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Effects of load and task duration on selected kinematic variables during a manual materials handling task on an inclined surface.

Ronald David. Henderson
University of Windsor

Effects of Load and Task Duration on Selected Kinematic Variables During a Manual Materials Handling Task on an Inclined Surface

by

Ronald David Henderson

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ABSTRACT

The purpose of this study was to examine the effects of both load and task duration on stride length, stride period, velocity (calculated in m/s and statures/second), cadence, elbow angle, arm angle and hip angle of the human body during a manual materials handling task on an inclined surface.

Eight male subjects (mean age 22.58 ±2.42 years) were used as subjects in this study. Each subject was required to repeatedly ascend and descend a 7.47 m runway inclined to a 9.41° slope, carrying a load on each ascent, for a period of fifteen minutes. Ascents began at thirty second intervals. The three load conditions used in this study were 6.25 kg, 11.25 kg and 18.25 kg.

The subjects' stride lengths and stride periods decreased significantly when ascending a 9.41° inclined surface with the 18.25 kg load. The subjects' cadence increased significantly when ascending the inclined surface with the 18.25 kg load.

The elbow angles of the subjects significantly increased as they ascended the inclined surface with the 18.25 kg load. The elbow angles of the subjects were also significantly different when measured at 0, 50 and 100 percent of the subjects' stride length.

The arm angles of the subjects significantly decreased as they ascended the inclined surface with the 18.25 kg load. The arm angles of the subjects were also significantly different when measured at 0, 50 and 100 percent of the subjects' stride length.

The results of this study suggest that changes in stride length, stride period, cadence, elbow angle, arm angle and hip angle occurred when completing a manual materials handling task on a 9.41° inclined surface. The results indicate that these changes are dependent on the mass of the load being handled.

Based on the results of this study in the completions of the required task, which was 15 minutes in duration, time does not affect any of the reported gait characteristics or body positions.

DEDICATIONS

I would like to dedicate this work to Eva Henderson and Eileen Parish. Their spirit, courage and strength has been a source of inspiration for me throughout my life.

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Without the love, support and continuous encouragement of my Mother, Father and Brother I would not have had the courage to leave home and follow my aspiration to attend university.

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LIST OF ABBREVIATIONS

AA(0)	Arm angle 0 (at 0 percent of stride length)
AA(50)	Arm angle 50 (at 50 percent of stride length)
AA(100)	Arm angle 100 (at 100 percent of stride length)
C	Cadence
EA(0)	Elbow angle 0 (at 0 percent of stride length)
EA(50)	Elbow angle 50 (at 50 percent of stride length)
EA(100)	Elbow angle 100 (at 100 percent of stride length)
HA(0)	Hip angle 0 (at 0 percent of stride length)
HA(50)	Hip angle 50 (at 50 percent of stride length)
HA(100)	Hip angle 100 (at 100 percent of stride length)
HT	Subject's height
L1	Value specified for load 1 = 6.25 kg
L2	Value specified for load 2 = 11.25 kg
L3	Value specified for load 3 = 18.25 kg
MMH	Manual Materials Handling
SL	Stride length
SP	Stride period
T1	Time duration to first data set collection = 30 seconds
T2	Time duration to second data set collection = 14.5 minutes
V1	Velocity (metres/second)
V2	Velocity (statures/second)

CHAPTER I

Introduction

Manual materials handling (MMH) tasks have been recognized as a major source of musculoskeletal overexertion injuries at the workplace. Employers in Ontario paid $2,528 million dollars in assessments to the Workers' Compensation Board of Ontario (WCB) in 1992. In turn, injured workers received $3,218 million dollars in benefits and benefit liability from the WCB. In total 377,019 injuries were reported to the WCB in 1992 (Workers' Compensation Board of Ontario, 1992). In the United States, the National Institute for Occupational Safety and Health (NIOSH) reported that MMH injuries accounted for one in every four industrial accidents in 1981 (NIOSH, 1981). Sources in the United States report 400,000 workers suffer disabling back injuries yearly (prior to 1978); as a result, direct costs to industry were reportedly $20 billion dollars annually (Jiang and Ayoub, 1987). In 1985 the USF&G insurance company reported that 28% of all workers' compensation claims were the result of back injuries and $151,020,582 in compensation awards were paid as a result of lifting injuries (Boyd and Cartier, 1990).

Overexertion injuries can result when workers are required to perform at levels beyond their physical capacities. Therefore, to prevent these types of injuries from occurring, tasks must be designed to account for the physical capacities and limitations of individuals (Garg and Ayoub, 1980; Genaidy and Asfour, 1987; Genaidy, Asfour, Mital and Tritar, 1988; Snook, 1978; Snook and Ciriello, 1990). Research has suggested that one-third of all MMH injuries could be prevented if tasks were designed to accommodate the abilities of 75% of the user population (Boyd et al., 1990; Snook 1978; Snook and Ciriello, 1991).

Since 1970 there has been an increase in research by ergonomists, physiologists and biomechanists in an attempt to evaluate human MMH capacities and limitations (Nicholson, 1989; Smith, Smith and McLaughlin, 1982). MMH studies can be categorized into 4 types: physiological, biomechanical, psychophysical and epidemiological. The main focus of research in these areas has been the prevention of injuries related to MMH tasks. Unfortunately there is little agreement in the conclusions reported by researchers in the various disciplines.

As a result of variations in reported findings, guidelines for determining physical capabilities and limitations, when completing MMH tasks, are generally based on only one research discipline and do not consider environmental factors or associated task requirements; for example, the mechanics of walking while carrying a load.

Several models have been developed to predict 'safe' or 'acceptable' limits for materials handled by workers

(Nicholson, 1989). According to Nicholson (1989) the research in the area of MMH can be categorized into two groups, 'safe' lifting limits and 'acceptable' lifting limits. Nicholson defines safe lifting limits as, "Based on biomechanical and/or physiological criteria, which are considered potentially unsafe to exceed". Acceptable limits are based on psychophysical research and are "...derived from what a worker is willing to handle". The NIOSH Lifting Guidelines (NIOSH, 1981) and guidelines suggested by Snook (1978) and Snook et al. (1990, 1991) are examples of these types of studies.

Historically the study of gait has focused on areas such as normal gait, pathological gait, or gait characteristics of specific groups like the elderly. The study of human gait is extremely complex because of the interrelations between the numerous gait parameters that can be observed (Andriacchi, Ogle and Galante, 1977). People, by nature, walk differently from each other, by choice and because of restrictions imposed by their environment. For example, workers are often required to walk at speeds to match conveyors or other machinery or equipment that is used in industrial sectors. Despite the complexity of human gait, people will walk in a repeatable and characteristic manner. Because of the associations between walking speed and gait parameters, walking speed becomes the dominant factor affecting gait in situations where a person's walking speed is controlled by the environment.

As a result of the diversity of job tasks and workplace environments a means for determining the physical requirements of MMH tasks based on stresses imposed on the musculoskeletal system, including the structures directly involved in the activity (lifting, lowering, pushing, pulling or carrying) and the indirect structures involved in body functions (walking, climbing or standing), is required.

Statement of the Problem

The purpose of this study was to examine the effects of both load and task duration on stride length, stride period, velocity (measured in m/s and statures/second), cadence, elbow angle, arm angle and hip angle of the human body during a manual materials handling task on an inclined surface.

Definitions

Table 1 lists definitions to clarify the terms used in this study.

Table 1. Definitions of Terms

Term	Definition
Manual Materials Handling	The unaided human acts of lifting, lowering, pushing, pulling, carrying or holding of an object having definable form and mass repetitively (equal to or greater than once every five minutes) for a specified length of time (Genaidy et al., 1988, p. 319).
Plane of progression	The vertical plane along which the centre of mass of the body moves during the stride period (Winter, 1988, p. 2).
Stride length	The horizontal distance covered along the plane of progression during one stride; it is the distance covered from initial contact to initial contact of the same foot expressed in metres (Winter, 1988, p. 4).
Stride period	The period of time for two steps, in seconds, and is measured from an event of one foot to the subsequent occurrence of the same foot (Winter, 1988, p. 3).
Velocity	The average speed of the body along the plane of progression measured for one stride period. Expressed in metres per second (m/s) or, when normalized for subject height, statures per second (statures/s).
Cadence	The number of steps per unit of time, expressed in steps/minute. Cadence (steps/min) = 120/stride period (seconds) (Winter, 1988, p. 4).

Table 1. Definitions of Terms - Continued

Natural or Free cadence

The cadence that the subject or patient achieves when given instructions to walk as naturally or freely as possible (Winter 1988, p. 4).

Elbow angle

The angle between the arm and the forearm.

Arm angle

The angle between the coronal plane of the body and the arm.

Hip angle

The angle between the thigh and the trunk.

