HYPOTHERMIA AND THE COLD EXPOSURE SYNDROME DURING PROLONGED EXERCISE IN A WET COLD ENVIRONMENT

by

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ABSTRACT

This study was designed to investigate hypothermia in humans, caused by prolonged exposure to rain, wind, and cold. The primary objective was to induce hypothermia ($T_{CORE} \leq 35°C$) in subjects exercising in these conditions, and to determine if hypothermia was a consequence of exhaustion. Secondarily, measures of motor and psychological performance were included, in order to study the relationship between prolonged wet, cold exposure and changes in behaviour. Lightly-clothed male subjects walked along a simulated hiking trail (*Wet Walk*) at a constant pace, exposed to continuous "rain" and "wind" for up to 4 hours at air temperatures near 5°C. Thermal and metabolic responses were monitored continuously during a trial exposure, as well as respiratory rate and heart rate. Tests of motor and behavioural performance were completed at specific intervals. Some subjects completed wet and dry (control) walks. Results show that wet, cold exposure is characterized by two stages.

(1) An initial, prolonged phase, referred to as the wet-cold exposure syndrome, was characterized by intense shivering (30–50% increase in oxygen consumption) and behavioural responses associated with the effects of peripheral cooling (8°C decrease in mean skin temperature). Subjects often exhibited signs and symptoms of "hypothermia" within 2 hours of wet, cold exposure, but rectal temperature was typically maintained above 36°C. Impaired motor function (grip strength < 70% normal; manual dexterity < 50% normal) and behavioural distress (20–40% reduction in cognitive test performance; significant reduction in vigilance performance) occurred without the development of hypothermia.

(2) Rapid descent towards clinical hypothermia was associated with decreased heat production due to exhaustion. In one case, a sudden decline in rectal temperature began after 3 hours of wet, cold exposure, concomitant with decreased oxygen consumption despite a constant walking pace: rectal temperature dropped 1.4°C to 35.3°C in less than 30 minutes. Signs of exhaustion (staggering, faintness, nausea) were evident. Observations also suggest that cold tolerance – the ability to maintain prolonged activity in wet-cold – is related to aerobic fitness and somatotype. For example, a low-fitness, ectomorphic subject, whose relative heat production decreased as his walking pace slowed, developed hypothermia (rectal temperature 35.2°C) while walking.

The overall conclusion from this study is that prolonged wet, cold exposure of humans produces significant cold stress as evidenced by thermoregulatory, psychological and motor responses, but does not produce a significant hypothermia in the absence of exhaustion.

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ACKNOWLEDGEMENTS

This dissertation would not have been completed without the contributions (both direct and indirect) of many people.

Research articles on "man in cold" rarely tell the story of stress and discomfort endured by the human subjects: the *Wet Walk* research put extraordinary demands on its subjects. Imagine taking a cold shower in front of a large fan on a cold winter night for 4 hours, then sitting around in your wet clothing for another 1.5 hours. To add insult to injury, you're also asked to walk up to 25 km in this man-made maelstrom. I don't think I need to say more! My thanks, therefore, to the many subjects who volunteered to participate in this unique series of experiments.

Data for this project would not have been collected without the able help of research assistants. Kerry Wilson, in particular, served many winters on the cold front, providing time, talent and insight. Special thanks also to Bart Miller, for his loyalty and hard work.

The production of the *Wet Walk* and associated equipment required the skills and interest of the department technicians, including Gordon Davies (machine shop) and Robert Douwens (electronics). They also tolerated a nonending stream of projects and gadgets – and various degrees of clutter!

Recently, Dennis Payne and Joe Parsons helped to create the atmosphere that allowed me to complete the dissertation.

My family have contributed in a number of ways. My father and mother provided financial and moral support, particularly during the rough times. My sister, Laurel, lent her considerable editorial skills.

Tessa Cherniavsky endured the trials and tribulations associated with graduate school, as well as the long hours I spent at the *Wet Walk*, during the

formative years of research. Those are years I will always remember. Many subjects enjoyed her company, and recuperated with the assistance of her fine cuisine.

The dissertation would never have been completed without the love and support given by Heather Biasio. Heather not only put in long hours by my side, but more importantly, provided the emotional support when the going got tough: the final months were perhaps as hard on her as they were on me! My love and appreciation.

My thanks to the committee for their critical comments and final adjudication of this project.

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And finally, there are the friendly prodders who *never* seemed to stop asking, "So, when will the thesis be done?" I leave you with the sage words of Thomas Marley, author of *A Plaine & Easie Introduction to Practicall Musicke* (1597):

> But as concerning the book itself, if I had before I began it imagined half the pains and labour which it cost me, I would sooner have been persuaded to anything than to have taken in hand such a tedious piece of work, like unto a great sea, which the further I entered into the more before me I saw unpassed, so that at length, despairing ever to make an end (seeing that grow so big in mine hands which I thought to have shut up in two or three sheets of paper) I laid it aside in full determination to have proceeded no further, but to have left it off as shamefully as it was foolishly begun. But then, being admonished by some of my friends that it

were pity to lose the fruits of the employment of so many good hours, and how justly I should be condemned of ignorant presumption in taking that in hand which I could not perform if I did not go forward, I resolved to endure whatsoever pain, labour, loss of time and expense and what not, rather than to leave that unbrought to an end in the which I was so far engulfed.

The *Wet Walk* research was funded by the National Sciences and Engineering Research Council of Canada, and the U.S. Naval Health Research Center (San Diego).

DEDICATION

This thesis is dedicated to all *Wet Walk* subjects, in recognition of your true grit. May all your showers be hot.

October 15th [between Fort Edmonton and Jasper House, 1846] - When we stopped to take breakfast it was very cold and snowing. We held a council, and it was determined that, as the weather had set in so bad, five men and one boat, with the clerk Charles, should return back to Fort Assiniboine with the Russian packs of otter skins. We were now all obliged to crowd into one boat, the others having gone back; and were frequently obliged to disembark and lighten the boat, owing to the unusual lowness of the river. We had almost continually to drag the boat onwards with a line, the men waist deep in water. One of them slipped off a log into deep water, and it was with no small difficulty we saved him from being drowned. We had not extricated him from the river five minutes before his clothes were stiff with ice. I asked him if he was not cold, and his reply was characteristic of the hardihood of the Iroquois, of which tribe our party principally consisted: "My clothes are cold, but I am not."

