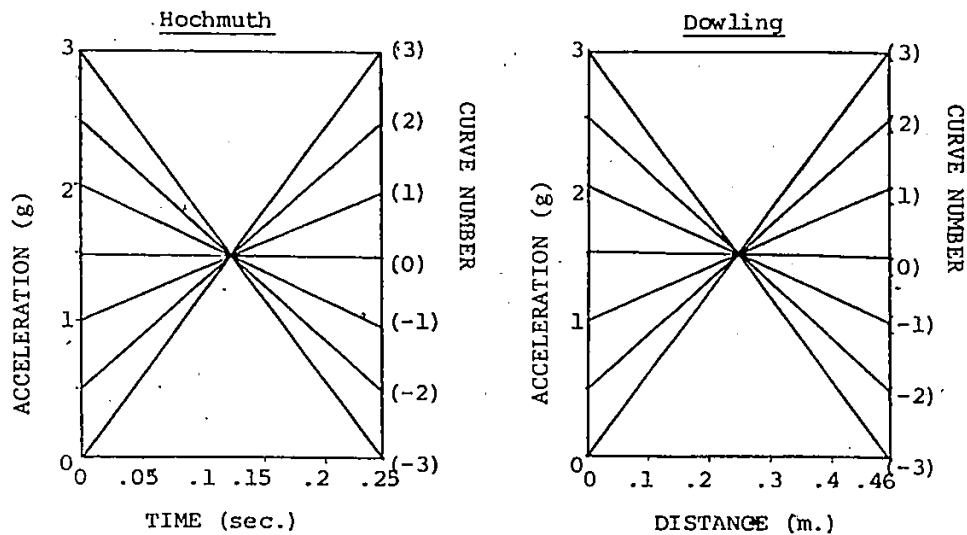
$$a = a_0 + bt$$

$$V = a_0 t + \frac{1}{2}bt^2$$

$$X = \frac{1}{2}a_0 t^2 + \frac{1}{6}bt^3$$

$$a = a_0 + bX$$

$$\frac{1}{2}V^2 = a_0 X + \frac{1}{2}bX^2$$

$$V = (2a_0 X + bX^2)^{\frac{1}{2}}$$

$$t = \int_0^X \frac{dX}{(2a_0 + bX^2)^{\frac{1}{2}}}$$

WHERE

a_0 — initial acceleration

b — slope of acceleration curve

t — time (sec.)

a — acceleration (g)

V — velocity (3.68 m/sec. constant)

X — displacement (m.)

Figure 4: Comparison of the mathematical modeling design of
Hochmuth's and Marhold's with Dowling's first method.
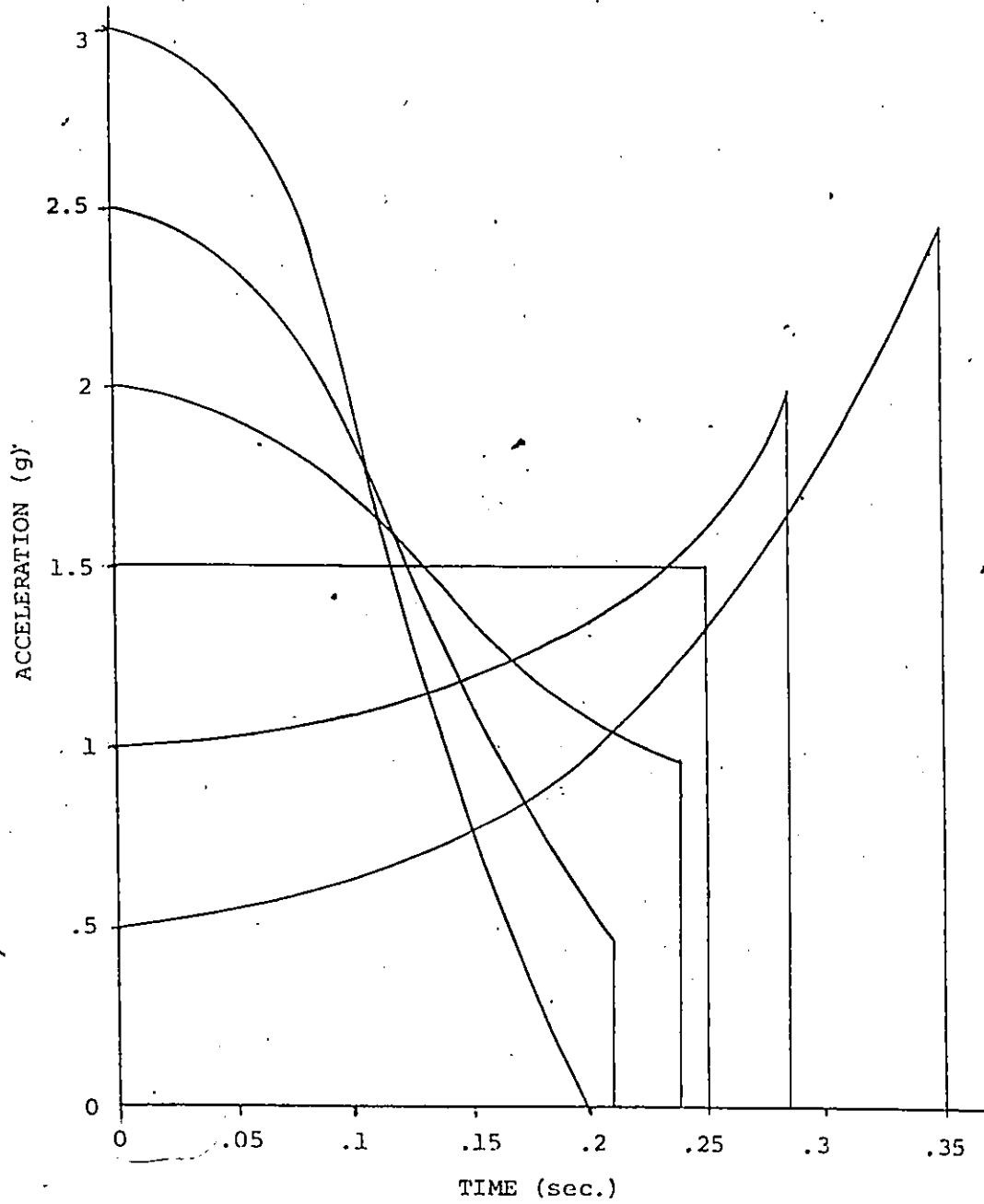
Figure 5:   The resulting acceleration-time curves of the distance method.

The second method of the present study examined the effect that initial acceleration had on movement time and was named the initial acceleration method. The initial acceleration values were the same as the functions of Hochmuth and Marhold and of the distance method of the present study. The resulting functions of this method are shown in FIG. 6.

It can be seen that as initial acceleration was increased the movement time was decreased. Again, when initial acceleration was zero, the the time was infinite as in curve (3) of the distance method.

The results of both methods are in agreement with Hochmuth and Marhold's conclusion that with a decreasing acceleration, the movement is completed in a shorter period of time than with an increasing acceleration. The acceleration functions of this study, however, achieved the lower time values without a decrease in final velocity or distance.