Hypotheses

The following hypotheses, related to the dependent variables in this study, were tested:

Hypothesis 1

H_0= SL (L1) equals SL (L2) equals SL (L3)
H_1= SL (L1) is not equal to SL (L2) is not equal to SL (L3)

Hypothesis 2

H_0= SL (T1) equals SL (T2)
H_1= SL (T1) is not equal to SL (T2)

Hypothesis 3

H_0= SP (L1) equals SP (L2) equals SP (L3)
H_1= SP (L1) is not equal to SP (L2) is not equal to SP (L3)

Hypothesis 4

H_0= SP (T1) equals SP (T2)
H_1= SP (T1) is not equal to SP (T2)

Hypothesis 5

H_0= V1 (L1) equals V1 (L2) equals V1 (L3)
H_1= V1 (L1) is not equal to V1 (L2) is not equal to V1 (L3)

Hypothesis 6

H_0= V1 (T1) equals V1 (T2)
H_1= V1 (T1) is not equal to V1 (T2)

Hypothesis 7

H_0= V2 (L1) equals V2 (L2) equals V2 (L3)
H_1= V2 (L1) is not equal to V2 (L2) is not equal to V2 (L3)

Hypothesis 8

H_0= V2 (T1) equals V2 (T2)
H_1= V2 (T1) is not equal to V2 (T2)

Hypothesis 9

H_0= C (L1) equals C (L2) equals C (L3)
H_1= C (L1) is not equal to C (L2) is not equal to C (L3)

Hypothesis 10

H_0= C (T1) equals C (T2)
H_1= C (T1) is not equal to C (T2)

Hypothesis 11

H_0= EA (L1) equals EA (L2) equals EA (L3)
H_1= EA (L1) is not equal to EA (L2) is not equal to EA (L3)

Hypothesis 12

H_0= EA(0) (T1) equals EA(0) (T2)
H_1= EA(0) (T1) is not equal to EA(0) (T2)

Hypothesis 13

H_0= AA (L1) equals AA (L2) equals AA (L3)
H_1= AA (L1) is not equal to AA (L2) is not equal to AA (L3)

Hypothesis 14

H_0= AA (T1) equals AA (T2)
H_1= AA (T1) is not equal to AA (T2)

Hypothesis 15

H_0= HA (L1) equals HA (L2) equals HA (L3)
H_1= HA (L1) is not equal to HA (L2) is not equal to HA (L3)

Hypothesis 16

H_0= HA (T1) equals HA (T2)
H_1= HA (T1) is not equal to HA (T2)

CHAPTER II

Review of Literature

As previously reported, manual materials handling (MMH) tasks have been recognized as a major source of overexertion injuries in industry (NIOSH, 1981). The National Institute for Occupational Safety and Health has reported that, in the United States, MMH injuries accounted for one in every four industrial accidents in 1981.

Manual materials handling tasks have been defined by Genaidy et al. (1988) as:

> The unaided human acts of lifting, lowering, pushing, pulling, carrying or holding of an object having definable form and mass repetitively (equal to or greater than once every five minutes) for a specified length of time. (p. 319)

Since 1970 there has been an increase in research by ergonomists, physiologists and biomechanists in an attempt to evaluate human MMH capacities and limitations (Nicholson, 1989; Smith et al., 1982). Generally, MMH studies can be categorized into 4 types: physiological, biomechanical, psychophysical and epidemiological. Physiological research focuses on the measurement of metabolic responses to MMH. Heart rate and oxygen consumption are commonly measured in physiological studies. Kinematic variables such as stride rate, stride length and walking velocity; and kinetic variables such as force, power and mechanical work are used in biomechanical research. The psychophysical approach applies subjective estimates to examine the relationship(s) between sensations and their physical stimuli (Snook, 1978). The epidemiological approach identifies the incident, distribution and potential controls of injuries (Jiang and Mital, 1986).

Unfortunately there is little agreement in the conclusions reported by researchers in the various disciplines. Garg et al. (1980) reviewed results from physiological, biomechanical and psychophysical studies of MMH tasks and concluded that:

> 1. The recommendations based on physiological, biomechanical and psychophysical studies are not in agreement.
>
> 2. The maximum permissable weights according to psychophysical studies are lower than those according to biomechanical fatigue criteria.
>
> 3. The psychophysical fatigue criteria, as compared to physiological fatigue criteria, will result in greater work loads at greater lifting frequencies.

The history of MMH research includes research in both physiological and biomechanical disciplines. Martin and Nelson (1986) summarized the contribution of each discipline in MMH research:

While the physiological responses of individuals to load carrying has been studied in some detail, there has been little research focused on the mechanical consequences of load carrying during locomotion activities. This is unfortunate since the results of biomechanical evaluations would certainly compliment those of the physiological analysis, and would provide greater insight into the responses of individuals to load carrying. (p. 1142)

Past research on MMH, specifically load carriage, is dominated by physiologically based assessments of body responses to increased load carriage requirements (Martin et al., 1986). Generally, biomechanically based MMH research has focused on the study of lifting tasks only. This neglects the possible compounding effects of lifting and carrying loads and environmental factors associated with workplace designs.

Physiological theories have been applied in many studies focusing on the energy expenditures of MMH tasks. One of the earliest studies was conducted by Cathcart, Richardson and Campbell in 1923. In their study energy expenditures, as a function of load, were used to determine optimal load values for marching soldiers (as cited in Pimental and Pandolf, 1979).

From the available studies, focusing on energy expenditures in MMH tasks, equations have been developed to predict the physical requirements (including energy expenditures) under general and specific MMH tasks. However, the accuracy of such equations is questionable.

Many factors affect energy expenditures in MMH tasks. As a result of the exclusion of factors and inaccuracies in the method(s) used general or universal applications of these equations may lead to incorrect conclusions (Pimental et al., 1979).

For more than 70 years research has continued in an attempt to develop an equation(s) to accurately and effectively predict the energy expenditures of MMH tasks (Asfour, Genaidy and Mital, 1988; Genaidy et al., 1987).

Over the past number of years several groups of researchers have used physiologically based or biomechanically based methods for determining energy expenditures. These assessment methods have been used either exclusively or in combination with each other to determine energy expenditures in MMH tasks.

In a study based solely on the biomechanical assessments of MMH, Kinoshita (1985) examined the effects of carrying loads, by means of two different carrying systems, on selected kinematic measures during the support phase of gait. Ten male subjects were required to walk 20 metres, at a controlled pace of 4.5 ±0.3 km/hr, under each of the following conditions:

1. Normal walking without any external load.
2. 20% of the body weight carried using a backpack system.
3. 40% of the body weight carried using a backpack system.

4. 20% of the body weight carried using a double backpack system.

5. 40% of the body weight carried using a double backpack system.

> The following conclusions were reported:
>
> More significant changes in body positions and gait characteristics were observed while carrying the heavy load compared with the light load, regardless of the carrying system employed, indicating that the risk of encountering stress related injuries is considerably greater as the load increased in magnitude. (p. 1359)
>
> The body positions and gait characteristics for the doublepack condition were nearer to those for normal walking than for the backpack condition, suggesting that the doublepack system was biomechanically more effective than the conventional backpack system for carrying the loads investigated. (p. 1359)

In a study by Gordon, Goslin, Graham and Hoare (1983) subjects were required to walk on a treadmill for ten minutes at a 10% grade and a constant speed of 1.34 m/s. While performing this task subjects were randomly assigned loads to be carried on a backpack. The loads ranged from an empty backpack to 40% of the subjects body weight (in 10% groupings). The results of their study indicated that vertical power output, heart rate, rating of perceived exertion, oxygen uptake and oxygen uptake (as a percentage of predicted maximum) all increased linearly as the load increased. Additionally, Cavanagh and Kram (1985) have reported the energy cost of walking up hill, without a load, is 1.6 cal/m/kg. Studies of manual materials handling tasks have historically focused on predicting acceptable weights that can be safely handled (lifted, carried, pushed or pulled). The analysis of lifting techniques, energy expenditure, and perceived physical effort are required to achieve the goal of protecting workers from injury. However, the working environment must be extended beyond the interaction between the object and the person handling the object. The physical environment of the workplace can greatly effect the ability of the person to safely handle a load. In situations where a person is required to carry a load the act of transportation, of the load and the person, must also be analyzed. Both energy expenditure, and perceived physical effort are greatly affected by the person's ability to transport the load. The principles of human gait become a factor in the analysis of manual materials handling tasks. Accordingly, the kinematic analysis of gait should be applied to study the effect of transporting a load and the body in MMH tasks.

The study of human gait is extremely complex because of the interrelations between the numerous gait parameters that can be observed (Andriacchi et al., 1977). People, by nature, walk differently from each other by choice and because of restrictions imposed by their environment. For example, workers are often required to walk at speeds to match conveyors or other machinery or equipment used in various industrial sectors. Despite the complexity of human gait, people will walk in a repeatable and characteristic manner. So much so that it is possible to recognize a person based on their gait characteristics, of which the variability of the characteristics, on a stride-to-stride or day-to-day basis is moderately low (Winter, 1988).

> Human gait is the most common of all human movements. It is one of the more difficult movements tasks that we learn, but once learnt [sic] it becomes almost subconscious. Only when this complex neuromuscular skeletal system is disturbed by traumatic injury, neuromuscular damage, gradual degeneration, or fatigue do we realize our limited understanding of the complex biomechanics and motor control mechanisms.
>
> (Winter, 1988, p.1)

> The sole purpose of walking or running is to transport the body safely and efficiently across the ground, on the level, uphill and downhill...For uphill or downhill gait, an additional factor, that of change in altitude, must be considered.
>
> (Winter, 1988, p.2)

Winter (1998) has suggested that there are five main functions that must be performed during each stride period of the gait cycle, they are:

1. Generation of mechanical energy to maintain the present velocity or to increase the forward velocity of the body.

2. Absorption of mechanical energy for shock absorption or stability or to decrease the forward velocity of the body.

3. Maintenance of support of the upper body (ie., prevent collapse of the lower limb) during stance.

4. Maintenance of upright posture and balance of the total body.

5. Control of foot trajectory to achieve safe ground clearance and gentle heel and toe landing.

(Winter, 1988, p. 2)

Studies have reported that gait parameters, including: step length, cadence, time of swing and support are velocity-dependent (Andriacchi et al., 1977; Grieve and Gear, 1966; Winter, 1988). Winter (1983) reported that both the stance and swing times in human gait decrease when cadence and velocity increase. Grieve et al. (1966) reported that both step length and cadence varied linearly with walking velocity. Accordingly, changes in walking speed will produce characteristic changes in step length and cadence (Andriacchi et al., 1977). Because of the associations between walking speed and gait parameters, walking speed becomes the dominant factor effecting gait in situations where a person's walking speed is controlled by their environment.