Paul Kane
Wanderings of an Artist among the Indians of North America

Chapter 1. INTRODUCTION

1.1. Background

Progression into hypothermia during exercise in wet, cold environments has received little research attention. Cooper (1986) states that information on the rate of body cooling in a terrestial environment is not readily available. Current explanations of physiological and behavioural performance during prolonged wet, cold exposure (Maclean and Emslie-Smith 1977; Kaufman 1983; Lloyd 1986) rely on a restricted database (Pugh 1966b, 1967), supplemented by anecdotal descriptions of exposure accidents (Pugh 1964, 1966a; Kreider 1967; Hunter 1968; Strang 1969; Ogilvie 1977). In addition, inferences may be drawn from dry cold exposure or cold water immersion studies. Since 1967, a period characterized by vigorous research on immersion hypothermia (Keatinge 1969; Hayward et al. 1975a, 1975b; Fox et al. 1979; Hayward 1984; Hayward and Eckerson 1984), no direct experimental investigation of this topic has been reported in the literature.

Wet-cold environments are characterized by cold temperatures (near freezing), precipitation (sleet, rain) and wind (Iampietro et al. 1958; Pugh 1966a), conditions typically encountered in outdoor recreation activities, such as hiking and mountaineering (Pugh 1966a; American Alpine Club 1982), caving (Kreider 1967; Thomson 1981), hunting (Hunter 1968), and cross-country skiing (Smolander and Loyhevaara 1986). Recently, hypothermia has received notable attention in long-distance running during wet, cool conditions (Maughan et al. 1982; Newsweek 1982). These conditions also present a significant problem in military conflicts (Vanggaard 1975; McCaig and Gooderson 1986). Reduced thermal insulation of wet clothing, exacerbated by displacement of still air and increased convective heat losses generated by exercise and wind, creates a serious thermoregulatory challenge (Hall et al. 1958; Pugh 1966b).

Experimental and anecdotal evidence (Pugh 1967) suggests that during exercise in wet-cold, core temperature is regulated for at least short periods of time (2 hrs), even at low exercise levels, albeit at lower rectal temperatures than in equivalent dry conditions. Shivering is observed during exercise in cold, concomitant with excess oxygen consumption (Pugh 1967; Nadel et al. 1973; Hong and Nadel 1979). It is assumed that maintenance of thermal balance in wet-cold requires high levels of exercise heat production and thermoregulatory shivering (Maclean and Emslie-Smith 1977), relative to the severity of ambient conditions.

Progression into core hypothermia ($T_{CORE} \leq 35°C$) is attributed to exhaustion and insufficient heat production (Freeman and Pugh 1969; Strang 1969; British Mountaineering Council 1963), implying a shift in thermoregulatory capacity (Maclean and Emslie-Smith 1977). For example, post-exercise, alcohol-induced hypoglycemia can inhibit shivering and result in hypothermia (Haight and Keatinge 1973). However, explanations of a thermoregulatory shift are ambiguous. Diminished heat production resulting from a voluntary reduction in exercise level may not be associated with a state of exhaustion. Fatigue-induced reduction in exercise heat production or cessation of exercise may result in lower core temperature (Pugh 1967), but not hypothermia *per se*. Progression into hypothermia during moderate exercise has not been demonstrated. Therefore, the contribution of shivering thermogenesis to the prevention of hypothermia during exercise has yet to be established.

Two classes of accidental hypothermia have been described, defined by the nature of the precipitating causes: (a) hypothermia occurring in normally healthy individuals as a result of cold exposure, and (b) that occurring in the population at large as a result of problems related to age, disease and/or drug/alcohol abuse (Ledingham and Mone 1980). The term "accidental hypothermia" has been restricted to exposure-related hypothermia (Popovic and Popovic 1974), exposure defined as "severe chilling of the body surface leading to a progressive fall in body temperature" (British Mountaineering Council 1963). The second type of hypothermia is classified as "spontaneous hypothermia" (Popovic and Popovic 1974) or "urban hypothermia" (Miller et al. 1980; Collins et al. 1981). In this paper, hypothermia refers specifically to accidental, exposure-induced hypothermia as defined by Popovic and Popovic (1974).

1.2. Objectives

The primary purpose of this research project was to investigate thermal and metabolic responses to prolonged exercise in moderate cold (5°C) during continuous exposure to rain and wind. The main objective was to induce hypothermia ($T_{CORE} \leq 35°C$) in subjects exposed to these conditions, and subsequently determine if progression into hypothermia was a consequence of fatigue and/or exhaustion.

Secondarily, measures of motor and psychological performance were included in the study, based primarily on observations of subject behaviour made during the early stages of the investigation. The overall purpose was thus expanded to include investigation of the "wet-cold syndrome", a condition characterized by performance decrements without significant hypothermia (Vanggaard 1975). It was presumed that the inclusion of behavioural responses to prolonged wet-cold exposure would enhance the primary purpose of the experiment, the study of hypothermia *per se*.

Three experiments were carried out within the context of this general purpose. The specific objectives of these studies, defined in the following section, are described in the introduction to each experiment.

1.3. Methods Overview

Procedures used in this investigation of wet-cold exposure were developed in accordance with two basic principles: *(1)* to enhance experimental validity, through simulation of "typical" wet-cold exposure conditions experienced by hikers and mountaineers; and *(2)* to induce mild hypothermia ($T_{CORE} \leq 35°C$) in subjects during exposure to these conditions. These objectives were similar to those of early investigations of immersion hypothermia carried out at the University of Victoria (Hayward et al. 1975b).

The design of the experimental hiking trail (*Wet Walk*: Fig. 1.1), the selection of clothing worn by subjects, and the exercise mode (walking), for example, reflect the interest in validity. This experimental situation contrasts to cold exposure studies by Pugh (1966b, 1967) in which subjects were not exposed to continuous rain, but wetted in a shower prior to the experiment, after which they pedalled an exercise bicycle in a cold chamber; it was sometimes necessary for subjects to re-shower as clothing dried (Pugh 1967). However, it should be noted that Pugh also made use of field studies in studying hiking fatigue (Pugh 1969). In retrospect, the simulated hiking scenario created the opportunity to observe spontaneous and unpredicted behaviours that otherwise might not have appeared in a laboratory environment.

This study is unusual in its attempt to deliberately induce significant hypothermia ($T_{CORE} \leq 35°C$). Most investigations of man in cold appear to emphasize general thermoregulatory responses to whole body cold exposure, or

Fig. 1.1. Photograph of the *Wet Walk* from the south side. This photograph was taken during EXP_3 – note the vigilance signal lights in foreground.

specific effects of localized peripheral cooling (Adolph and Molnar 1946; Iampietro et al. 1958; Glickman et al. 1967; Vanggaard 1975; Haymes et al. 1982). Pugh's investigations (1967) and preliminary observations suggested that induction of core hypothermia would require extended exposure times, possibly beyond the limits of subject cold tolerance. Ideally, experimental conditions should enhance core cooling – increasing the likelihood of inducing hypothermia – but at the same time, should not be too severe, causing termination of experiments prior to significant core cooling. For example, in an investigation of reaction time in the cold, Teichner (1958) observed a high subject attrition rate under severe exposure conditions; only 3 of 18 subjects completed the experiment at −26°C with a 30 mph wind. The selection of environmental stress levels, therefore, must accommodate average subject cold tolerance; the challenge is to determine the balance of conditions that maximizes the probability of inducing hypothermia.