In the initial acceleration method, the curves with the greatest initial acceleration required the least time but they also had the greatest maximum acceleration values (also maximum force assuming mass was constant). When curve (1) is compared to curve (-1) or (2) with (-2) in the first method (FIG. 4), the maximum acceleration values are the same but the initial acceleration values are different. Also the maximum values never achieve the maximum of 3g's as in curve (-3). Thus in order to obtain an optimal path of acceleration, the initial acceleration should be manipulated as in the initial acceleration method but the maximum acceleration should be achieved in each case. This was done using the average acceleration formula of the initial acceleration method.
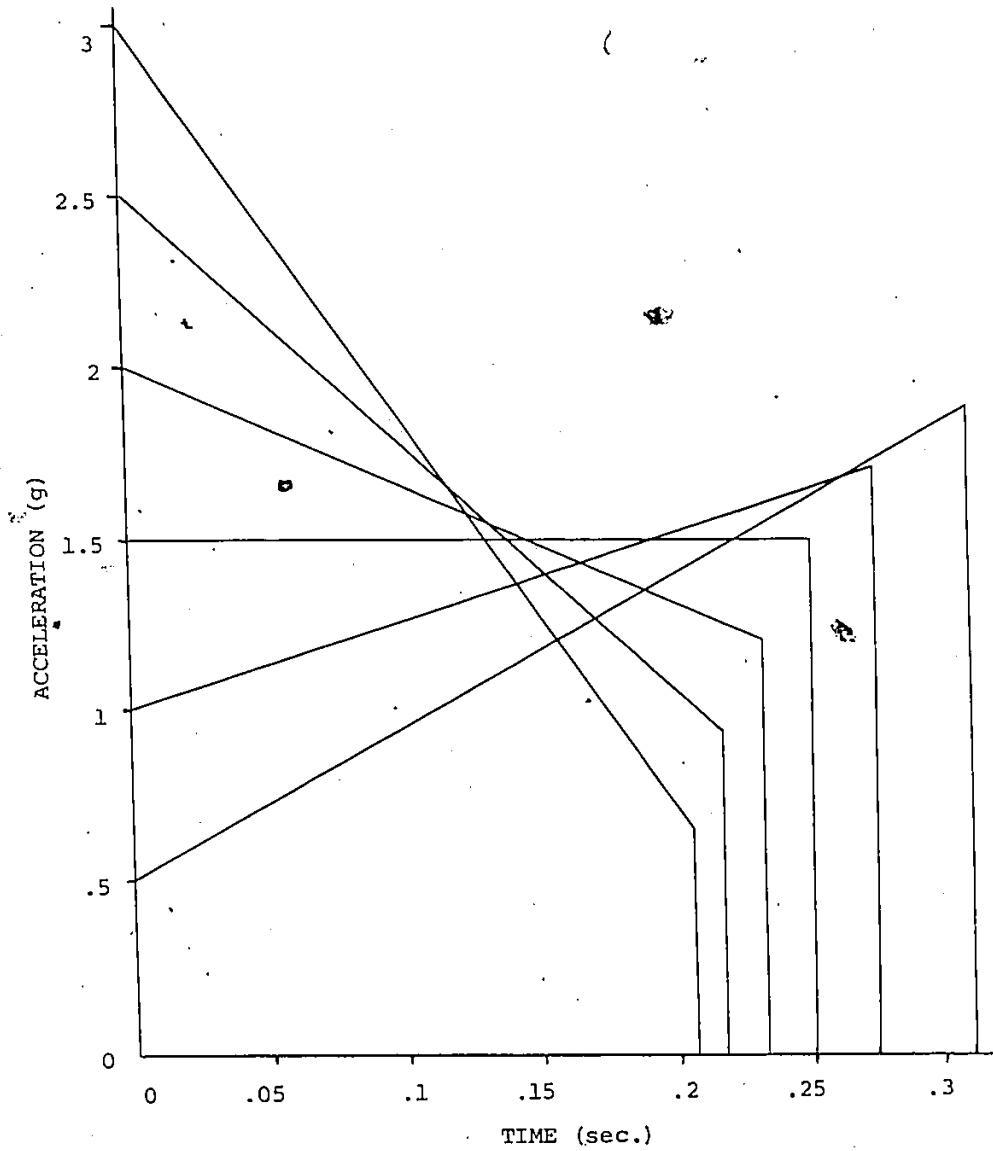
Figure 6:   The resulting acceleration-time curves of the initial
            acceleration method.

$$\bar{a} = \frac{a_o + a_1}{2}$$

$$v_1 = \bar{a}t_1$$

$$t_1 = \frac{v_1}{a_1}$$

Where:

$\bar{a}$ — average acceleration

a_o — initial acceleration

a_1 — final acceleration (3g's)

v_1 — final velocity (3.68 m/sec.)

t_1 — movement time

From FIG. 7, it can be seen that as the initial acceleration is increased, the movement time decreases. The time values are considerably shorter than any of the previous methods with the curve where the initial acceleration is equal to the maximum acceleration of 3g's requiring the minimum time (.125 seconds). This time cannot be improved upon without exceeding the maximum acceleration and thus this is the optimal acceleration path for ballistic movements. As a result, it can be concluded that the optimal acceleration path for ballistic movements is one in which the initial acceleration is equal to the maximum acceleration and is maintained throughout the entire range of motion.

Assuming mass is constant and using Newton's second law,

$$\text{FORCE} = \text{mass} \times \text{acceleration} \qquad (4)$$

this optimal acceleration path is also characteristic of the optimal force path which means that the maximum force must be maintained throughout the entire range of motion.

Due to the contractile properties of muscle, it is impossible to maintain the maximum force of contraction throughout the entire range of motion. The force-velocity relationship of isolated muscle fibers states that the maximum force is exerted when velocity is zero and decreases as

Figure 7: The resulting acceleration-time curves of the maximum
            acceleration method.

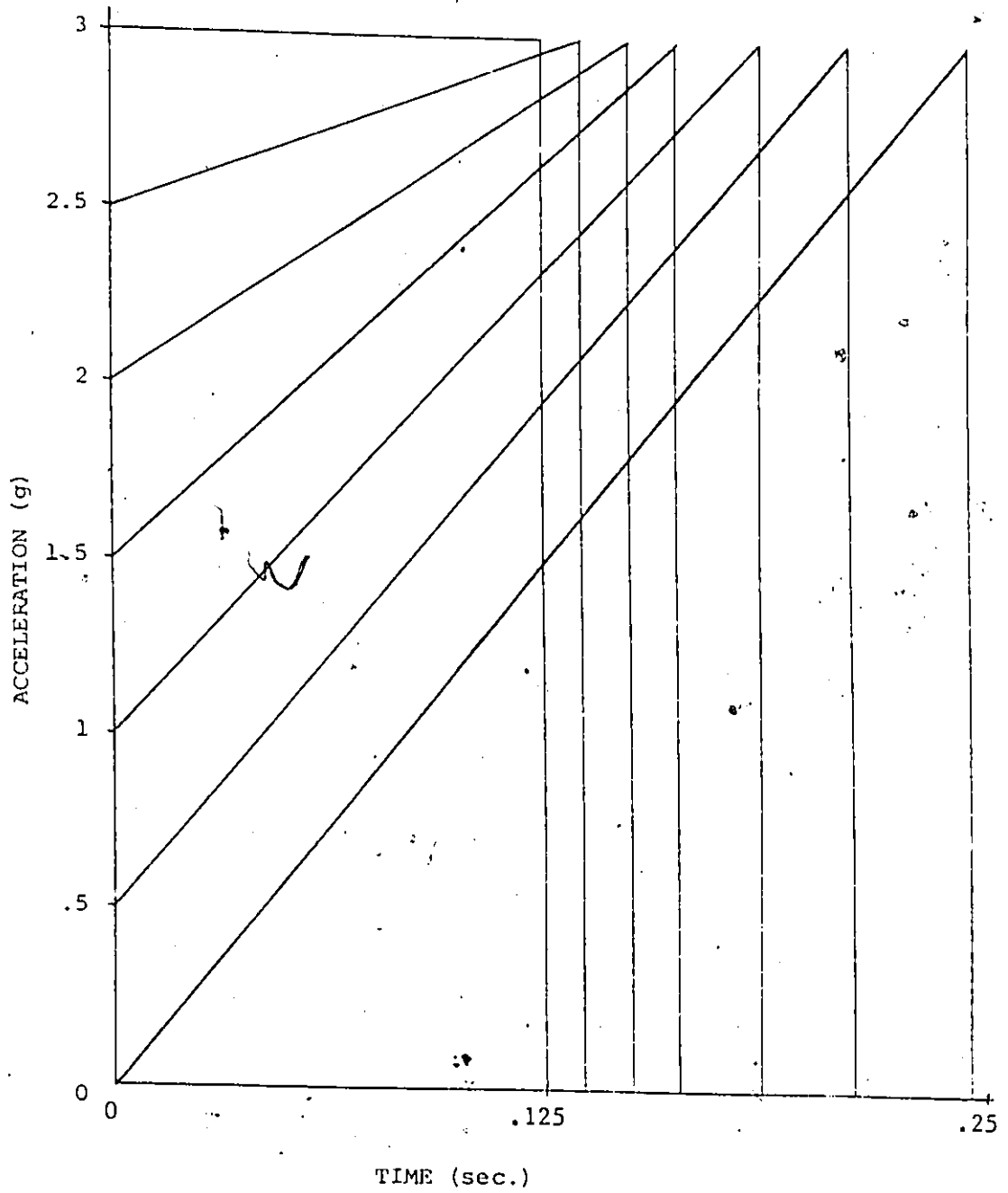velocity increases. The length-tension relationship of muscle states that the maximum force can be generated at resting length and that force decreases as the muscle either shortens or lengthens. In ballistic movements (ie. jumping or throwing) the initial velocity is zero at the start of the movement, and the force-velocity relationship is optimal for maximum force generation but the length is not optimal. The optimal length is not achieved until the end of the movement. Thus the absolute maximum muscle force can never be generated during the movement because at the beginning, the velocity is optimal but the length is not and at the end, the length is optimal but the velocity is not. It may be possible, however, to maintain a constant submaximal force over the entire range of motion. The rectangular acceleration path of the optimum pattern will be followed and the maximum force that the muscle is capable of applying under ideal conditions never has to be achieved (see FIG. 8).