Murray, Drought and Kory (1964) reported that when allowed to walk at a free cadence subject's cadence varied widely. However, subjects who participated in pretrial fixed cadence trials (at 112 steps per minute) produced no significant differences between corresponding stride lengths, in repeated trials or successive stride lengths in the same trial, under free walking conditions.

In a study of 30 male subjects, Murray (1967) reported that fast-walking subjects (218 ±25 cm/sec) had a greater forward tilt of the pelvis than free-speed walking subjects (151 ±20 cm/sec). Murray suggested that this increased forward tilt was required to accommodate the forward inclination of the trunk that occurred during faster walking speeds.

The purpose of this study was to examine the effects of both load and task duration on stride length, stride period, velocity (calculated in m/s and statures/second), cadence, elbow angle, arm angle and hip angle of the human body during a manual materials handling task on an inclined surface. The importance of including gait characteristic analyses in MMH studies, especially when focusing on carrying tasks, has not been comprehensively addressed.

This study was design to address the analyses of a MMH task using gait characteristics as a primary focus.

CHAPTER III

Methodology

Subjects

Eight male subjects (age range 20.1 to 26.1 years, mean age 22.58 ±2.42 years) free from any known gait abnormalities were used as subjects in this study. All subjects were volunteers and were required to sign a consent form (Appendix A) prior to participating in this study. The experimental protocol was presented to each subject prior to their participation in this study.

Procedure

Each subject was required to repeatedly ascend and descend a 7.47 m runway, carrying a load, for a period of fifteen minutes (thirty ascents and thirty descents). Ascents began at thirty second intervals. The runway was constructed of three sections. The first section (2.49 m long) was level with respect to the floor surface. The end of the second section (2.49 m long) was elevated to produce a 9.41° incline. The third section (2.49 m long) was positioned level to the floor surface, but elevated to accommodate the incline of the second section.

The carrying distance in this study encompasses the distance study by Drury, Law and Pawenski (1982), Snook

(1978), Snook et al. (1990, 1991), Nottrodt and Manley (1989) and various other researchers.

The three load conditions used in this study are presented in Table 2. The 18.25 kg load (L3) is similar to the load (18 kg) reported by Dutta and Taboun (1989) as resulting in the highest mechanical efficiency in their study of manual carrying tasks.

The load was secured in the wooden box so that it would not shift or provide auditory or visual clues to the subjects regarding its' weight.

Table 2. Load conditions

Load condition	Mass	Weight
L1	6.25 kg	61.25 N
L2	11.25 kg	110.25 N
L3	18.25 kg	178.85 N

Pace of the task was self-selected. However, subjects were required to complete a cycle (one ascent and one descent) within thirty seconds. Subjects were only required to carry the load on each ascent of the ramp. Subjects performed two trials in succession. A 45 minute rest period was given between trials. During this period the subjects were required to sit and avoid physical activity. Each subject was required to complete two trials under each level of the dependent variable of load. The order of trials was randomized by load. The randomization matrix is presented in Table 3.

The required task falls within the acceptable weight recommended by Snook (1978), Snook et al. (1990, 1991) for carrying (male subjects only; 75% of industrial population; all movements were in the knuckle to shoulder height range).

The load was comprised of a wooden box with handles (0.4 m long, 0.25 m wide and 0.30 m high). The box used in this study was slightly different in size to the median box dimensions of 0.38 m long, 0.305 m wide and 0.215 m high reported by Drury et al. (1982) in a survey of more than 2000 different MMH tasks using boxes. The handles were spaced 0.585 m apart. The load was transported in front of the body. Subjects were requested to carry the load in such a manner that the box was level and did not contact their trunk.

Table 3. Subject Load Condition for each Trial

Subject	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
	Load Condition					
1	L2	L1	L1	L3	L3	L2
2	L3	L1	L1	L3	L2	L2
3	L2	L1	L3	L2	L1	L3
4	L2	L1	L2	L3	L1	L3
5	L1	L3	L3	L2	L1	L2
6	L1	L2	L2	L1	L3	L3
7	L1	L1	L3	L3	L2	L2
8	L1	L3	L1	L2	L2	L3

Note: L1 = 6.25 kg, L2 = 11.25 kg, L3 = 18.25 kg

Data Collection

Subjects were filmed with 4-X reversal film using a 16 mm Locam camera operating at 50 Hz. Real time values were obtained from data provided by an internal LED operating at two times the frequency of sampling (100 Hz).

Film data were collected at two points during each trial. The first data collection point was during the second ascent of the ramp; after the subject had completed the first 30 seconds of the task. The second data collection point was during the thirteenth ascent; after the subject had completed 14.5 minutes of the task. On both occasions film data were collected for one stride (heel contact to heel contact of the same foot).

Stride length, stride period, elbow angle, hip angle and arm angle were measured directly from the film data using the segmental model produced for each subject. Stride period, velocity 1, velocity 2 and cadence were calculated from film data and additional anthropometric data from subjects. Velocity measures were calculated using subjects' displacement along the inclined surface.

Subjects were required to complete a questionnaire at the end of each trial (Appendix B).

Film Analysis

Film data were analyzed using a Vanguard projector, an Altek AC 30 digitizer and an Apple II microcomputer. A thirteen segment model of the subject was used for the purpose of film analyses. A scale factor was determined by placing an object of known length, a one metre pole, in the subject's plane of progression after any alterations in the filming process, for example, after reloading the camera or prior to each data collection session. The computational programs used in this study have been previously validated and employed in previous research.

Data collection techniques were validated prior to data collection in this study.

Segmental Model

The thirteen segment model consisted of: right foot, left foot, right shank, left shank, right thigh, left thigh, right hand, left hand, right forearm, left forearm, right upper arm, left upper arm and trunk (including the head). This thirteen segment model was defined by twenty segment endpoints.

Markers were placed at both distal and proximal endpoints of each segment. Such marker locations were defined by anatomical landmarks to insure consistency in the segmental model construction between subjects. Segmental endpoint data were then used to determine and calculate dependent variable values.

Additional Data Collection

The following anthropometric data were collected: subject height, weight, thigh length, shank length, foot length, trunk length, arm length, forearm length and hand length.

Independent Variables (IV)

The independent variables in this study were: the external load (three levels) and the task duration (two levels). The independent variables levels and values are presented in Table 4.

Table 4. Independent Variables Level and Values

Independent variable	Level	Value
Load (L1)	1	6.25 kg
Load (L2)	2	11.25 kg
Load (L3)	3	18.25 kg
Time (T1)	1	30 seconds
Time (T2)	2	14.5 minutes

Dependent Variables (DV)

The dependent variables that were measured in this study are: stride length, stride period, velocity (measured in m/s and statures/second), stride rate, cadence, elbow angle (0, 50 and 100 percent of stride), arm angle (0, 50 and 100 percent of stride) and hip angle (0, 50 and 100 percent of stride). Refer to Table 5 for a list of the dependent variables in this study.

Statistical Analysis

The mean values of each dependent variable, for each subject under each level of the independent variables, were determined.

A series of two-way within subject analyses of variance (ANOVA) were used to test for significant differences between dependent variable values in this study. Statistically significant differences were accepted at $p<0.05$. For post hoc comparisons a Tukey's Studentized

Range (HSD) test was used to determine between which level(s), of the independent variable(s), significant differences were present.

Table 5. Dependent Variables

Dependent Variable	Abbreviation
stride length	SL
stride period	SP
velocity 1 (SL*C/120)(m/s)	V1
velocity 2 (SL/HT*C/120)(statures/sec)	V2
cadence	C
elbow angle 0 (at 0 percent of stride length)	EA(0)
elbow angle 50 (at 50 percent of stride length)	EA(50)
elbow angle 100 (at 100 percent of stride length)	EA(100)
arm angle 0 (at 0 percent of stride length)	AA(0)
arm angle 50 (at 50 percent of stride length)	AA(50)
arm angle 100 (at 100 percent of stride length)	AA(100)
hip angle 0 (at 0 percent of stride length)	HA(0)
hip angle 50 (at 50 percent of stride length)	HA(50)
hip angle 100 (at 100 percent of stride length)	HA(100)

CHAPTER IV

Results

The age range of the subjects in this study was 20.1 to 26.1 years. The mean age of the subjects was 22.58 ±2.42 years. A summary of the subjects' anthropometric data are presented in Table 6. Individual subject's anthropometric data are presented in Appendix C.

Based on the mean value of the subjects' weight the 6.25 kg, 11.25 kg and 18.25 kg loads represent 7.8%, 14.0% and 22.7% of the mean value body weight respectively.

Complete trial data, for each subject, are presented in Appendix D.