A rectal temperature of 35°C (or drop of 2°C) is an experimental standard for hypothermia research (Hayward et al. 1975a, 1975b; Hayward and Eckerson 1984; Fox et al. 1979; Morrison et al. 1979; Giesbrecht et al. 1987). This degree of hypothermia is safe and within the allowable experimental limitations for ethical research. Moreover, the clinical definition of hypothermia is a core body temperature of 35°C or lower (Collins et al. 1977; Ledingham and Mone 1980; Bristow and Giesbrecht 1984).

The common features of the three experiments (EXP_X) introduced in the description of objectives, carried out over a four-year period, are outlined in this section, including a detailed description of the *Wet Walk*. Specific methods are given in the respective chapters in which these experiments are described.

EXP_1 (chapter 2). The effect of walking pace on thermal balance and progression into hypothermia was investigated in the first year of research; a test of cognitive performance was incorporated into the original design. The results of this study demonstrated the need to increase the degree and severity of cold exposure, and illustrated the significance of behavioural responses during wet, cold exposure.

EXP_2 (chapter 3). In the following year, the duration of wet exposure was increased, and wind was included as a factor. Increased attention was given to behavioural responses: tests of motor performance, such as grip strength and balance, and additional objective measures of psychological response, were included in the design.

EXP_3 (chapter 4). A vigilance test was designed and applied in the final research year, based on earlier observations suggesting reduced subject vigilance during prolonged wet-cold exposure.

1.3.1. The *Wet Walk*

Research was conducted at an outdoor facility developed specifically for this project, located in a wooded area approximately 10 km from the University of Victoria, B.C. The experimental exercise track (*Wet Walk*) was a 25-m walking trail, covered by an arched framework supporting a rain-generating sprinkler system (Fig. 1.1). As previously described, an outdoor setting was chosen to facilitate simulation of hiking in wet, cold conditions; it also simplified the logistics of having subjects walk in continuous rain and wind. The site was developed with the intention of creating an environment closely approximating a natural hiking setting. Undergrowth and small trees were removed only where necessary; the *Wet Walk* and associated facilities were located to accommodate local growth. During the winter, ambient temperatures in Victoria are within an appropriate range for wet-cold exposure research (5.0 ± 2.5°C). The location of the facility in a mature coniferous forest provided protection from ambient rain and wind.

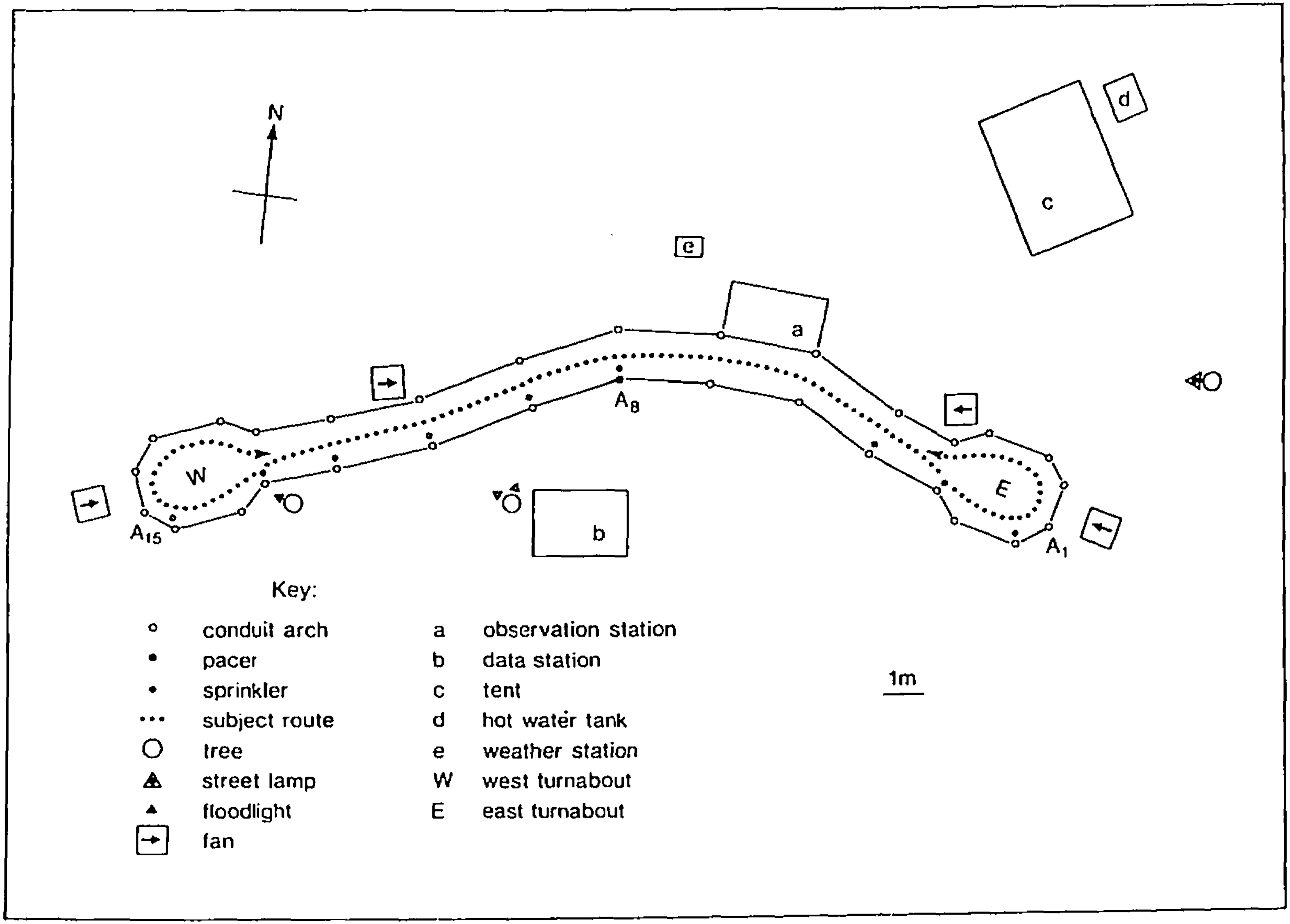
Walking Trail. The walking trail (Fig. 1.2) was slightly curved and followed the contours of the terrain, rising in a gradual incline from the relatively open, flat east end (Fig 1.3) to pass among large coniferous trees towards the west end (Fig. 1.4). The rise towards the west end, from the observation station through the turnabout, was 0.9 m (Fig. 1.5); the overall elevation change was 1.05 m (Appendix A3).