The curved line in FIG. 8 represents the ascending portion of the force-time curve of a vertical jump from a force platform. The velocity is zero at the start of the upward movement and reaches a maximum at the end when force is zero. The shorter rectangle in FIG. 8 has the same area as the curve and thus the same final velocity. If a training device were built to perform according to this rectangle, a person could train according to the optimum pattern. The maximum force does not have to be maintained and neurologically the muscles are trained to perform according to the optimum acceleration path. That is to say that with this type of exercise, the muscles will be training at the same speed that they will be performing at and the muscle will be trained according
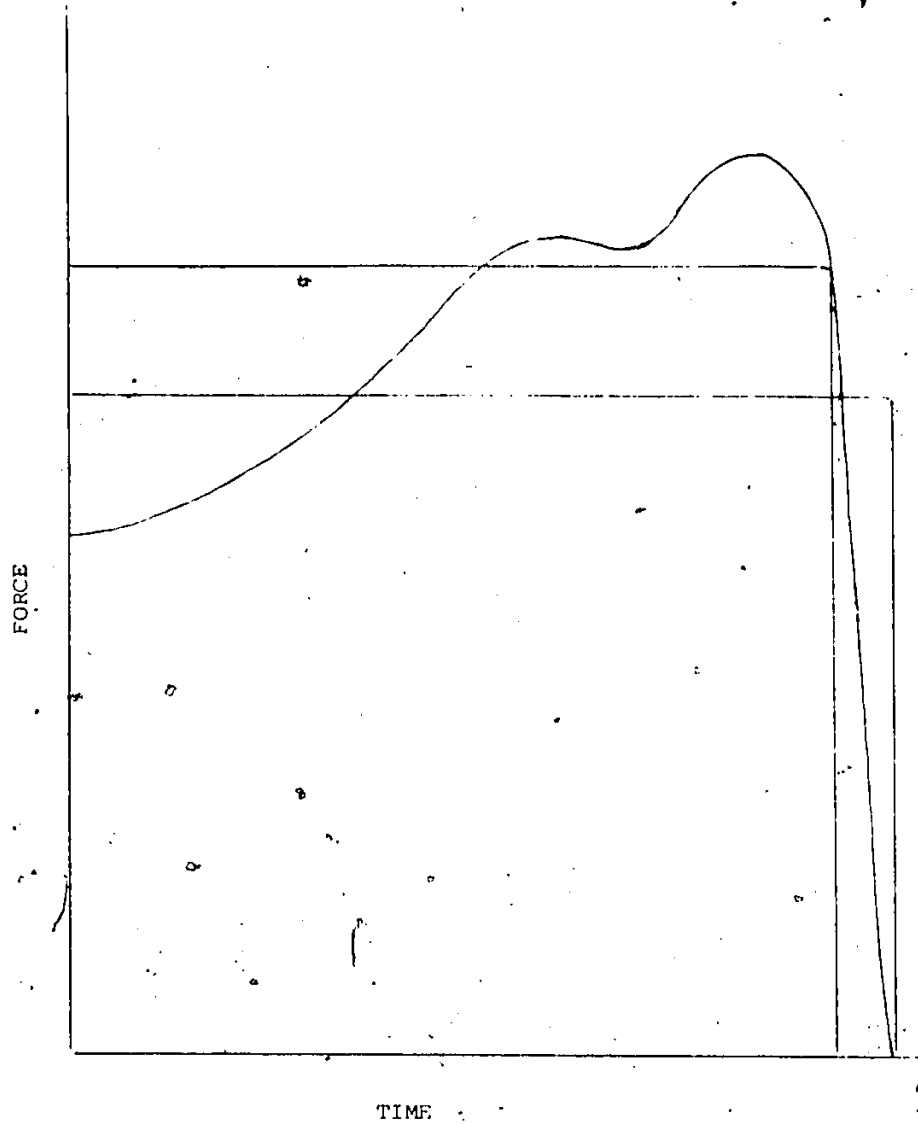
Figure 8: Force-time curves of the ascending portion of the vertical
           jump (curved line) and theoretical acceleration specific
           training curves (rectangles).

to the optimum motion pattern.

As the training program progresses, the rectangle can be altered (similar to increasing the weight in conventional programs) to the taller rectangle in FIG. 8. Here the area is slightly greater than the first and thus a greater final velocity is achieved and the movement time is less. Thus it is possible that this sort of exercise may achieve both criteria and that in order to achieve better perfomances in ballistic movements, an acceleration specific training program is necessary.

Conclusions

From the results of this mathematical modeling study, it can be concluded that a decreasing acceleration path as a function of distance allows a movement to be completed in a shorter period of time than a constant or increasing acceleration path without allowing a decrease in the final velocity. It can also be concluded that as initial acceleration is increased in functions that attain the maximum acceleration, the time of the movement is decreased until the initial acceleration equals the maximum acceleration. Finally it can be concluded that the optimal acceleration path for ballistic movement is one in which the initial acceleration is equal to the maximum acceleration and is maintained throughout the entire range of motion. This maximum acceleration can be determined from the final velocity and movement time of any ballistic movement.

THE DESIGN OF AN

ACCELERATION SPECIFIC TRAINING DEVICE

Introduction

It has been pointed out in the previous chapters that an exercise device that will train athletes for ballistic movements should provide overload (strength adaptation within the muscle) and be capable of accommodating resistance in such a way that an acceleration pattern which allows for a change in velocity from zero to the maximum for each particular athlete (strength adaptation within the nervous system) is followed. This acceleration path must allow the movement to be completed in the least amount of time that the athlete requires to complete the actual movement and be controlled externally so that the optimum (rectangular) acceleration path is followed regardless of the applied force. The acceleration path must also be adjustable so that the final velocity and movement time can be changed to allow the athlete to achieve progressively greater final velocities in progressively shorter time periods (see FIG. 8).