Table 6. Subject Anthropometric Data

Anthropometric measure	Mean value	Standard deviation
Height (m)	1.81	±0.08
Weight (kg)	80.35	±11.70
Thigh length (cm)	45.29	±3.33
Shank length (cm)	43.00	±3.04
Foot length (cm)	30.23	±1.74
Trunk length (cm)	80.94	±3.61
Arm length (cm)	27.20	±3.34
Forearm length (cm)	25.61	±2.36
Hand length (cm)	20.05	±1.87

Statistically significant differences were found between the stride lengths of the subjects as they ascended the inclined surface under the 3 load conditions (DF = 2, F = 18.72, $p<0.05$) (Table 7). The stride lengths of the subjects was significantly shorter as they ascended the inclined surface with the 18.25 kg load (L3) (Table 8). There were no significant differences in the stride lengths of the subjects between the time conditions (T1 and T2). There were also no significant differences in the stride lengths of the subjects as a result of the interaction of load and time conditions.

Table 7. Analysis of Variance Results for Stride Length

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	0.0619	0.0309	18.72*
Time	1	0.0016	0.0016	0.97
Load*Time	2	0.0042	0.0021	1.30

*p<0.05

Table 8. Tukey's Studentized Range (HSD) Test Results for Stride Length

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	1.471	48	A
Load	2	1.457	48	A
Load	3	1.422	48	B
Time	1	1.447	72	A
Time	2	1.453	72	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Statistically significant differences were found between the stride periods of the subjects as they ascended the inclined surface under the 3 load conditions (DF = 2, F = 65.89, $p<0.05$) (Table 9). The stride periods of the subjects decreased as they ascended the inclined surface with the 18.25 kg load (L3) (Table 10). There were no significant differences in the stride periods of the subjects between the time conditions (T1 and T2). There were also no significant differences in the stride periods of the subjects as a result of the interaction of the load and time conditions.

Table 9. Analysis of Variance Results for Stride Period

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	0.0616	0.0308	65.89*
Time	1	0.0002	0.0002	0.48
Load*Time	2	0.0003	0.0013	0.28

*p<0.05

No significant differences were found between the velocities (V1) of subjects, under all levels of both independent variables, as they ascended the inclined surface. There were no significant different between the velocities (V1) of the subjects as a result of the interaction of the load and time conditions (Tables 11 and 12).

Table 10. Tukey's Studentized Range (HSD) Test Results for Stride Period

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	1.156	48	A
Load	2	1.152	48	A
Load	3	1.110	48	B
Time	1	1.138	72	A
Time	2	1.140	72	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Table 11. Analysis of Variance Results for Velocity 1

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	0.0007	0.0034	1.77
Time	1	0.0005	0.0005	0.26
Load*Time	2	0.0097	0.0049	2.51

Table 12. Tukey's Studentized Range (HSD) Test Results for Velocity 1

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	1.278	48	A
Load	2	1.270	48	A
Load	3	1.288	48	A
Time	1	1.277	72	A
Time	2	1.281	72	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

No significant differences were found between the velocities (V2) of the subjects (normalized for subject height), under all levels of both independent variables, as they ascended the inclined surface. There were no significant differences between the velocities (V2) as a result of interaction of the load and time conditions (Tables 13 and 14).

Table 13. Analysis of Variance Results for Velocity 2

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	0.0184	0.0092	1.34
Time	1	0.0052	0.0052	0.76
Load*Time	2	0.0354	0.0177	2.58

Table 14. Tukey's Studentized Range (HSD) Test results for Velocity 2

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	2.329	48	A
Load	2	2.309	48	A
Load	3	2.336	48	A
Time	1	2.319	72	A
Time	2	2.330	72	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Statistically significant differences were found between the cadence of the subjects as they ascended the inclined surface under the 3 load conditions (DF = 2, F = 70.89, $p<0.05$) (Table 15). The cadence of the subjects increased as they ascended the inclined surface with the 18.25 kg load (L3) (Table 16). There were no significant differences in cadence of the subjects between the time conditions (T1 and T2). There were also no significant differences in the cadence of the subjects as a result of the interaction of load and time conditions.

Table 15. Analysis of Variance Results for Cadence

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	540.88	270.44	70.89*
Time	1	1.0000	1.0000	0.26
Load*Time	2	8.3750	4.1875	1.10

*p<0.05

Statistically significant differences were found between the elbow angle of the subjects as they ascended the inclined surface under the 3 load conditions (DF = 2, F = 13.33, $p<0.05$) (Table 17). Significant differences were also found between the elbow angle of the subjects when measured at 0, 50 and 100 percent of the subjects' stride length (DF = 2, F = 37.41, $p<0.05$) (Table 17). The elbow angle of the subjects increased as they ascended the inclined surface with the 18.25 kg load (L3) (Table 18). The elbow angles of the subjects were significantly different when measured at 0, 50 and 100 percent of the subjects' stride length as they ascended the inclined surface (Table 18). No significant differences in elbow angles were found between the time conditions (T1 and T2). There were no significant differences in the elbow angle of the subjects as a result of the interaction of load, time and percentage of stride length conditions.

Table 16. Tukey's Studentized Range (HSD) Test Results for Cadence

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	104.25	48	A
Load	2	104.67	48	A
Load	3	108.56	48	B
Time	1	105.92	72	A
Time	2	105.75	72	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Significant differences were found between the hip angle of the subjects as they ascended the inclined surface under the 3 load conditions ($DF = 2$, $F = 9.77$, $p<0.05$) (Table 19).

Table 17. Analysis of Variance Results for Elbow Angle

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	649.98	324.99	13.33*
Time	1	11.67	11.67	0.48
Angle	2	1823.92	911.96	37.41*
Load*Time	2	151.41	75.70	3.11
Load*Angle	4	103.90	25.97	1.07
Time*Angle	2	15.11	7.56	0.31
Load*Time*Angle	4	7.93	1.98	0.08

*p<0.05

Table 18. Tukey's Studentized Range (HSD) Test Results for Elbow Angle

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	101.34	48	A
Load	2	99.10	48	A
Load	3	96.15	48	B
Time	1	99.15	72	A
Time	2	98.58	72	A
Percentage of stride	1	94.71	48	A
Percentage of stride	2	98.48	48	B
Percentage of stride	3	103.40	48	C

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Significant differences were also found between the hip angles of the subjects when measured at 0, 50 and 100 percent of the subjects' stride length (DF = 2, F = 23.37, $p<0.05$) (Table 19). The hip angle of the subjects decreased as they ascended the inclined surface with the 6.25 kg load (L1) (Table 20). The hip angle of the subjects was significantly different when measured at 50 percent of the subjects' stride length, compared to 0 and 100 percent, as they ascended the inclined surface (Table 20). No significant differences in the hip angle were found between the time conditions (T1 and T2). There were no significant differences in the hip angle of the subjects as a result of the interaction of load, time and percentage of stride length conditions.

Table 19. Analysis of Variance Results for Hip Angle

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	104.45	52.23	9.77*
Time	1	0.08	0.08	0.02
Angle	2	249.82	124.91	23.37*
Load*Time	2	1.46	0.73	0.14
Load*Angle	4	22.42	5.61	1.05
Time*Angle	2	6.36	3.18	0.59
Load*Time*Angle	4	3.24	0.08	0.15

*p<0.05

Statistically significant differences were found between the arm angle of the subjects as they ascended the inclined surface under the 3 load conditions (DF = 2, F = 19.68, p<0.05) (Table 21).

Table 20. Tukey's Studentized Range (HSD) Test Results for Hip Angle

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	172.02	48	A
Load	2	173.48	48	B
Load	3	174.04	48	B
Time	1	173.16	72	A
Time	2	173.20	72	A
Percentage of stride	1	174.90	48	A
Percentage of stride	2	171.33	48	B
Percentage of stride	3	174.31	48	A

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

Statistically significant differences were also found between the arm angle of the subjects at 0, 50 and 100 percent of the subjects' stride length (DF = 2, F = 147.23, $p<0.05$) (Table 21). The arm angle of the subjects increased as they ascended the inclined surface with the 18.25 kg load (L3) (Table 22). The arm angles of the subjects were significantly different when measured at 0, 50 and 100 percent of the subjects' stride length as they ascended the inclined surface (Table 22). No significant differences in arm angles were found between the time conditions (T1 and T2). There were no significant differences in the arm angle of the subjects as a result of the interaction of load, time and percentage of stride length conditions.

Table 21. Analysis of Variance Results for Arm Angle

Source	DF	ANOVA SS	Mean Square	F Value
Load	2	295.32	174.66	19.68*
Time	1	13.12	13.12	1.75
Angle	2	2119.17	1059.59	141.23*
Load*Time	2	7.21	3.60	0.48
Load*Angle	4	42.34	10.59	1.41
Time*Angle	2	1.76	0.88	0.12
Load*Time*Angle	4	6.25	1.56	0.21

*p<0.05

Table 22. Tukey's Studentized Range (HSD) Test Results for Arm Angle

Independent variable	Level	Mean	N	Tukey Grouping
Load	1	-6.71	48	A
Load	2	-7.75	48	A
Load	3	-10.14	48	B
Time	1	-7.90	72	A
Time	2	-8.50	72	A
Percentage of stride	1	-13.39	48	A
Percentage of stride	2	-6.98	48	B
Percentage of stride	3	-4.23	48	C

Means with the same Tukey Grouping letter are not significantly different (alpha = 0.05).

When subjects were asked to rate the degree of difficulty of completing the trials with the 6.25 kg load (L1) all subjects reported the degree of difficulty as 1 (easy) out of 5 (difficult). Eighty seven and one-half percent (87.5%) of the subjects reported the degree of difficulty of completing trials with the 11.25 kg load (L2) as 2 out of 5. One half of the subjects reported the degree of difficulty of completing the trials with the 18.25 kg load (L3) as 3 out of 5. Refer to Table 23 for a complete breakdown of ratings.