The walking distance for one length of track, from the midpoint of the east end turnabout to the midpoint of the west end turnabout, was 25 m. The trail was 1.2 m wide along the central axis; expanded turnabout areas at each end of the track allowed subjects to reverse direction without interrupting their walking rhythm. To provide consistent footing in wet and dry conditions, the trail bed was layered with wood chips (average depth 20 cm); elevation of the trail bed also enhanced drainage. When compressed by walking, the cedar chips provided a firm walking base; new layers of chips were added as required.

Archway. The archway was designed to provide a support for the sprinkler system, as well as a framework for a tarp designed to protect subjects from ambient rain and wind. The *Wet Walk* arch framework consisted of 15 conduit arches linked by fir strapping at the arch apices, and straight lengths of conduit at the lateral arch angles (Appendix A1). The height of the track at the apex was 2.75 m, and 2.15 m to the level of the lateral arch angle. Further construction details are described in Appendix A.

The roof of the archway was permanently covered with orange plastic polyweave material extending 1 m down the sides of the archway system, affording

Fig. 1.2. Plan of the *Wet Walk* (EXP_2). The fans, weather station, data station, and west end lighting were added after EXP_1.


N
d
c
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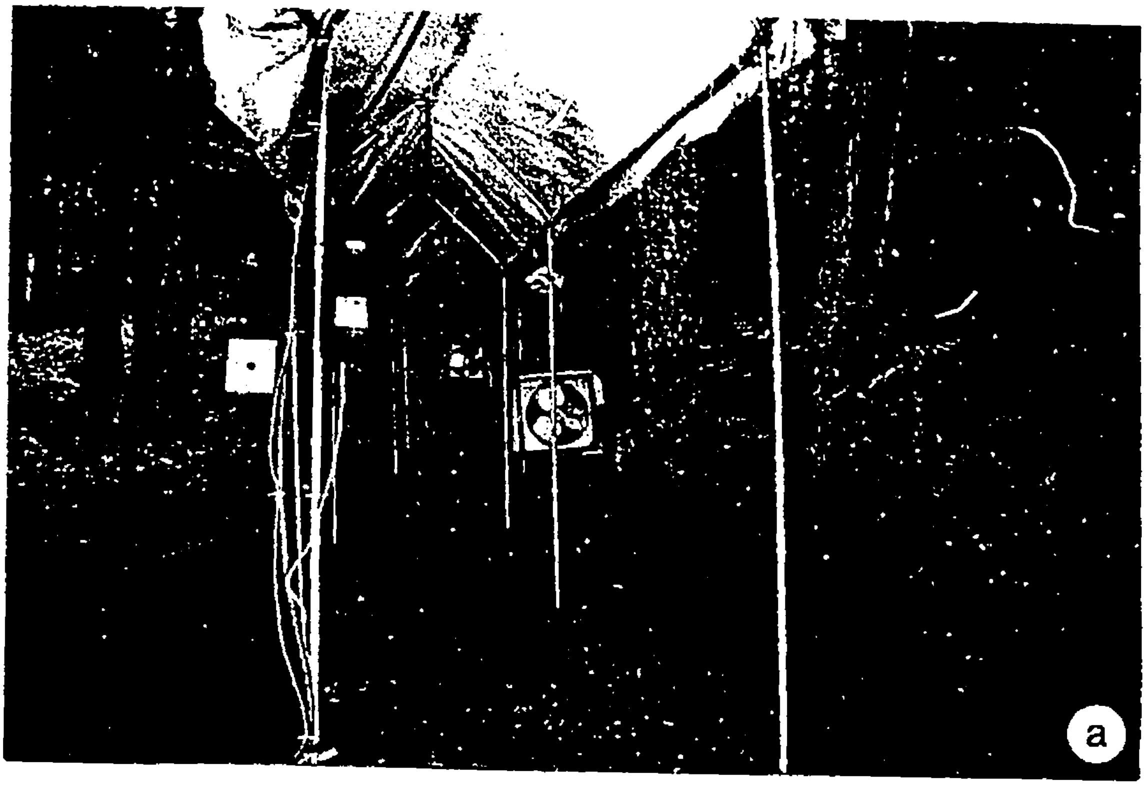
A8
A15
A1
b
Key:
○ conduit arch
● pacer
• sprinkler
••• subject route
○ tree
▲ street lamp
▲ floodlight
→ fan
a observation station
b data station
c tent
d hot water tank
e weather station
W west turnabout
E east turnabout
1m

Fig. 1.3. The east end of the *Wet Walk*. (a) The east end turnabout from opposite the observation area. Note the sprinkler hose ascending the second arch to the right. (b) The observation area from the east end turnabout. Note the tent in the right background. The *TeePee* (EXP_2) is hanging from the arch opposite the observation area. The vigilance control centre data screen (EXP_3) is visible in the observation area.


a

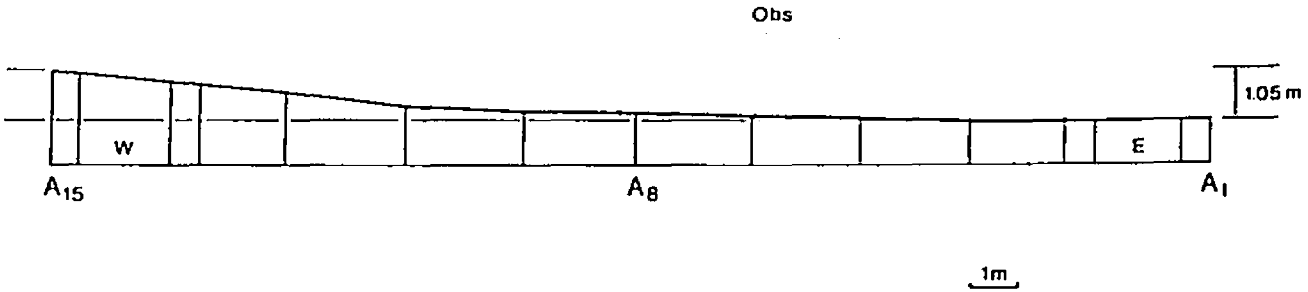

b

Fig. 1.4. The west end of the *Wet Walk*. (a) Looking up the slope towards the west end from the observation area. Note the balance beam and target shoot on the left. (b) Looking down the *Wet Walk* from the west turnabout towards the east end. The data station is on the right; note the tent in the left background.


a


b

Fig. 1.5. Elevation diagram of the *Wet Walk*. The slope at the west end rises 0.9 m. Obs = observation area.