Objectives of the Training Device

1) To externally control the motion of the device so
    that a rectangular (optimal) acceleration path is·
    followed regardless of the applied force of the

user.

2) To be capable of accomodating resistance so that
   the optimal acceleration path is followed while
   providing overload.

3) To be capable of adjustment to allow progressive
   increases in performance as well as to accommodate
   users of differing sizes, strengths, and speeds.

4) To be capable of measuring the applied force and
   provide a written copy of the user's force-time
   record.

Design

To minimize complexity, the exercise device was designed for a simple leg extension exercise (FIG. 9). The device consisted of a moveable cart that slid along a track on ball bearings. Since the motion of the cart was to be controlled regardless of the force applied to it by the user, the cart had to be designed with a force plate so that the user's progress in terms of force application could be measured.

The front of the cart consisted of a machined plate to keep the user's feet from slipping off. The plate fit inside a teflon lined bracket and was attached to a load cell. The purpose of the bracket was to prevent motion of the platform in any direction other than the line of action of the load cell. The purpose of the teflon lining was to reduce friction as much as possible ($\mu = 0.04$) and thus transmit as much of the applied force to the load cell as possible. FIG. 9 shows the device in the early stages of its development. The force application was
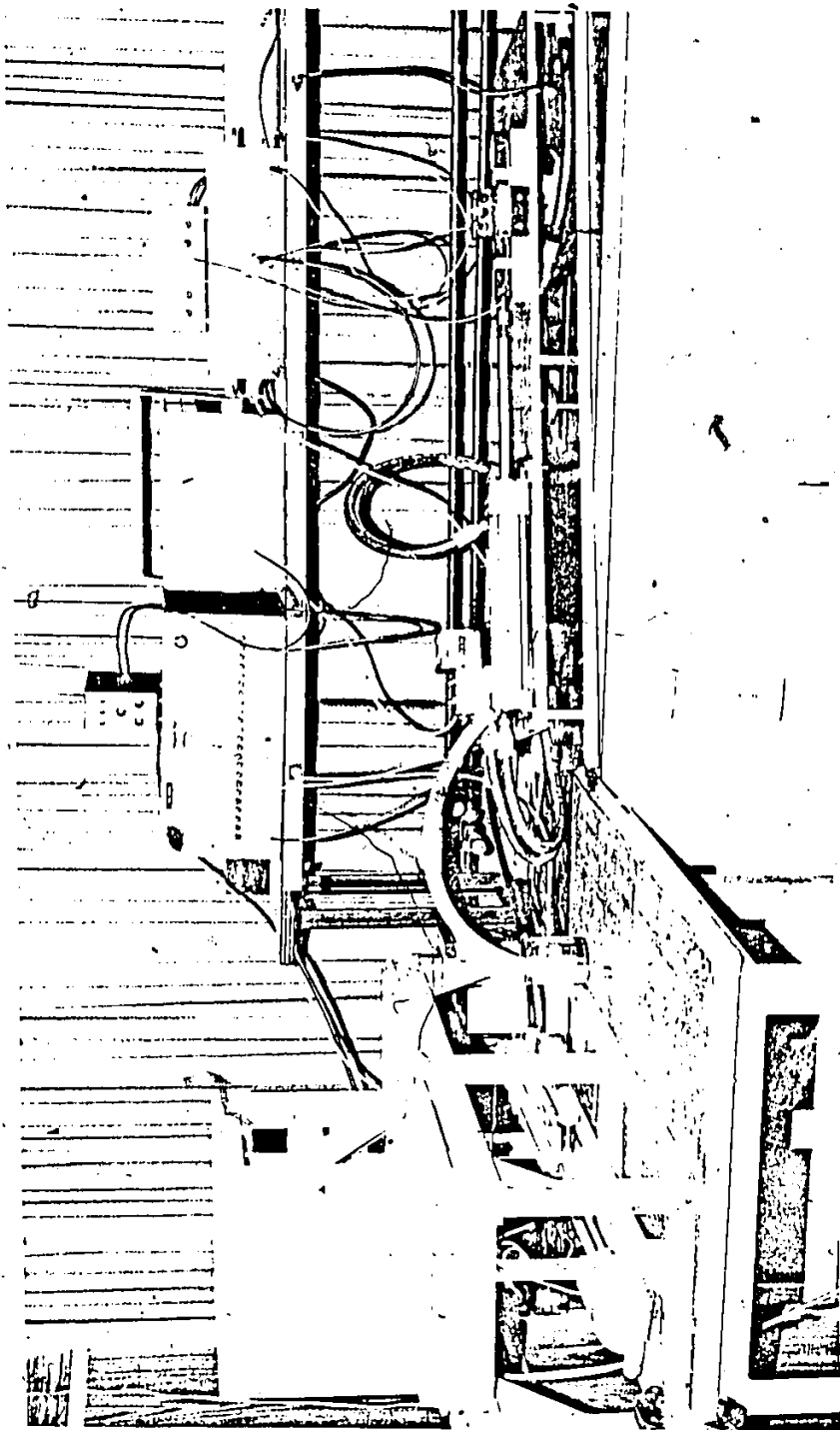
32

Figure 9: The acceleration specific training device (left) and experimental setup.

transformed to an electrical signal by the load cell and recorded on a

Beckman Type RS Dynograph. The force platform was removable from the

cart so that it could be used to measure force applications in the skill

as well as during the training. The force platform then had to be tested

for accuracy in recording applied forces.

Force Platform Testing

The platform was connected to the Beckman Type RS Dynograph and

calibrated using known weights as well as the subject's body weight.

The subject then performed six vertical jumps from the platform while

simultaneously being filmed with a high speed Locam 16 mm camera. The

film speed of the camera was 100 frames per second and the paper speed

of the Dynograph was 50 millimeters per second.

The film was analyzed using a Numonics digitizer from which the 14

segmental end points of the subject were taken in order to determine the

location of the subject's center of gravity in each of the analyzed

frames. The center of gravity was determined via a computer program

based on Dempster's (1955) and Clauser's (1969) data and run on an Apple

II microcomputer.

The force-time curves from the Dynograph were used to obtain the

force-time coordinates for each jump (50/sec.). These force values were

divided by the subject's body mass in order to obtain the acceleration-

time coordinates. A computer program, run on the Apple II microcomputer,

fit a least squares polynomial (14 order) to the data and integrated the

polynomial in order to get a velocity value at take-off for each jump.

This velocity value (V) was used in equation (5) in order to determine

the height of the jump.

$$HEIGHT = V^2/2g \qquad\qquad (5)$$

where g = 9.81 m/sec/sec.

The resulting height value was compared with the vertical displacement of the subject's center of gravity from take-off to the peak height of the jump as determined from the film.

The results revealed a slight underestimation of the actual height achieved in each case and thus a slight error in the force plate. This error is probably due to a small component of the force that was applied at right angles to the line of action of the load cell or is due to the friction of the bracket around the force plate. FIG. 10 shows the force-time curve of trial 1 as well as the velocity-time curve obtained by integrating the 14th order polynomial that was fit to the acceleration-time coordinates determined from the force-time curve. The actual final velocity of the subject's center of gravity was 2.53 m/sec. as determined using equation (5) and the film data. The velocity-time curve of FIG. 10 does not quite reach this value and reflects the slight underestimation of the actual vertical force by the force platform. This underestimation was quite small in each case (generally less than 5%) and since the force-time record is not needed for quantitative analysis but only to judge the progress of the user of the training device, it was felt that the force platform was more than adequate for the task.