In 1 out of 16 trials (6.25%), with the 6.25 kg load (L1), one subject reported that the difficulty of the task became easier over the course of the trial. In 15 out of 16 trials (93.5%), with the 6.25 kg load (L1), subjects reported that the difficulty of the task did not change over the course of the trial. There were no reports of the degree of difficulty of the task increasing over the course of the trial with the 6.25 kg load (L1).

Table 23. Subjects' Rating of the Degree of Effort Required to Complete the Task (expressed as a percent of the number of trials)

Load	Degree of difficulty				
	1	2	3	4	5
6.26 kg	100%	0%	0%	0%	0%
11.25 kg	87.5%	12.5%	0%	0%	0%
18.25 kg	12.5%	31.25%	50%	6.25%	0%

In 2 out of 16 trials (12.5%), with the 11.25 kg load (L2), subjects reported that the degree of difficulty of the task became easier over the course of the trial. In 12 out of 16 trials (75%), with the 11.25 kg load (L2), subjects reported that the difficulty of the task did not change over the course of the trial. In 2 out of 16 trials (12.5%), with the 11.25 kg load (L2), subjects reported that the difficulty of the task became harder over the course of the trial.

In 5 out of 16 trials (31.25%), with the 18.25 kg load (L3), subjects reported that the difficulty of the task became easier over the course of the trial. In 6 out of 16 trials (37.5%), with the 18.25 kg load (L3), subjects reported that the difficulty of the task did not change over the course of the trial. In 5 out of 16 trials (31.25%), with the 18.25 kg load (L3), subjects reported that the difficulty of the task became harder over the course of the trial.

After completing each 15 minute trial (16 out of 16 and 16 out of 16 respectively), with both the 6.25 kg and the 11.25 kg loads (L1 and L2), subjects reported that they could continue the trial for 20 minutes or more. After completing each 15 minute trial, with the 18.25 kg load (L3), subjects only reported being able to continue for 20 minutes or more in 10 out of 16 trials (62.5%). In 1 out of 16 (12.5%) and 5 out of 16 (31.25%) of the trials the subjects reported that they could only continue for 1-10 and 10-20 minutes respectively.

When asked to estimate the mass of the load used in the trial subjects accurately estimated the mass of the load in the 6.25 kg (L1) trials as 0-10 kg in 100% of the trials. When completing trials with the 11.25 kg load (L2) subjects estimated the load to be 0-10 kg 75% of the time. In 25% of the trials with the 11.25 kg load (L2) the subjects estimated the load mass as 10-20 kg. When subjects were asked to estimate the mass of the load in trials with the 18.25 kg load (L3) subjects estimated the mass of the load as 0-10 kg 12.5% of the time, 10-20 kg 25% of the time and 20+ kg 62.5% of the time. An outline of the estimated mass of the load per trial load condition is presented in Table 24.

When asked, immediately upon completion of a trial, to compare the degree of difficulty of that trial to the trial preceding it, subjects in 62.5% of trials accurately reported the appropriate degree of difficulty of the completed trial. The degree of difficulty reported corresponded to changes in the mass of the load, if any, between the trials.

Dependent group t-tests were performed on selected independent variables, at selected load conditions, in order to determine the subjects' reliability. Each independent variable was analyzed at T1 and T2. In all tests the t-ratio was less than the significance value (DF = 7, t = 3.499, $p<0.05$) (Table 25).

Table 24. Subjects' Rating of the Degree of Effort Required to Complete the Task (expressed as a percent of response)

Load condition	Estimate of mass of load		
	0-10 kg	10-20 kg	20+ kg
6.26 kg	100%	0%	0%
11.25 kg	75%	25%	0%
18.25 kg	12.5%	25%	62.5%

Table 25. Dependent Group T-Test Results

Independent Variable	Load Condition	Time	DF	T-Ratio
Cadence	L1	T1	7	0.2025
Cadence	L1	T2	7	0.2215
Cadence	L2	T1	7	0.6816
Cadence	L2	T2	7	0.6364
Cadence	L3	T1	7	0.7031
Cadence	L3	T2	7	0.9640
EA (0% of stride)	L1	T1	7	3.2113
EA (0% of stride)	L1	T2	7	2.8467
EA (0% of stride)	L2	T1	7	2.6965
EA (0% of stride)	L2	T2	7	2.7959
EA (0% of stride)	L3	T1	7	3.1823
EA (0% of stride)	L3	T2	7	2.5325
HA (50% of stride)	L1	T1	7	0.1678
HA (50% of stride)	L1	T2	7	0.9642
HA (50% of stride)	L2	T1	7	0.0000
HA (50% of stride)	L2	T2	7	0.3121
HA (50% of stride)	L3	T1	7	0.1869
HA (50% of stride)	L3	T2	7	0.8767
AA (100% of stride)	L1	T1	7	0.7655
AA (100% of stride)	L1	T2	7	0.8310
AA (100% of stride)	L2	T1	7	0.1478
AA (100% of stride)	L2	T2	7	0.2813
AA (100% of stride)	L3	T1	7	0.7395
AA (100% of stride)	L3	T2	7	2.9442

CHAPTER V

Discussion

From injury statistics reported in the literature it is evident that work environments and tasks often exceed human MMH capabilities and limitations. Past research has focused on a person's ability to perform MMH tasks; for example, the maximum weight that can be carried, energy expenditure and the most effective carrying means have all been studied. The impact that the work environment has on MMH task requirements has not received the same scrutiny. Environmental factors in industry such as line speeds, walking surfaces and walking grades have the potential to effect human MMH capabilities and limitations.

The focus of this study was to examine the effects of both load and task duration on selected kinematic variables during a MMH task on an inclined surface. The intent was to determine if gait characteristics and/or body positions were affected by load, task duration and grade. The load, task duration and grade were all fixed to resemble factors in a work environment.

Stride length

In this study subjects' stride length (1.422 m) was significantly shorter when ascending the inclined surface with the 18.25 kg load (L3) only. Stride lengths in trials with the 6.25 kg load (L1) and 11.25 kg load (L2) were 1.471 m and 1.457 m respectively. These values were not significantly different. However, the results indicate a trend; suggesting that carrying greater loads results in shorter stride lengths. When measured at 30 seconds (T1) the subjects' stride length was 1.447 m compared to 1.453 m measured at 14.5 minutes (T2). These values were also not significantly different.

Kinoshita (1985) conducted a study in which subjects were required to walk on level ground at 4.5 ±0.3 km/hr under load conditions ranging from no load to 40% of the subject's body weight (carried in a backpack or doublepack system). Kinoshita reported that subjects' stride lengths were not significantly different between load conditions. The stride length values reported for no load, 20% of body weight and 40% of body weight were 148.6 cm, 147.86 cm and 146.32 cm respectively.

The stride length values found in this study were slightly lower than those reported by Kinoshita. As the load values increased in the results reported by Kinoshita the stride length values decreased. This same trend, that was seen in Kinoshita's study, was found in this study. However, our results indicated that a 18.25 kg load (L3) significantly affected stride length on an inclined surface.

Nottrodt et al. (1989) reported stride length values of 1.16 m and 1.13 m, for two trials, for self paced walking on a level surface with 33.5 ±5.3 kg and 34.4 ±6.9 kg load respectively. During these trials the subjects' preferred walking speeds were 1.14 ±0.16 m/s and 1.10 ±0.16 m/s. In the first trials subjects were required to carry the load in front of the body with the arms bent at 90°. In a second set of trials subjects were required to perform the same task with the arms positioned straight down. The following results were reported from those trials. Subjects' stride lengths were 0.99 ±0.10 m and 0.95 ±0.07 m at preferred walking speeds of 1.01 ±0.18 m/s and 0.96 ±0.14 m/s.

Martin et al. (1986) reported stride length values for level walking at 1.78 m/s for 5 m as: 88.5 ±4.5 cm (no load), 90.3 ±4.2 cm (carrying a 9 kg load), 88.2 ±4.3 cm (carrying a 17 kg load), 88.5 ±3.5 cm (carrying a 29 kg load) and 87.9 ±4.2 cm (carrying a 36 kg load). Loads 1 - 3 were carried on the body and loads 4 - 5 were carried in a backpack.

The stride lengths values reported by Nottrodt et al. (1989) and Martin et al. (1986) are shorter that the results reported in this study or in the study by Kinoshita (1985). The stride lengths results reported by Kinoshita (1985), Nottrodt et al. (1989) and Martin et al. (1986) indicated a trend; suggesting that carrying greater loads during MMH tasks result in shorter stride lengths. This trend was also found in this study.

Murray et al. (1964) reported stride length values of 156.5 ±11.4 cm for normal gait without a load. Similar results were also reported by Murray (1967) for walking classified as fast and free speeds. The stride length for free walking was reported as 156 ±13 cm and as 186 ±16 cm for fast walking.