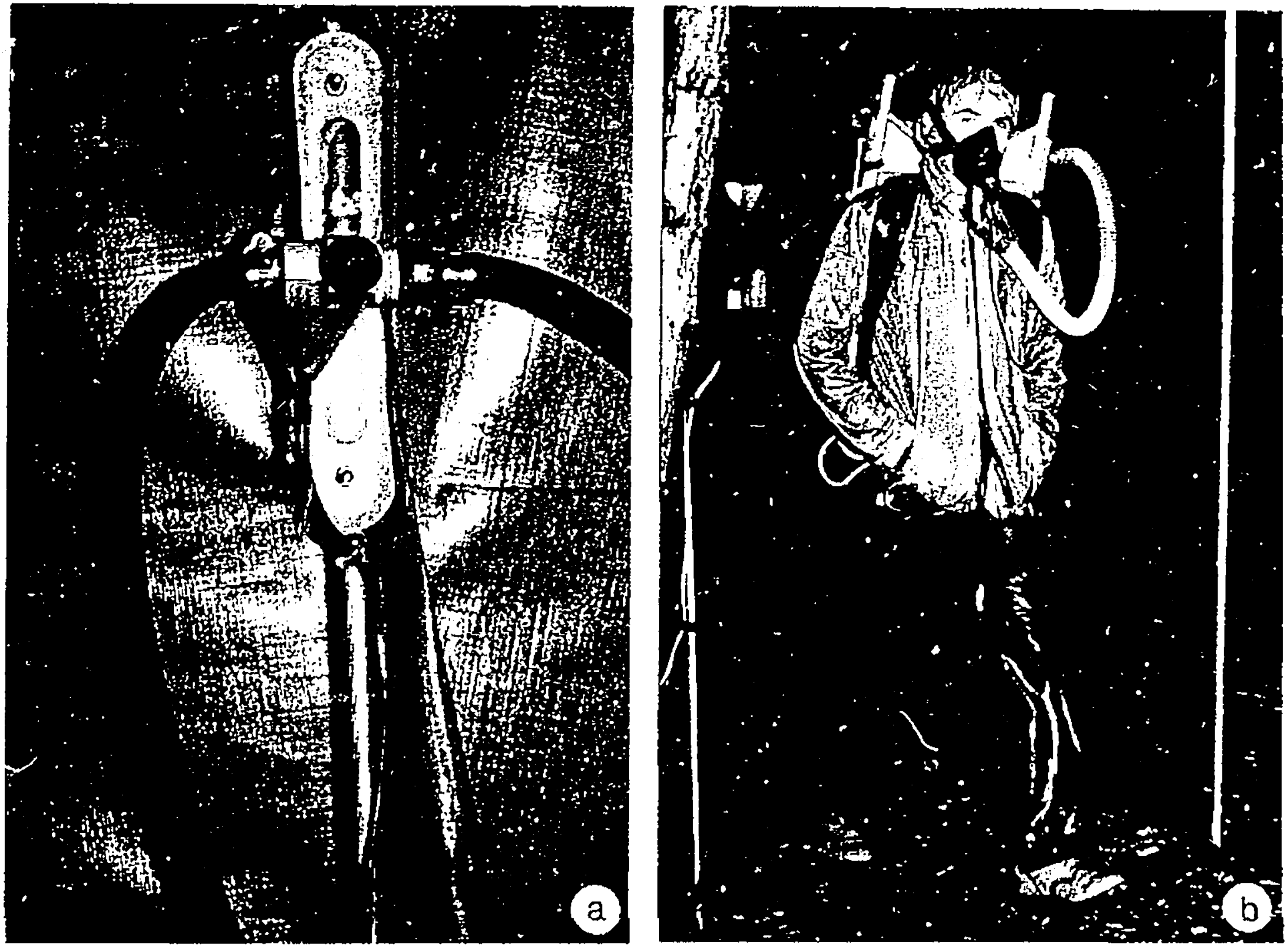

Obs
1.05 m
W
E
A_{15}
A_8
A_1
1m

extra protection from ambient rain and wind; normally, these sidewalls were rolled up to the roofline unless required. The effects of ambient rain and wind were usually negligible due to protection from the surrounding forest (Fig. 1.1).

Rain. "Rain" was created by connecting a series of 9 sprinklers (Nelson Cricket Stationary Sprinklers) along the arches of the south side. These were bolted midway along the arch angle, approximately 2.5 m above the track surface (Fig. 1.6.). The location of the sprinklers is indicated in Fig. 1.2; a series of sprinklers is seen in Fig. 1.4. The sprinklers were turned on by valves located along the south side of the track. Rainfall averaged 7.4 $cm \cdot hr^{-1}$ (Appendix A4), more than sufficient to maintain clothing saturation (Fig. 1.6). Rain was generated along the length of track except for an area opposite the observation area. Temperature of the water at the sprinkler head (Fig. 1.6) averaged approximately 8°C, about 3°C above ambient temperature.

Wind. Four large fans (Sureflame "Air Mover" Model FN-20 Type KRJ variable speed fans; blade diameter 46 cm) were placed along the track at strategic locations, two at the east end facing west (Fig. 1.3), and two at the west end facing east (Fig. 1.4). During each complete lap, wind was at the subject's back for half the circuit and in his face for the remaining half circuit; the subject always faced a headwind proceeding up the hill at the west end (Fig. 1.4). The fans were set to produce a windspeed averaging 8 $km \cdot hr^{-1}$ (headwind at chest level; Appendix A5) along the length of the *Wet Walk*. Windspeed was greatest in the turnabouts and least at the centre of the track in the vicinity of the observation area. A moderate wind speed was chosen since results of a pilot study suggested that the combination of high windspeed and wet exposure would not be tolerated by subjects for extended periods of time.

Fig. 1.6. The *Wet Walk* rain storm: cause and effect. (a) A sprinkler on a *Wet Walk* arch, with the rain temperature measurement system. (b) A saturated subject walking during the wet/wind phase of an experiment (EXP_2).


a
b

Other Facilities. The main observation area was attached to the track along the north side near the midpoint of the *Wet Walk* (Fig 1.3). An auxiliary data shelter (Fig. 1.4) was constructed for EXP_2. The site also included a 2.75 × 3.65-m canvas wall tent (Fig. 1.3) containing a hydrotherapy bath used to rewarm subjects. The tent was heated with a propane heater and temperatures were maintained around 18°C. The tent was also used for subject preparation, equilibration and some psychological testing. Power and water were supplied from connections to sources in the residence on the property, located 75 m from the site. The residence also provided access to an emergency telephone.