Acceleration Control

There are two ways in which to control acceleration. The first method requires feedback and the second requires a microprocessor to program the motion.
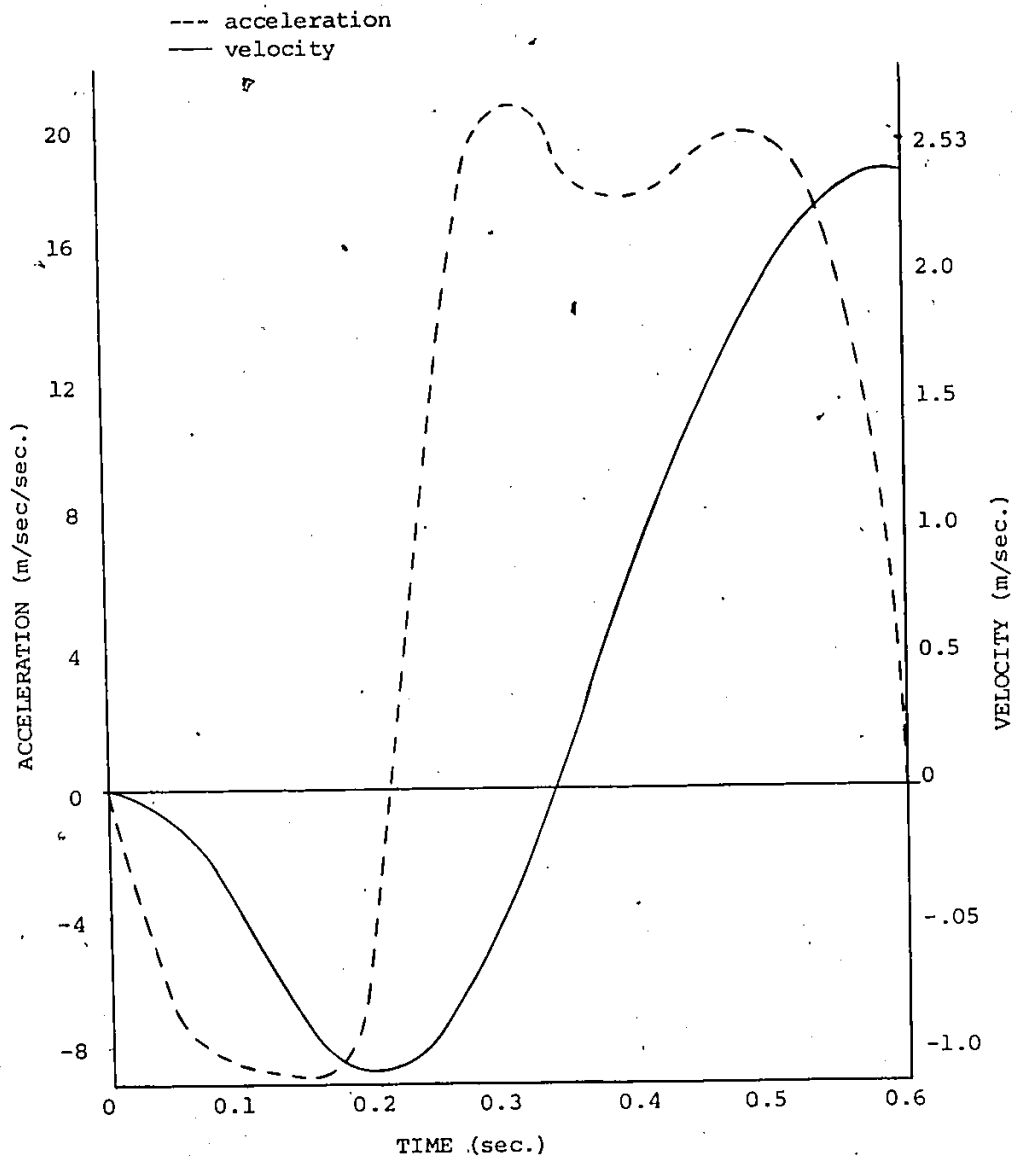
35

Figure 10: Acceleration-time curve obtained from the force-time data and the velocity-time curve obtained from the polynomial fit and integration of the acceleration-time curve.

Feedback Method

In order to control the acceleration of the cart regardless of the applied force by the user, it is necessary first to be able to measure the acceleration of the cart. It is then neccessary to compare that acceleration with the desired acceleration and have feedback of that difference to the controlling mechanism of the cart's motion.

An accelerometer must be mounted on the cart in order to measure the acceleration of the cart. Since the desired acceleration of the cart is to be constant, accelerometers utilizing piezoelectric crystals are insufficient because they only measure constantly changing accelerations. The accelerometer must be designed to incorporate a linear variable differential transducer (LVDT) mounted on a cantilever beam so that as force is applied to accelerate the cart, the cantilever beam bends due to the inertia of the mass of the LVDT and this causes a displacement of the shaft which is measured by the LVDT and converted to an electrical current. This accelerometer must then be calibrated so that the voltage per unit of acceleration can be determined.

Feedback

The electrical signal from the accelerometer must be taken to a signal conditioner (see FIG. 11) where it is compared with the reference signal (desired acceleration) generated by a potentiometer. The voltage from the potentiometer can be varied depending on the desired acceleration value. The signal conditioner filters out any noise in the voltage and subtracts the voltage from the accelerometer (signal B) from the potentiometer (signal A) and produces a new signal (signal A-B) which
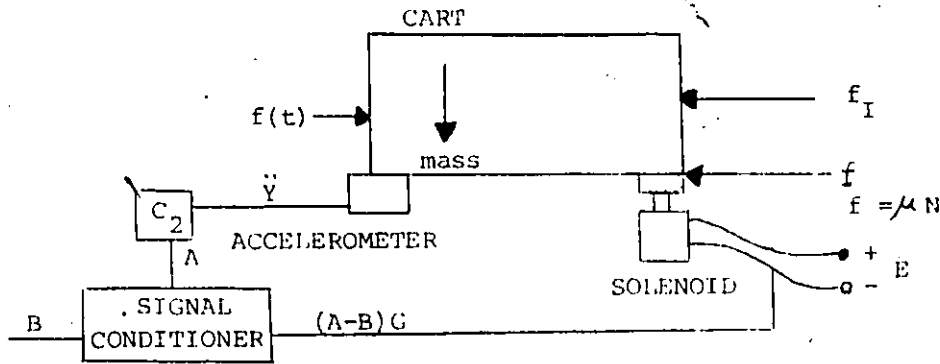
f_I - inertia force

f(t) - applied force

f - force applied by solenoid

μ - coefficient of friction

N - normal force

C_2 - constant

B - signal from accelerometer

A - signal from potentiometer

G - gain

E - current to solenoid

$\ddot{Y}$ - acceleration of cart
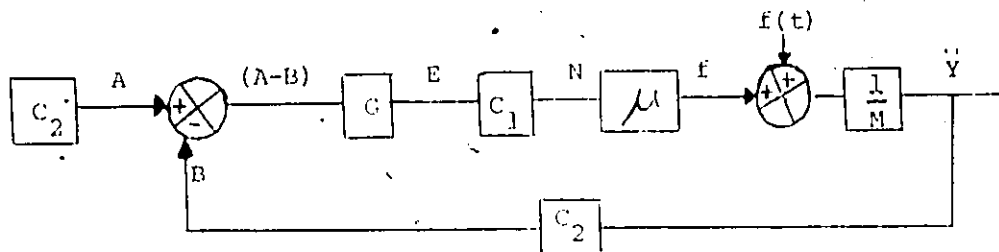
Figure 11: Schematic and block diagrams of the feedback control
system of the solenoid method.

represents the difference between the actual acceleration of the cart. and the desired acceleration. This signal, amplified by a gain, is fed back to the controlling mechanism of the cart so that the difference between the two signals is kept as close to zero as possible.