The stride lengths results reported in this study were shorter than the results reported for normal walking on a level surface by Murray et al. (1964) and free walking reported by Murray (1967). The stride lengths results reported by Murray et al. (1964) and Murray (1967) were longer that any other results reported in the literature reviewed. These results suggest that in MMH tasks subjects' stride lengths are shorter than when walking normally. As a result, subjects' cadence must increase to maintain the same walking speed or the walking speed must be decreased. Additionally, the stride length results reported by Kinoshita (1985), Nottrodt et al. (1989), Martin et al. (1986) and those reported in this study indicate that a trend exists; suggesting that as the weight of a load increases an accompanying decrease in stride length results. Similar trends have also been found between oxygen consumption and increased load (Gordon et al., 1983)

Stride period

The stride period under L3 (18.25 kg) was significantly decreased when ascending the inclined surface. The stride period with the 18.25 kg load (L3) was 1.110 s. The stride period under L1 (6.25 kg) and L2 (11.25 kg) were 1.156 s and 1.152 s respectively. As with values obtained for T1 (30 seconds) and T2 (14.5 minutes) these values were not significantly different. The stride periods for T1 and T2 were 1.138 s and 1.140 s respectively.

Murray et al. (1964) have reported stride periods of 1.03 ±0.10 seconds. Murray (1967) reported stride periods, classified as fast, of 0.87 ±0.06 seconds. Free walking stride periods were reported as 1.06 ±0.09 seconds.

In comparison to findings reported in the literature the stride period results reported in this study were similar, but greater than, the results reported by Murray et al. (1964) for normal walking and Murray (1967) for free walking. From this it is suggested that differences in stride periods between normal walking and MMH on an inclined surface, are related to other gait characteristics such as stride length, cadence or velocity, not stride period.

Velocity 1 and 2

There were no significant differences found between velocities (both V1 and V2 values) in all trials, under all load conditions and time conditions, as subjects ascended the inclined surface. The self selected walking speeds for subjects in this study were V1 = 1.278 m/s, V2 = 2.329 statures/s (under L1); V1 = 1.270 m/s, V2 = 2.309 m/s (under L2); V1 = 1.288 m/s, V2 = 2.336 statures/s (under L3); V1 = 1.277 m/s, V2 = 2.319 statures/s (under T1) and V1 = 1.281 m/s, V2 = 2.33 statures/s (under T2).

In a study of MMH tasks on a level surface Nottrodt et al. (1989) reported self paced walking speeds, for two trials on a level surface with 33.5 ±5.3 kg and 34.4 ±6.9 kg load respectively, of 1.14 ±0.16 m/s and 1.10 ±0.16 m/s. In these trials subjects were required to carry the load in front of the body with the arms bent at 90°. In a second set of trials subjects were required to perform the same task with the arms positioned straight down. For these trials subjects' preferred walking speeds were 1.01 ±0.18 m/s and 0.96 ± 0.14 m/s.

In this study the values reported were similar to the results reported by Nottrodt et al. (1989) but the values are marginally higher. The results from this study may have been higher due to differences in grade or in the weight of the load(s) carried. The latter could also be related to the effect of load on stride length as previously discussed.

Snook (1978) reported subjects' maximum acceptable walking speed, while carrying a load, was 1.31 m/s. This value is higher than the results reported in this study, however, subjects in this study performed the required task at their own walking speed not their maximum walking speed.

Cadence

Cadence values for trials under L3 (18.25 kg) were significantly higher at 108.56 steps/minute when ascending the inclined surface. Cadence values of 104.25 steps/minute and 104.67 steps/minute were found for ascents while carrying L1 (6.25 kg) and L2 (11.25) respectively. These values were not significantly different.

In past research Nottrodt et al. (1989) reported cadence values of 0.98 ±0.08 and 0.98 ±0.09 strides/second for a carrying task with the arms bent at 90° and 1.01 ±0.01 and 1.01 ±0.11 strides/second for a carrying task with the arm straight at the elbows. Several other researchers have reported cadence values in the literature. For the purpose of experimental design, Winter (1983) has classified slow cadence values as 84.7 ±10.4 steps/minute, natural cadence as 105 ±7.7 steps/minute and fast cadence 121.6 ±5.3 steps/minute. Winter (1988) has also reported natural cadence values of 107 ±8.8 steps/minute. Murray et al. (1964) reported cadence values of 117 steps/minute and Murray (1967) reported cadence values of 218 ±25 steps/minute for fast walking and 151 ±20 steps/minute for free walking.

When compared to cadence results reported by Winter (1983, 1988) the cadence values in this study could be classified within the range of natural cadence. The results are higher than those reported by Nottrodt et al. (1989) and lower that the results reported by Murray (1967). However in the walking velocities reported for Nottrodt et al. (1989) were slower than the velocities reported in this study. Concurrently, the velocities reported by Murray (1967) were faster than the velocities reported in this study. Based on the relationship between velocity and cadence the results reported in this study are in line with the results reported in the literature.

Elbow angle

The elbow angle of subjects' increased as they ascended the inclined surface in trials under L3 (18.25 kg). There were no significant differences in elbow angles in trials under L1 (6.25 kg) and L2 (11.25 kg) or between time conditions. The elbow angle values were as follows: 101.34°, 99.10° and 96.15° for L1, L2 and L3 respectively.

Elbow angles measured at 0%, 50% and 100% of stride length (94.71°, 98.48° and 103.40° respectively) during each ascent were statistically different between each period in a stride.

In a study of normal gait Murray (1967) has reported the range of flexion and extension of the elbow, while walking, to be 30° ±11° with peak flexion as 47 ±11° and peak extension as 17 ±8°. The values reported in this study fall within the range of extension, specified by peak extension reported by Murray (1967).

Hip angle

During ascents under L1 (6.25 kg) subjects' hip angle were statistically smaller than under L2 (11.25 kg) and L3 (18.25 kg). There were no significant differences found between the hip angle values for L2 or L3 ascents. The hip angle values were as follows: 172.02°, 173.48° and 174.04° for L1, L2 and L3 respectively. There were also no significant differences found between the hip angle values measures at T1 and T2.

The hip angle value measured at 50% of stride length was significantly smaller than the hip angle value 0% or 100% of stride length. It is suggested that this is related to the double support period found at 50% of stride length.

Arm angle

Subjects' arm angle was statistically different when ascending the inclined surface in trials under L3 (18.25 kg). No significant differences were found between arm angles in trials under load conditions L1 and L2. The arm angle values were as follows: -6.71°, -7.75° and -10.14° respectively. There were no significant differences found between arm angles under time conditions T1 and T2 (-7.90° and -8.50°)

Arm angles measures at 0%, 50% and 100% of stride length were significantly different between each period of the stride.

Murray has reported the range of forward flexion and extension of the shoulder, while walking, to be 32° ±10° with peak flexion as 8 ±10° and peak extension as 24 ±6°. The arm values reported in this study are within the range of flexion and extension values reported by Murray (1967).

Questionnaire results

When asked, subjects reported that the degree of difficulty of completing a trial increased as the weight of the load increased. Gordon et al. (1983) reported similar findings in their study of subjects walking at 1.34 m/s on a 10% grade (with a load in a backpack). As load values increased from 10% to 50% of body weight, subjects reported an increase in perceived exertion. In 93.5%, 75% and 37.5% of trials, in this study, subjects reported that the degree of difficulty did not change over the course of the trial with the 6.25 kg (L1), 11.25 kg (L2) and 18.25 kg (L3) loads respectively. In trials with the 6.25 kg, 11.25 kg and 18.25 kg loads 0%, 12.5% and 31.25% of subjects reported that the degree of difficulty of completing the task increased over the course of the trials.

At the completion of each trial subjects reported that they could continue the task for 20 minutes or more in 100%

of trials with the 6.25 kg load (L1). Only 62.5% of subjects reported that they could continue the task for 20 minutes or more with the 18.25 kg load (L3).

When asked to estimate the load mass, in each trial, subjects correctly estimated the mass of L1 100% of the time. L2 and L3 were correctly estimated 25% of the time. In 75% of trials with L2 the mass of the load was underestimated. Subjects over estimated the mass of L3 in 62.5 % of trials.

Subjects accurately reported a change in the degree of difficulty of completing a trial, when compared to the preceding trial with a different load, in 62.5% of trials.

CHAPTER VI

Summary and Conclusions

Subjects' stride lengths, stride periods and cadence were significantly different when ascending a 9.41° inclined surface with a 18.25 kg load (L3). Elbow angle, hip angle and arm angle were also significantly different when ascending the inclined surface with the 18.25 kg load (L3).

Both elbow angle and arm angles were significantly different when measured at 0%, 50% and 100% of stride length.

Subjects' hip angle was significantly different when ascending a 9.41° inclined surface with a 6.25 kg load (L1). The hip angle was also significantly different at 50% of the subjects' stride length. This result appears to be unique and is related to the double support period that occurs at 50% of the stride length.

In all trials no significant differences were found in the dependent variables over the time condition T1 and T2. There were no statistically significant indications that any interactive relationships occurred between the load and time conditions.

Self reported degree of difficulty for the task indicated that the degree of difficulty increased between L1 and L3 (6.25 kg to 18.25 kg).

In 62.5% of the trials, under all load conditions, subjects reported that they could continue the required task for 20 minutes or more. The same percentage of subjects accurately reported changes in the degree of difficulty of the task associated with changes in load conditions between trials.

Subjects accurately estimated the weight of L1 (6.25 kg) in 100% of trials under this condition. Twenty-five percent of subjects accurately estimated the weight of L2 (11.25 kg) and L3 (18.25 kg) in trials under the specific load conditions.

Gait characteristics and body positions were significantly altered when ascending a 9.41° inclined surface with a 18.25 kg load (L3) (representing 22.7% of the average subject body weight) in comparison to trials with lighter loads. Elbow angle and arm angle were also significantly different between 0%, 50% and 100% of subjects stride length. Subjects' stride length and stride period decreased when completing the task with a 18.25 kg load (L3). A corresponding increase in cadence accompanied these changes. Subjects' elbow angle increased and arm angle decreased over the course of each trial with the 18.25 kg load.