Lighting. Exterior lighting was required since most experiments took place at night during winter months. The minimum amount of lighting required for safety was selected in order to retain a storm-like atmosphere. A street light was suspended in a tree (elevation 4 m) near the east end of the *Wet Walk* (Fig. 1.2), lighting the east end of the track and the tent area. The west end of the track was initially illuminated with a single 100W "trouble light" hung from a tree opposite the west turnabout. Lighting at the west end was increased in EXP_2, with the addition of the balance beam and target shoot tests. Three 100W exterior floodlights were mounted in trees on the south side of the *Wet Walk* towards the west end (Fig. 1.2). They were high enough so that they did not shine directly into subjects' eyes. Indirect lighting from the observation areas and tent was also a factor.

1.3.2. Other Common Features

Subjects. Male subjects were recruited from the University of Victoria; most volunteers were undergraduate students in biology, and were familiar with research on immersion hypothermia associated with the University of Victoria. No special guidelines were established in recruiting subjects (except for a specific fitness requirement in EXP_3), apart from meeting medical criteria. The objective was to create a subject pool representing "average" young male university students in respect to fitness and anthropometric characteristics. Standard procedures were followed regarding the rights, health and safety of subjects. Experimental procedures for each experiment were approved by the Committee for Research on Human Subjects at the University of Victoria. Although all subjects were volunteers, they received a small honorarium for participation, regardless of whether or not they completed the protocol. Subjects also received a custom-designed T-shirt.

Ambient Conditions. An ambient temperature of 5.0°C was selected as the experimental exposure temperature. Pugh (1966b, 1967) used an ambient temperature of 5°C in his research, comparable to conditions during the Four Inns walking competition accident (Pugh 1964). It is also at the midpoint of the defined wet-cold zone of -5 to 15°C (Iampietro et al. 1958) and in the "above zero" range discussed by Vanggaard (1975). Given the expected variation in ambient temperature in an outdoor setting, a range of 5.0°C (5.0 ± 2.5°C) was established as the experimental operating temperature range. Minor differences in ambient temperature were not expected to affect regulated core temperature significantly during exercise (Nielsen and Nielson 1962; Kitzing et al. 1968, cited in Brengelmann 1977). Analysis of local temperature data for the period 1976/77 through 1979/80 (Environment Canada records, Victoria International Airport) indicated temperatures within this range an average of 44.4 ± 7.5 days (range 36 - 58 days) between 1700 and 2200 hours, from November through March. A review of this data indicated a sufficient reduction in available days if a lower mean ambient temperature was used as a base (i.e., 3°C). In the winter of 1979/80, for example, only 33 days were in the 1 - 6°C range while 51 days were in the 2 - 7°C range. Experiments were usually conducted in the late afternoon and evening, from December through March. Ambient windspeed was also considered as a factor. A windspeed of 8 $\text{km}\cdot\text{hr}^{-1}$ was set as the maximum allowable limit, although ambient wind movement was rarely a significant factor. Stable environmental conditions were enhanced by location of the research site under a protective forest canopy (Fig. 1.1).

Protocol. A similar protocol was followed in all three experiments, each divided into 5 principal phases:

(1) An equilibration period of 10–15 minutes;

(2) walking at the established pace under dry (no wet/wind stress) conditions, to establish physiological steady-state levels;

(3) walking at pace in rain (and wind in EXP_2 and EXP_3), until completion of the walking phase of the protocol;

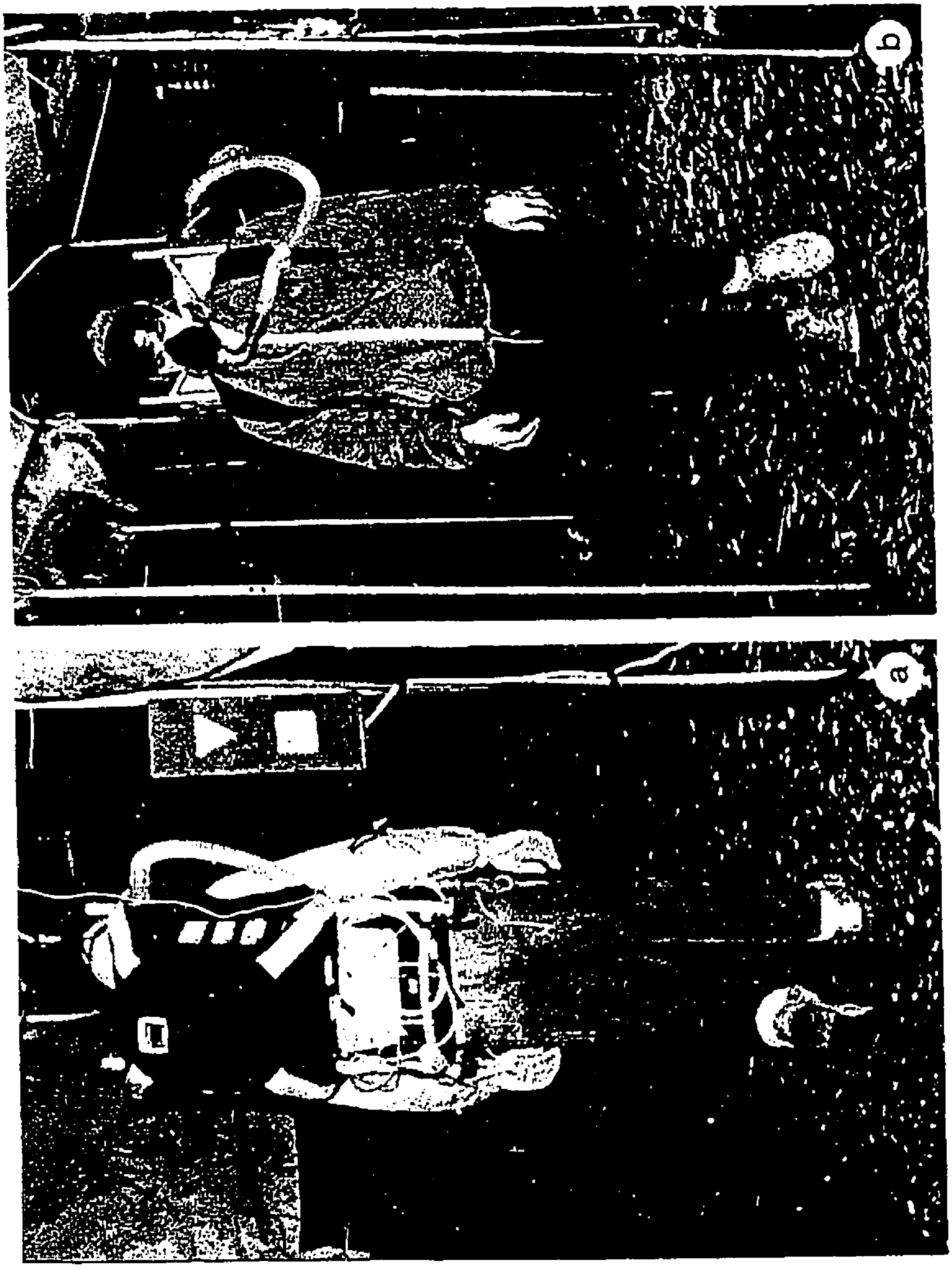
(4) sitting in wet clothing (no rain or wind) for up to 90 minutes;

(5) rewarming in a therapeutic warm-water bath.