Controlling Mechanisms

Hydraulic Cylinder Method

It was first thought that the best method for controlling the motion of the cart would be the use of a hydraulic cylinder with an electrically operated servo valve. The servo valve would receive the electrical feedback signal and adjust the flow through the valve orifice and thus the motion of the piston within the hydraulic cylinder and ultimately the motion of the cart. This idea was abandoned when it was realized that the flow through the valve orifice, even when completely open, was not great enough to allow the cart to attain velocity values even close to those achieved in ballistic motions. The use of pneumatic cylinders was also ruled out because air is compressible and thus the motion of the cart could not be controlled regardless of the applied force.

Electrical Solenoid Method

A DC electrical solenoid could be attached to the cart in such a way that the arm of the solenoid contacts the frame of the device. It could be set up in such a way that the solenoid could exert a frictional force against the frame and thus decrease the acceleration of the cart (FIG. 11).

The voltage difference between A and B causes the arm of the solenoid to either extend or retract thus increasing or decreasing the normal

force (N) and similarily affecting the frictional force (f) opposing the motion of the cart.

The Microprocessor Method

Another method of controlling the acceleration of the cart involves the use of an electrical stepping motor, an A-D converter and a microprocessor instead of a feedback control system.

The stepping motor rotates a certain number of degrees for each electrical impulse. If a cable were attached at one end to the cart and the other around an axle rotated by the stepping motor, then the motion of the cart could be controlled by the rate at which the cable is given out by the motor. The rate at which the cable is given out by the motor can be controlled by the rate of electrical impulses given to the motor.

For each electrical impulse given to the motor, the motor rotates a constant number of degrees (one step) and thus the axel gives out a constant length of cable and the cart is allowed to move a constant distance. If the electrical impulses are given at a constant rate (ie. 5000 impulses per second) then the rate of displacement of the cart is constant and a constant velocity is achieved. In order to achieve a constant acceleration, the rate of electrical impulses to the stepping motor must be linearly increased (see FIG. 12).

The microprocessor would contain the program that would send the impulses at the proper times to the stepping motor via the A-D converter The 12 bit A-D converter has the capacity to transmit 100,000 impulses per second but the stepping motors do not have nearly this capacity (max. 20,000 steps per second).
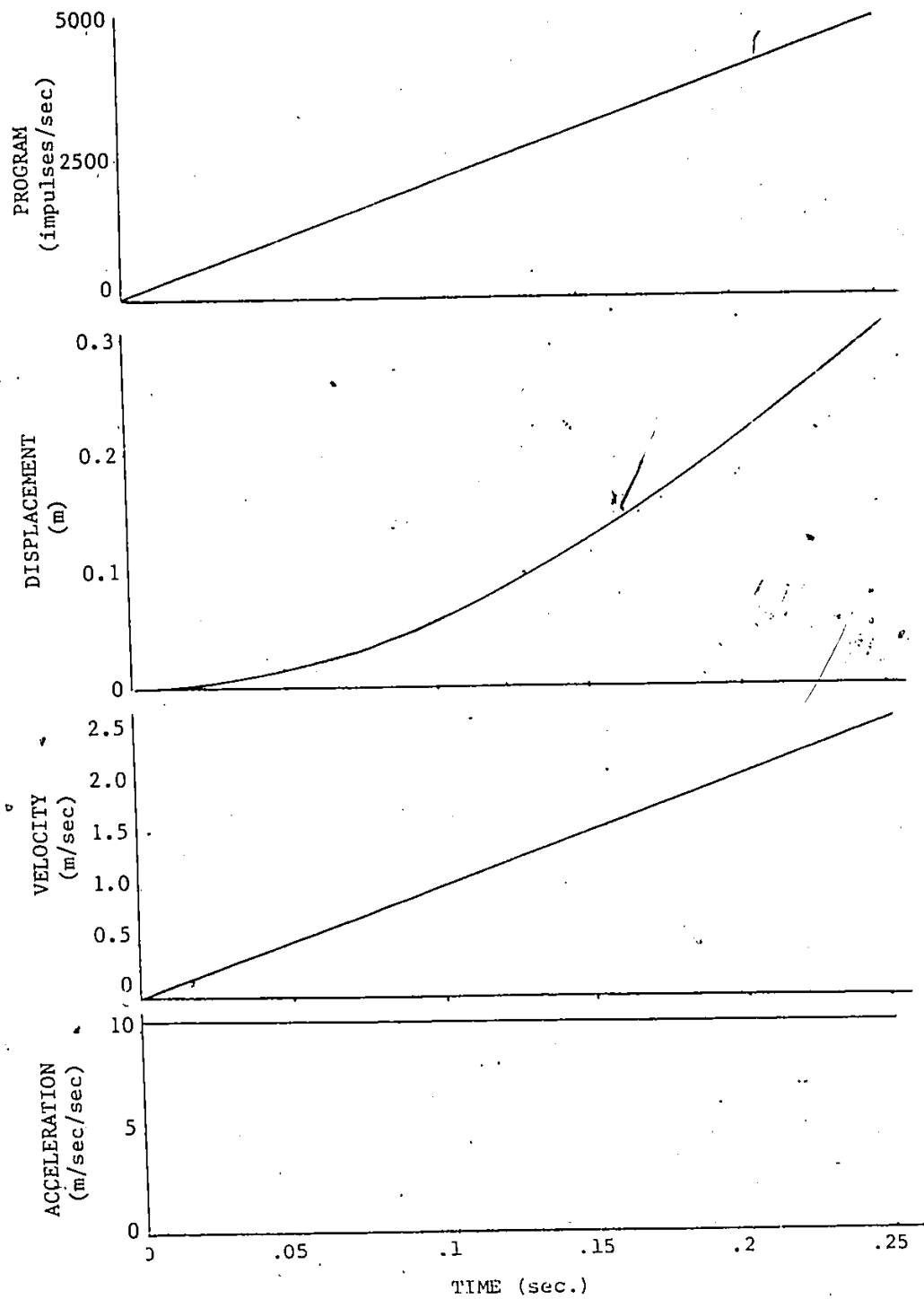
Figure 12: Electrical stepping motor simulation of the vertical
jump (ascending portion) of FIG. 10.

A stepping motor that is capable of 5000 steps per second can produce 1035 steps in a movement of 0.247 seconds in length (such as the ascending phase of the vertical jump in FIG. 10). FIG. 12 shows the simulation of this vertical jump which was used to evaluate the force platform. From the low point of the jump to take-off, the hip was elevated 0.313 meters which was taken as the distance over which the legs were extended. The final velocity was 2.53 meters per second. For constant acceleration (a = c) then velocity = ct (integrating once) and distance = $(ct^2)/2$ (integrating twice).

$$a = \dot{c}$$

$$V = ct \qquad \text{where} \quad V = 2.53 \text{ m/sec.}$$

$$X = (ct)/2 \qquad \text{where} \quad X = 0.313 \text{ m.}$$

$$\text{where} \quad t = 0.247 \text{ sec.}$$

using $\qquad V = ct$

$$0.253 = c(0.247)$$

$$c = 10.24 \text{ m/sec/sec.}$$

Because both the motor and the cart move in discreet steps, the motion of the cart will consist of oscillations. For this movement (X = 0.313 m.) the length of each step is 0.0003 m. (0.313/1035). The longest duration between steps is 7.6 milliseconds. It is thought that the steps will be small enough in both length and duration that the user will not experience any discomfort and it will appear to be one smooth continuous motion.

The major limitaion of this method is the running torque of the stepping motor. The motor must be able to withstand the torque applied

to it by the user via the cable attached to the cart and wrapped around its axle without slipping. In the vertical jump task, the subject exerted forces of over 1800 N against the platform. A stepping motor capable of simulating the motion (FIG. 11) would require an axle radius of 0.00925 m. The torque applied to the motor by the cable would then be 16.65 N-m. The stepping motor which was available and capable of the motion simulation described earlier, had a maximum running torque of 0.434 N-m. Therefore a device could be built to perform according to acceleration specific training principles and would simulate a ballistic movement that exerts a maximum force of less than 50 N.