The length of the trial (time period between T1 and T2) did not appear to effect any of the dependent variables measured in this study. This is in contrast to the information reported by subjects who indicated a trend exists between the weight of the load and total endurance. The results of this study indicate that specific gait characteristics and body positions change when ascending a 9.41° inclined surface with a 18.25 kg load compared to 6.25 kg and 11.25 kg loads. Subjects' stride length and stride period decreased causing the subjects to take more steps when ascending the inclined surface with the 18.25 kg load (L3).

There were no differences found in any dependent variables between T1 and T2 indicating that fatigue was not a factor over the 15 minute trial. However, elbow angle and arm angle results indicate that over the course of each trial the load affected body positions. The height of the load, in reference to the level floor surface, decreased over the course of each ascent as the load weight increased.

Additionally, only 62.5% of subjects reported that they could continue the required task for 20 minutes or more with the 18.25 kg load, where 100% of subjects reported that they could continue the required task for 20 minutes or more with the 6.25 kg and 11.25 kg loads. Empirically, chronic fatigue was not a factor yet when measured via a psychophysical criterion it appears to be a factor.

The results of this study indicate that both gait characteristics and body positions are affected by the weight of a load during the completion of a MMH task on an inclined surface (9.41° incline). The results suggest that a critical load value exists when ascending a 9.41° inclined surface. When this critical load value is exceeded changes in gait characteristics and body positions result. This critical value is likely between 11.25 kg and 18.25 kg. This critical weight only results in changes in gait characteristics and body positions and may or may not adversely affect the person performing the task.

Based on these findings, further research is required to determine what affects loads, grade, task duration, velocity and box size have on gait characteristics and body positions when ascending an inclined surface. Many of these factors have be studied for level MMH and from the results of those studies standards for MMH have been published. As the results of this study indicate, gait characteristics and body positions vary between level and inclined surface MMH. Therefore, MMH tasks on inclined surfaced must be investigated to the same degree as MMH tasks on levels surfaces have been studied. Additionally, the effects of other environmental factors such as walking on anti-fatigue matting or steel grating should be investigated to determine if published standards are applicable to MMH tasks on these surfaces.

In reviewing the purpose of this study, which in summary was to examine the effects of both load and task duration on gait characteristics and body positions during a manual materials handling task on an inclined surface, the results indicate tnat gait characteristics and body positions are affected by a MMH task on an inclined surface. These affects could be compounded by the working environment in which the task must be performed, i.e. ascending an inclined surface.

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APPENDIX A

Consent Form

University of Windsor
Department of Kinesiology

<u>Consent Form</u>

I have willingly volunteered to participate in this study. I understand that I am free to leave at any point. I have been instructed that all results will remain strictly confidential.

____________________ ____________________

Participant **Date**

____________________ ____________________

Witness **Date**

APPENDIX B

Subject Questionnaire

Subject name ____________________ Trial number ___________

Please answer the following questions:

1. Using the scale below, rate the degree of effort it took to complete the task.

   1 2 3 4 5
   easy difficult

2. Over the course of the trial the task _________.

   A. became easier
   B. the difficulty did not change
   C. became harder

3. If the trial was not stopped, for how long could you have continued the task?

   A. 1 - 10 minutes
   B. 10 - 20 minutes
   C. 20 + minutes

4. Estimate the weight of the box used in the trial.

   A. 0 - 10 kg
   B. 10 - 20 kg
   C. 20 + kg

If this is the second trial you have completed today please answer question 5.

5. Compared to the previous trial, this trial was ______.

   A. easier
   B. more difficult
   C. as difficult as the previous one

6. Have you been physically active in the last 2 hours? (except for any previous trials completed)

   A. yes
   B. no

If you answered 'yes' to question 6 please answer this question.

7. What type of activity did you do and for how long?

____

APPENDIX C

Subject Anthropometric Data

Subject 1 Anthropometric Data

Birth date (month/day/year)	01/21/66
Height (m)	1.85
Weight (kg)	96.4
Thigh length (cm)	47.1
Shank length (cm)	44.1
Foot length (cm)	32.0
Trunk length (cm)	80.7
Arm length (cm)	32.1
Forearm length (cm)	28.4
Hand Length (cm)	21.2

Subject 2 Anthropometric Data

Birth date (month/day/year)	01/01/70
Height (m)	1.82
weight (kg)	88.6
Thigh length (cm)	44.9
Shank length (cm)	42.8
Foot length (cm)	31.4
Trunk length (cm)	84.2
Arm length (cm)	25.2
Forearm length (cm)	23.9
Hand length (cm)	21.5

Subject 3 Anthropometric Data

Birth date (month/day/year)	06/30/70
Height (m)	1.75
Weight (kg)	72.7
Thigh length (cm)	42.9
Shank length (cm)	39.7
Foot length (cm)	28.8
Trunk length (cm)	79.2
Arm length (cm)	25.1
Forearm length (cm)	23.3
Hand length (cm)	17.5

Subject 4 Anthropometric Data

Birth date (month/day/year)	06/03/71
Height (m)	1.70
Weight (kg)	70.5
Thigh length (cm)	42.1
Shank length (cm)	42.9
Foot length (cm)	31.1
Trunk length (cm)	77.2
Arm length (cm)	24.3
Forearm length (cm)	23.9
Hand length (cm)	18.3

Subject 5 Anthropometric Data

Birth date (month/day/year)	01/14/71
Height (m)	1.93
Weight (kg)	93.6
Thigh length (cm)	49.2
Shank length (cm)	46.0
Foot length (cm)	30.8
Trunk length (cm)	87.9
Arm length (cm)	31.5
Forearm length (cm)	28.4
Hand length (cm)	22.9

Subject 6 Anthropometric Data

Birth date (month/day/year)	02/20/71
Weight (m)	1.91
Weight (kg)	81.8
Thigh length (cm)	48.9
Shank length (cm)	47.0
Foot length (cm)	30.8
Trunk length (cm)	81.6
Arm length (cm)	29.2
Forearm length (cm)	28.5
Hand length (cm)	20.6

Subject 7 Anthropometric Data

Birth date (month/day/year)	06/02/65
Height (m)	1.72
Weight (kg)	75.6
Thigh length (cm)	40.1
Shank length (cm)	38.0
Foot length (cm)	27.0
Trunk length (cm)	77.6
Arm length (cm)	23.4
Forearm length (cm)	24.0
Hand length (cm)	18.3

Subject 8 Anthropometric Data

Birth date (month/day/year)	03/20/66
Weight (m)	1.83
Weight (kg)	63.6
Thigh length (cm)	47.1
Shank length (cm)	43.8
Foot length (cm)	30.5
Trunk length (cm)	79.1
Arm length (cm)	26.8
Forearm length (cm)	24.5
Hand length (cm)	20.1

APPENDIX D

Subject Trial Data

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.38	1.40	1.32	1.31	1.28	1.42
Stride Period (seconds)	1.11	1.10	1.08	1.11	1.07	1.03
Velocity (SL*C/120)(m/s)	1.24	1.27	1.22	1.18	1.20	1.38
Velocity (SL/HT*C/120)(statures/s)	2.30	2.36	2.26	2.19	2.22	2.55
Cadence (steps/minute)	108	109	111	108	113	117
Elbow Angle at 0% of Stride	112.25	98.50	112.00	98.25	97.00	93.00
Elbow Angle at 50% of Stride	115.75	106.00	86.00	100.25	100.25	97.25
Elbow Angle at 100% of Stride	116.25	105.00	109.00	105.50	105.00	110.50
Hip Angle at 0% of Stride	161.50	165.25	166.50	167.50	164.25	166.75
Hip Angle at 50% of Stride	161.75	165.25	176.00	164.50	165.50	163.25
Hip Angle at 100% of Stride	162.25	165.75	165.00	167.75	165.25	168.25
Upper Arm Angle at 0% of Stride	-5.00	-10.50	-10.50	-13.00	-12.75	-14.25
Upper Arm Angle at 50% of Stride	-2.00	-7.75	-6.50	-11.00	-10.50	-12.25
Upper Arm Angle at 100% of Stride	0.25	-4.00	-3.50	-7.00	-6.75	-5.00

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.53	1.51	1.48	1.51	1.48	1.41
Stride Period (seconds)	1.27	1.31	1.34	1.31	1.22	1.24
Velocity (SL*C/120)(m/s)	1.20	1.15	1.11	1.15	1.21	1.14
Velocity (SL/HT*C/120)(statures/s)	2.19	2.10	2.02	2.09	2.21	2.07
Cadence (steps/minute)	95	92	90	92	98	97
Elbow Angle at 0% of Stride	112.50	109.25	107.75	106.75	103.75	109.75
Elbow Angle at 50% of Stride	116.50	116.00	113.25	116.25	105.75	114.25
Elbow Angle at 100% of Stride	120.50	120.25	118.75	121.00	112.75	117.50
Hip Angle at 0% of Stride	173.75	174.00	176.00	175.00	173.50	175.25
Hip Angle at 50% of Stride	168.25	170.00	174.25	170.50	171.50	173.50
Hip Angle at 100% of Stride	168.25	169.50	174.25	170.50	171.50	173.50
Upper Arm Angle at 0% of Stride	-3.75	-4.50	-5.25	-6.50	-8.25	-2.25
Upper Arm Angle at 50% of Stride	5.25	4.75	6.25	7.00	0.25	2.75
Upper Arm Angle at 100% of Stride	7.75	6.00	6.50	4.50	2.25	5.75