Tests of behavioural and psychological performance were incorporated within this fundamental exposure paradigm.

Clothing. Clothing worn by subjects was representative of an "average", unprepared hiker (Fig. 1.7). Subjects dressed in a standard set of clothing: T-shirt, long-sleeved shirt, a non-waterproof nylon "windbreaker", short cotton briefs, long pants, wool socks, and hiking boots. This set of clothing provided less insulation than that used by Pugh (1966b), in order to enhance the cooling rate, and seemed a typical example of clothing worn by an "unprepared" hiker. ("Unprepared" refers to an individual who is out on a day outing, neither expecting rain or stormy weather

Fig. 1.7. Subjects walking along the *Wet Walk*. (a) Walking towards the east end of the *Wet Walk* at the midpoint of the track, showing back of backpack (EXP_2), and (b) approaching the east end of the *Wet Walk* (EXP_3). Note the clothing difference in these photographs (footwear and pants).


a
b

nor prepared for an overnight bivouac.) During wet-wind exposure, subjects raised the hood on the jacket, in order to reduce cold discomfort, thereby maximizing the time of experimental exposure.

Backpack. Subjects carried a lightweight, insulated backpack containing apparatus for measuring thermal, metabolic, and cardiac variables (Fig. 1.7). This system was initially developed to allow the subject to walk unimpeded by an umbilical system. The backpack was also consistent with a mountaineering scenario, and precedent was noted in the literature (Durnin, 1955).

Exercise mode. Walking was chosen as the appropriate exercise, in keeping with the mountaineering scenario. While exercise level (walking pace) was an independent variable in the first research year (EXP_1), a single moderate pace was adopted in the final two years of research (EXP_2, EXP_3).

Subjects exhibited a marked ability to maintain a consistent walking pace, after an initial learning period of 10–15 minutes. A constant pace was particularly important during wet exposures in order to facilitate the estimation of shivering thermogenesis. Feedback mechanisms were used to assist a subject in maintaining a constant pace, and to provide information on subject pace to the experimenter.

Physiological variables. The principal variables investigated were rectal temperature, skin temperatures and metabolic rate. Heart rate was also monitored continuously. Most of the devices used to measure these responses were carried by the subject in the backpack. Subjects wore an oronasal mask connected to the Oxylog carried in the backpack (Fig. 1.7). Subjects were stopped at regular intervals in order to record output from devices carried in the pack.

Behavioural variables. Various tests of motor and psychological performance were included within the framework of the cold exposure syndrome. For example, the *PETER* subtest (Appendix G) was completed by subjects during rest breaks and the sitting period in EXP_1. Generally, behavourial measurements were ancillary to physiological interests, and served primarily as indices of changes in physiological status.

Analysis of Results. In all experiments, analysis was complicated by subject attrition or occasional equipment malfunction. Generally, results were analyzed with respect to: (1) group means based on similar tolerance times, and (2) individual responses, when a subject represented a typical or unusual response.

Chapter 2. EFFECTS OF WALKING PACE AND RAIN ON THERMAL AND METABOLIC RESPONSES OF LIGHTLY-CLOTHED SUBJECTS EXERCISING IN A COLD ENVIRONMENT (EXP_1)

2.1. Introduction

Interpretations of wet-cold exposure hypothermia are largely based on the results of a single study (Pugh 1967), part of a series of papers on exposure hypothermia (Pugh 1964, 1966a, 1966b, 1967, 1969) stimulated by the tragic deaths of three youths during the Four Inns walking competition (Pugh 1964). In order to test for a causative relationship between exhaustion and hypothermia, Pugh investigated the interactions of exercise thermogenesis, shivering thermogenesis and core temperature. Anecdotal information suggested a strong relationship between hypothermia and exhaustion during exposure incidents. Conversely, individuals who stopped prior to exhaustion, and found simple shelter, frequently survived a night of exposure (Pugh, 1966b).

Subjects ($n = 3$) in Pugh's experiment (1967) exercised in wet mountaineering clothing for two hours in an environmental chamber at 5°C, exposed to a 15 $km \cdot hr^{-1}$ wind, on a bicycle ergometer. Pugh demonstrated that at lower exercise levels, there was a 0.4 to 0.5 $l\ O_2 \cdot min^{-1}$ increase in oxygen consumption above that for the same level under dry conditions, and that this increase was related to shivering. At high work loads (above 800 $kg \cdot m \cdot min^{-1}$), no difference was seen in the metabolic response between wet and dry conditions, and subjects did not shiver.

Changes in rectal temperature followed a similar course. At low exercise levels, mean rectal temperature was 0.6°C below that for the dry level; this difference decreased with increasing loads until work rates above 800 $kg \cdot m \cdot min^{-1}$.

at which little or no difference was observed between wet and dry conditions. Mean levels of core temperature for all exercise levels following 2 hours of exposure were above 36°C, despite considerable discomfort expressed by subjects. Pugh was unable, however, to demonstrate a direct relationship between exhaustion, shivering thermogenesis and rectal temperature.

Nonetheless, he suggested that fit individuals able to maintain high levels of exercise heat production would maintain high core temperatures near dry, "set-point" levels, and could maintain such activity for prolonged periods. Less fit individuals would be forced to walk at slower paces, with an increased VO_2 due to shivering, suffering greater heat losses and operating at lower rectal temperatures, or be forced into a state of exhaustion at higher paces. However, no data are presented to support this hypothesis (fitness levels of subjects were not reported). The data show that at lower heat productions, lower levels of rectal temperature are reached.

Unfortunately, Pugh did not compare post-exercise cold stress responses. If exhaustion was a factor, then impairment of shivering may have resulted in lower core temperatures achieved by higher-fatigued individuals (Hervey 1973). Secondly, once rectal temperature appeared to approach steady levels, suggesting thermal balance, the experiments were stopped. It is therefore difficult to predict whether or not rectal temperature would be regulated at these lower levels. If core temperature was regulated, how long would this status be maintained?