CHAPTER V

CONCLUSIONS AND RECOMENDATIONS

The purposes of the study were to determine the optimal accelera-
tion path for ballistic movements and design a training device that per-
forms according to that acceleration path. It can be concluded that the
optimal acceleration path for ballistic movements is one in which the
initial acceleration is equal to the maximum acceleration and is main-
tained throughout the entire range of motion.

Three attempts were made to design an acceleration specific train-
ing device as economically as possible. Several different approaches
were taken and in most cases it was felt that a device could be built to
perform according to the developed criteria but in each case the equip-
ment required to achieve these goals was very expensive. The high costs
of the equipment prevented the completion and testing of the device.
FIG. 13 shows the approximate cost breakdown of the three approaches to
designing an acceleration-specific training device. The figures are
based on the equipment that was avialable during the construction of the
device and are therefore only estimates of what the actual prototype
costs may be.

These figures are only meant for comparison between the different methods.

The stepping motor with the microprocessor is probably the most ec-

43

Hydraulic Feedback Method

```
hydraulic cylinder --------------------------------------- $ 300.00
servo valve --------------------------------------------      400.00
LVDT accelerometer -------------------------------------      700.00
signal conditioner -------------------------------------      800.00
servo amplifier ----------------------------------------     1200.00
conditioning amplifier ---------------------------------      800.00
hoses, connections, etc. -------------------------------       75.00
exercise device ----------------------------------------      200.00
TOTAL                                                        4475.00*
```

Solenoid Feedback Method

```
solenoid ------------------------------------------------ $ 250.00
potentiometer ------------------------------------------       25.00
LVDT accelerometer -------------------------------------      700.00
signal conditioner -------------------------------------      800.00
conditioning amplifier ---------------------------------      800.00
exercise device ----------------------------------------      200.00
TOTAL                                                        2525.00*
```

Programmed Stepping Motor Method

```
stepping motor ----------------------------------------- $1200.00
A-D converter ------------------------------------------      150.00
microprocessor -----------------------------------------      300.00
exercise device ----------------------------------------      200.00
TOTAL                                                        1850.00*
```

* 1982 Canadian Dollars

Figure 13: Comparison of the approximate prototype costs of the three methods of acceleration specific training device design.

onomical and may allow the greatest flexability in terms of changing the
acceleration path to suit the needs of different subjects or to simulate
different skills.

The cost of building the acceleration specific training device which
utilizes the electrical stepping motor is not high when compared with
the cost of velocity specific training devices such as the Cybex. Micro-
processors are quite inexpensive and if the lab already has a microcom-
puter, it can be interfaced with the A-D converter and the stepping motor.

The review of literature suggests that there is a strong case
to be made that acceleration specific training may have the greatest
transfer of strength gains from the training program to the performance
of the skill of any training method and when the optimal acceleration
path is followed, it may increase performance more than practice of
the skill itself. When this is coupled with the relatively low cost of
building the device, it is strongly recommended that the device be built
and tested using human subjects to see what adaptations occur due to
training on the device and how these adaptations compare with those of
other methods and simple practice of the skill. FIG. 14 shows the recom-
mended design of the acceleration specific training device.

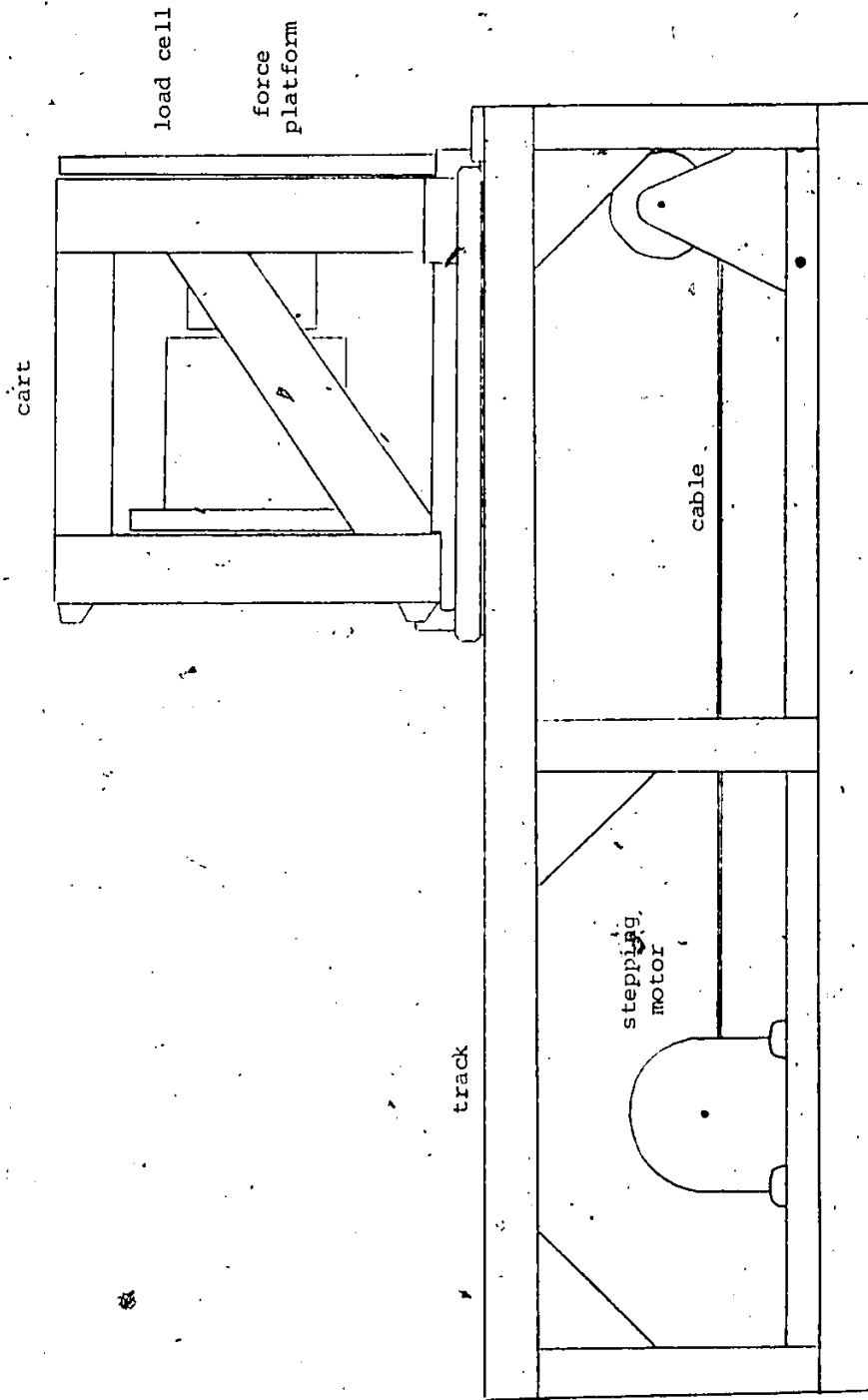load cell

force
platform

cart

track

cable

stepping
motor

Figure 13: Recommended design of an acceleration
specific training device.

REFERENCES

Ariel, G. The ultimate high jump performance. TRACK AND FIELD QUARTERLY
    REVIEW. 77(3):fall 1977.

Baldwin, K., W.W. Winder and J.O. Holloszy. Adaptation of actomyosin
    ATPase in different types of muscle endurance exercise. AMERICAN
    JOURNAL OF PHYSIOLOGY. 229:422-426. 1975.

Beer, F.P. and E.R. Johnston. VECTOR MECHANICS FOR ENGINEERS. McGraw-
    Hill Inc., New York. 1977.