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.44	1.55	1.40	1.41	1.41	1.38
Stride Period (seconds)	1.12	1.08	1.11	1.07	1.06	1.05
Velocity (SL*C/120)	1.28	1.44	1.26	1.32	1.33	1.30
Velocity (SL/HT*C/120)(statures/s)	2.24	2.52	2.21	2.31	2.33	2.27
Cadence (steps/minute)	107	111	108	112	113	114
Elbow Angle at 0% of Stride	97.00	99.00	103.50	107.25	91.25	106.00
Elbow Angle at 50% of Stride	98.75	99.25	107.50	108.00	99.50	112.25
Elbow Angle at 100% of Stride	105.75	101.25	114.50	109.00	107.00	120.75
Hip Angle at 0% of Stride	170.75	174.25	171.75	172.00	172.75	174.00
Hip Angle at 50% of Stride	169.00	167.00	170.75	171.25	174.50	173.50
Hip Angle at 100% of Stride	172.75	173.75	174.00	174.25	178.25	175.25
Upper Arm Angle at 0% of Stride	-4.75	-9.25	-4.00	-2.75	-12.25	-4.00
Upper Arm Angle at 50% of Stride	-0.50	-0.25	0.00	1.25	-3.75	2.00
Upper Arm Angle at 100% of Stride	2.00	-2.00	8.00	5.50	2.75	10.00

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.43	1.39	1.42	1.43	1.40	1.37
Stride Period (seconds)	1.15	1.11	1.13	1.15	1.07	1.14
Velocity (SL*C/120)	1.24	1.26	1.26	1.25	1.31	1.20
Velocity (SL/HT*C/120)(statures/s)	2.12	2.13	2.14	2.12	2.23	2.04
Cadence (steps/minute)	104	108	106	104	112	105
Elbow Angle at 0% of Stride	100.75	100.25	103.50	106.75	102.00	93.00
Elbow Angle at 50% of Stride	103.50	105.50	105.75	106.00	104.00	103.25
Elbow Angle at 100% of Stride	111.25	111.25	111.25	110.50	116.25	111.00
Hip Angle at 0% of Stride	179.00	179.00	180.25	182.25	180.50	177.75
Hip Angle at 50% of Stride	174.25	173.50	174.50	176.75	174.75	175.25
Hip Angle at 100% of Stride	180.50	179.75	181.25	182.25	180.00	177.50
Upper Arm Angle at 0% of Stride	-12.75	-11.00	-14.50	-11.50	-13.00	-20.50
Upper Arm Angle at 50% of Stride	-4.25	-4.00	-6.50	-4.75	-7.25	-8.00
Upper Arm Angle at 100% of Stride	-0.75	-2.75	-2.00	-2.25	-0.25	-3.25

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.59	1.55	1.56	1.62	1.45	1.56
Stride Period (seconds)	1.25	1.28	1.25	1.25	1.15	1.21
Velocity (SL*C/120)	1.28	1.21	1.25	1.29	1.26	1.29
Velocity (SL/HT*C/120)(statures/s)	2.46	2.34	2.41	2.50	2.43	2.49
Cadence (steps/minute)	96	94	96	96	105	99
Elbow Angle at 0% of Stride	89.75	91.75	79.25	83.25	86.75	83.75
Elbow Angle at 50% of Stride	97.50	101.50	86.25	89.00	91.25	89.25
Elbow Angle at 100% of Stride	97.25	102.00	87.75	99.00	96.00	95.75
Hip Angle at 0% of Stride	171.50	170.25	171.75	172.75	171.75	172.00
Hip Angle at 50% of Stride	170.75	167.00	166.25	167.50	171.50	171.25
Hip Angle at 100% of Stride	175.75	173.00	171.00	167.50	176.75	174.50
Upper Arm Angle at 0% of Stride	-17.50	-15.50	-21.25	-18.50	-14.25	-20.75
Upper Arm Angle at 50% of Stride	-14.00	-10.75	-10.50	-11.25	-13.50	-17.00
Upper Arm Angle at 100% of Stride	-10.75	-8.75	-12.50	-7.00	-10.25	-12.75

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.46	1.49	1.62	1.51	1.48	1.45
Stride Period (seconds)	1.15	1.17	1.14	1.14	1.15	1.10
Velocity (SL*C/120)	1.27	1.28	1.42	1.32	1.27	1.32
Velocity (SL/HT*C/120)(statures/s)	2.43	2.44	2.71	2.53	2.42	2.52
Cadence (steps/minute)	104	103	105	105	104	109
Elbow Angle at 0% of Stride	96.50	91.50	93.75	89.75	76.25	80.00
Elbow Angle at 50% of Stride	100.00	97.00	97.00	94.50	81.25	85.75
Elbow Angle at 100% of Stride	101.50	98.50	99.75	98.75	85.50	88.50
Hip Angle at 0% of Stride	173.00	173.00	177.25	178.25	178.50	178.25
Hip Angle at 50% of Stride	168.25	168.25	171.75	173.00	175.75	176.75
Hip Angle at 100% of Stride	172.25	172.50	177.00	179.25	176.50	179.00
Upper Arm Angle at 0% of Stride	-14.50	-11.50	-14.25	-15.75	-20.75	-19.25
Upper Arm Angle at 50% of Stride	-5.50	-6.25	-9.50	-10.25	-15.75	-13.00
Upper Arm Angle at 100% of Stride	-4.75	-5.00	-7.25	-7.75	-11.00	-8.50

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.25
Stride Length (metres)	1.30	1.31	1.29	1.22	1.29	1.29
Stride Period (seconds)	1.15	1.13	1.13	1.15	1.14	1.11
Velocity (SL*C/120)	1.13	1.16	1.15	1.06	1.13	1.17
Velocity (SL/HT*C/120)(statures/s)	1.94	2.11	1.97	1.82	1.96	2.01
Cadence (steps/minute)	104	106	106	104	105	108
Elbow Angle at 0% of Stride	100.00	96.75	89.00	93.25	86.75	80.75
Elbow Angle at 50% of Stride	101.00	94.25	93.50	92.50	89.00	87.50
Elbow Angle at 100% of Stride	103.50	98.00	95.75	94.75	99.50	90.50
Hip Angle at 0% of Stride	177.00	174.75	174.75	176.25	174.00	174.75
Hip Angle at 50% of Stride	175.75	174.50	172.75	173.00	174.00	176.00
Hip Angle at 100% of Stride	176.00	177.25	174.75	176.00	175.75	176.75
Upper Arm Angle at 0% of Stride	-11.00	-13.00	-13.75	-16.75	-19.00	-23.50
Upper Arm Angle at 50% of Stride	-7.25	-9.00	-7.75	-11.00	-15.50	-20.25
Upper Arm Angle at 100% of Stride	-3.00	-8.25	-9.00	-9.75	-6.25	-15.25

Subject						
	Trial A		Trial B		Trial C	
Variable	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
Box Weight (kilograms)	6.25	6.25	11.25	11.25	18.25	18.26
Stride Length (metres)	1.58	1.63	1.60	1.61	1.55	1.57
Stride Period (seconds)	1.05	1.06	1.02	1.05	1.00	1.02
Velocity (SL*C/120)	1.51	1.54	1.57	1.53	1.56	1.54
Velocity (SL/HT*C/120)(statures/s)	2.76	2.82	2.87	2.80	2.83	2.81
Cadence (steps/minute)	114	113	118	114	120	118
Elbow Angle at 0% of Stride	85.75	79.75	79.00	79.75	82.00	81.00
Elbow Angle at 50% of Stride	92.75	82.75	86.25	85.75	87.75	82.25
Elbow Angle at 100% of Stride	97.25	85.00	91.75	90.50	87.00	87.75
Hip Angle at 0% of Stride	177.00	174.00	175.00	176.00	174.75	176.50
Hip Angle at 50% of Stride	172.00	169.75	170.75	171.50	173.25	173.25
Hip Angle at 100% of Stride	178.50	176.75	176.75	176.75	178.00	178.25
Upper Arm Angle at 0% of Stride	-20.25	-21.00	-22.75	-19.70	-20.75	-20.75
Upper Arm Angle at 50% of Stride	-10.25	-11.00	-10.26	-11.00	-11.98	-12.77
Upper Arm Angle at 100% of Stride	-9.25	-10.50	-10.25	-12.00	-12.75	-12.50

VITA AUCTORIS

NAME:	Ronald David Henderson
PLACE OF BIRTH:	North York, Ontario, Canada
YEAR OF BIRTH:	1965
EDUCATION:	Don Mills Collegiate Institute, North York, Ontario, Canada *Ontario Secondary School Honours Graduation Diploma (1985)* University of Windsor, Windsor, Ontario, Canada *Bachelors of Human Kinetics (1989) (Honours Kinesiology)* University of Windsor, Windsor, Ontario, Canada *Master of Human Kinetics (1993) (Human Movement Sciences)*
AWARDS:	University of Windsor Post-Graduate Tuition Award (1989-1991) Canadian Association of Sport Sciences Student Award (1988-1989) Human Kinetics Society Award (1988-1989) Michael W. Ayris Memorial Award (1988-1989) Faculty of Human Kinetics Dean's Honour Role (1988 Winter semester) Faculty of Human Kinetics Dean's Honour Role (1988 Fall semester)

Rotary Club of Windsor Bursary Award (1986)

Faculty of Human Kinetics Dean's Honour Role (1986 Winter semester)

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