Clauser, C., J. McConville and J. Young. Weight, volume, and centers of
    mass of segments of the human body. (AMRL Technical Report 69-70),
    Wright Patterson Air Force Base, 1969.

Costill, D., R. Sharp and J. Troup. Muscle strength: contributions to
    sprint swimming. SWIMMING WORLD. 21(2):29-34. 1980.

Caiozzo, V., J.J. Perrine and V.R. Edgerton. Alterations in the in vivo
    force-velocity relationship. MEDICINE AND SCIENCE IN SPORTS AND
    12(2):134(abstract) 1980.

Coyle, E.F. and D. Feiring. Muscular power improvements: specificity of
    training velocity. MEDICINE AND SCIENCE IN SPORT AND EXERCISE. 12(2):134
    (abstract). 1980.

Cratty, B.J. MOVEMENT BEHAVIOR AND MOTOR LEARNING. Philadelphia: Lea and
    Febiger. 1973.

Dempster, W. Space requirements of the seated operator (WADC Technical
    Report 55-159), Wright Patterson Air Force Base, 1955.

Desmedt, J.E. Patterns of motor commands during various types of voluntary

movement in man. TRENDS IN NEUROSCIENCES. 3:265-268. 1980.

Desmedt, J.E. and Godaux. Voluntary motor commands in human ballistic

movements. ANN. NEUR. 5:415-421. 1979.

Desmedt, J.E. and E. Godaux. Ballistic contractions in fast or slow human

muscles: discharge patterns of single motor units. JOURNAL OF PHYSIOLOGY.

285:185-196. 1978.

Desmedt, J.E. and E. Godaux. Fast motor units are not preferentially

activated in rapid voluntary contractions in man. NATURE (London).

267:717-719, 1977.

Dowling, J.J. The relationship between time of take-off and vertical

velocity in the Fosbury Flop high jump. UNIVERSITY OF WINDSOR. (unpublished).

1980.

Dowling, J.J. and G.W. Marino. Mathematical modeling to determine accelera-

tion specific training principles. (paper presented at the Ontario Exercise

Physiology annual meeting: January 25, 1982) Collingwood, Ontario.

Ecker, Tom. TRACK AND FIELD TECHNIQUE THROUGH DYNAMICS. (Tafnews Press:

Los Altos, Calif.) 1976.

Gordon, A.M., A.F. Huxley and F.J. Julian. The variation in tension with

sarcomere length in vertebrate muscle fibers. JOURNAL OF PHYSIOLOGY.

184:170, 1966.

Hay, J.G. THE BIOMECHANICS OF SPORT TECHNIQUES. Englewood Cliffs, N.J.:

Prentice Hall Inc. 1973.

Hay, J.G. The Hay technique - ultimate in high jump style? ATHLETIC JOURNAL

April 1975.

Henneman, E., G. Somjen and D. Carpenter. Functional significance of cell

   size in spinal motoneurones. J. NEUROPHYSIOL. 28:650-680. 1965.

Hill, A.V. The heat of shortening and dynamic constants of muscle. PROC.

   ROY. SOC. B. 126.:136-195. 1938.

Hochmuth, G, and G. Marhold. The further development of biomechanical

   principles. in BIOMECHANICS VI-B. ed. by Erling Asmussen and Kurt

   Jorgensen. (University Park Press: Baltimore). p93-106. 1977.

Holman, J.P. EXPERIMENTAL METHODS FOR ENGINEERS. McGraw-Hill Inc.,

   New York. 1971.

Huxley, A.F. Muscular contraction. JOURNAL OF PHYSIOLOGY. 243:1-43. 1974.

Lindh, M. Increase of muscle strength from isometric quadriceps exercises

   at different knee angles. SCAND. J. REHAB. MED. 11:33-36, 1979.

MacDougall, J.D., G.C.B. Elder, D.G. Sale, J.R. Moroz and J.R. Sutton.

   Effects of strength training and immobilization on human muscle fibres.

   EUR. J. APPL. PHYSIOL. 43:25-34, 1980.

MacDougall, J.D., D.G. Sale, J.R. Moroz, G.C.B. Elder, J.R. Sutton and

   H. Howald. Mitochondrial volume density in human skeletal muscle following

   heavy resistance training. MED. SCI. SPORTS. 11:164-166, 1979.

MacDougall, J.D., G.R. Ward, D.G. Sale and J.R. Sutton. Biochemical

   adaptation of human skeletal muscle to heavy resistance training and

   immobilization. JOURNAL OF APPLIED PHYSIOLOGY. 43:700-703, 1977.

Mariani, J., B. Maton and S. Bouisset. Motor unit recruitment and force in

   the course of voluntary movements. BIOMECHANICS VI-A ed. Erling Asmussen

   and Kurt Jorgenson. (University Park Press: Baltimore) p153-159, 1978.

Marteniuk, R.G. INFORMATION PROCESSING IN MOTOR SKILLS. New York: Holt,

   Rinehart and Winston. 1976.

Moffroid, M. and R.H. Whipple. Specificity of exercise. PHYS. THER. 50:1693-1699, 1970.

Rash, P.J. and C.E. Morehouse. Effect of static and dynamic exercise on muscular strength and hypertrophy. JOURNAL OF APPLIED PHYSIOLOGY. 11:29-34 1957.

Sale, D. and D. MacDougall. Specificity in strength training: a review for the coach and athlete. CANADIAN JOURNAL OF APPLIED SPORT SCIENCES. :87-92 1981.

Schmidtbleicher, D. and G. Haralambie. Changes in contractile properties of muscle after strength training in man. EUROPEAN JOURNAL OF APPLIED PHYSIOLOGY. 46:221-228, 1981.

Solmons, S, and F.A. Sréter. Significance of impulse activity in the transformation of skeletal muscle type. NATURE. 263:30-34, 1976.

Staudt, H.W., G.U. Exner and D. Pette. Effects of short term, high intensity (sprint) training on some contractile and metabolic character- istics of fast and slow muscle of the rat. PFLUGERS ARCH. 344:159-168, 1973.

Taub, E. and A.J. Berman. Movement and learning in the absence of sensory feedback. In S.J. Freedman (ed.), THE NEUROPSYCHOLOGY OF SPATIALLY ORIENTED BEHAVIOR. Homewood, Ill.: Dorsey Press. 1968.

Thorstensson, A., B. Hulten, W. von Doben and J. Karlson. Effect of strength training on enzyme activities and fiber characteristics in human skeletal muscle. ACTA PHYSIOL. SCAND. 96:392-398, 1976.

Wilkie, D.R. The relation between force and velocity in human skeletal muscle. JOURNAL OF PHYSIOLOGY. 110:249-280, 1950.

VITA AUCTORIS

James J. Dowling

Date and Place of Birth:

July 28, 1956, Toronto, Ontario, Canada.

Education:

Honours Secondary School Graduation Diploma
Leaside High School, 1975.

Honours Bachelor Degree of Human Kinetics (1st class)
The University of Windsor, 1981.

Professional Positions Held:

Teaching Assistant, University of Windsor, 1981-82.

Computer Technician, Baseball Canada, 1982.

Academic Awards:

President's Roll of Scholars, University of Windsor, 1978-79.

President's Roll of Scholars, University of Windsor, 1979-80

Ontario Graduate Scholarship, 1982-

Presentations and Publications of Research:

Mathematical Modeling to Determine Acceleration Specfic
Training Principles. J. J. Dowling and G. W. Marino. Presented
at the Ontario Exercise Physiology Annual Meeting, Collingwood,
Ontario, January 25, 1982.

Mathematical Modeling to Determine Acceleration Specific
Training Principles. J. J. Dowling and G. W. Marino. Canadian
Society of Biomechanics. (Published)

51