Exhaustion during prolonged exercise is primarily based on depletion of glycogen reserves (Pruett 1970), accompanied by a fall in blood glucose. Low levels of muscle glycogen may interfere with shivering (Hervey 1973). Haight and Keatinge (1973) demonstrated that alcohol-associated impairment of energy mobilization and reduced shivering after exhaustive exercise lead to mild hypothermia, indirectly supporting the claim that exhaustion may be a critical factor in maintaining thermal balance during exposure. Recently, Davies et al. (1975) and Bergh and Ekblom (1979) have demonstrated that maximal aerobic capacity decreases with decreasing body temperature. Pugh's 1967 proposal is therefore consistent with general expectations. However, there is no direct experimental evidence to support the claim that exhaustion alone causes hypothermia.

This first set of experiments was designed to compare thermal and metabolic adjustments to wet-cold exposure at different exercise levels (walking paces), ranging from 0 (sitting) to 6 $\mathrm{km \cdot hr^{-1}}$. It was expected that individuals walking at the low pace (3 $\mathrm{km \cdot hr^{-1}}$) might become hypothermic during the exercise phase of the experiment due to low exercise heat production. Conversely, individuals who became exhausted at the high exercise rate (6 $\mathrm{km \cdot hr^{-1}}$) would be expected to show a decrease in rectal temperature associated with decreased exercise and/or shivering thermogenesis. Before, during, and after exposure, a set of four cognitive tests was administered to subjects as a means of evaluating changes in cognitive performance with progressive body cooling.

2.2. Methods

Pilot studies were conducted during summer and autumn preceding $\mathrm{EXP_1}$ to test apparatus and procedures in both wet and dry conditions, although at temperatures above the experimental range. Subjects were able to maintain a consistent pace, and completed the walks without incident. The backpack used in these studies (Appendix E1) was not suitable for use in ambient temperatures below 5°C, due to the apparent effects of cold on electronic recording devices, and a second pack (Appendix E2) was constructed for use in $\mathrm{EXP_1}$.

2.2.1. The *Wet Walk*

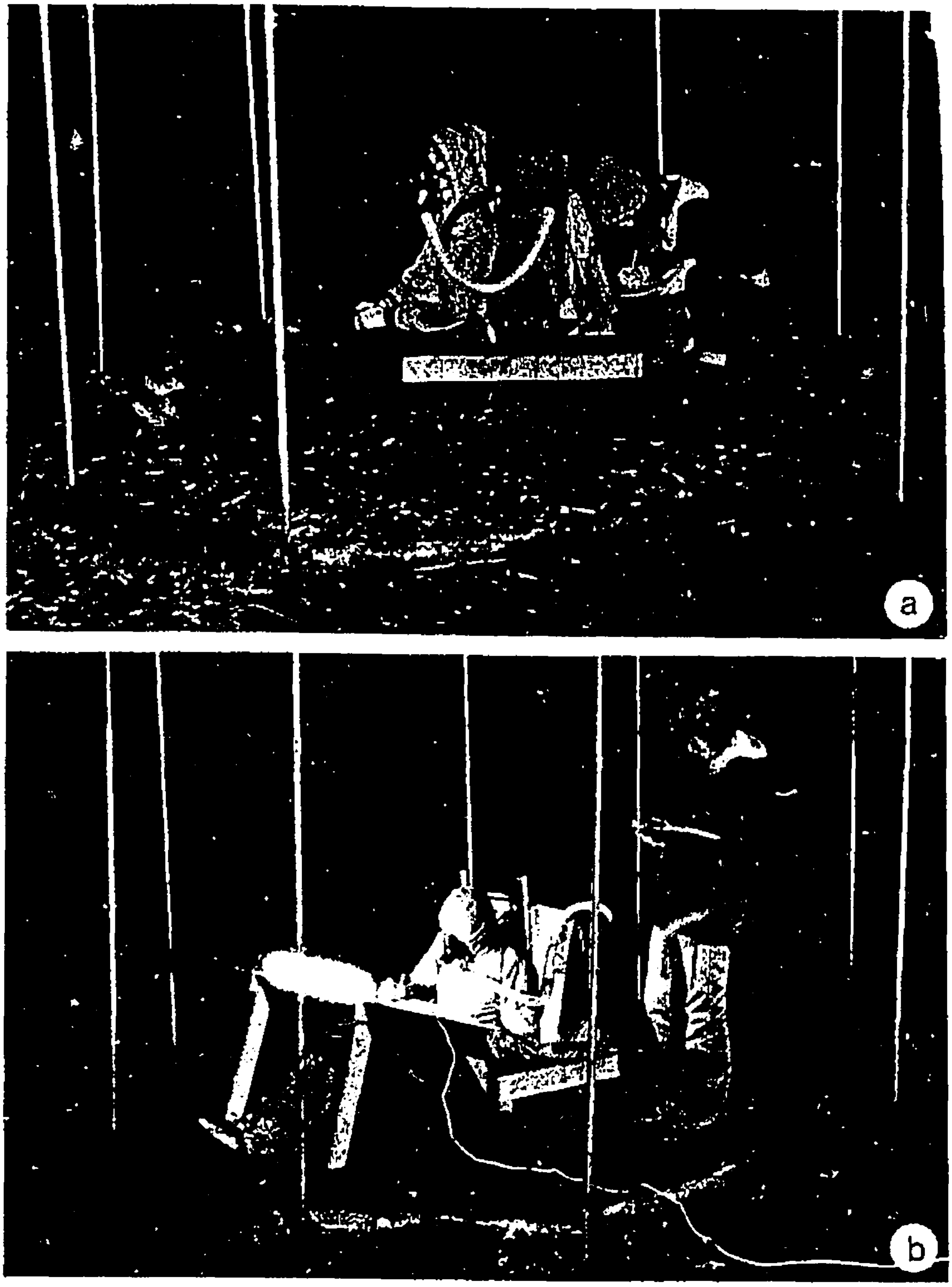
The layout of the *Wet Walk* was similar to that shown in Fig. 1.2, with minor differences. The fans, Stevenson weather screen and data station were not added until EXP_2. As previously described, the west end of the track was illuminated by a 100W "trouble light" suspended from a tree on the north side of the west turnabout. During the sitting periods of the protocol, i.e. equilibration, completion of *PETER* tests during rest periods, and the final sitting stage, subjects sat on an elevated area in the center of east turnabout (Fig. 2.1).

2.2.2. Subjects

Experimental procedures were approved by the Committee for Research on Human Subjects at the University of Victoria. Each subject was informed of his right to withdraw from the experiment at any time; subjects were reminded of this right prior to the beginning of an experimental session. An experiment was normally terminated if *(a)* rectal temperature reached 35°C, or *(b)* a subject requested to withdraw from the experiment. The experimenter also reserved the right to terminate an experiment if he felt the subject's health and/or well-being was in jeopardy.

Subject selection. Thirty-one male subjects volunteered to participate in the experiment. Informed consent was obtained from each subject after he had been familiarized with the purpose and procedures of the study. Subjects also completed a medical history questionnaire and the *ParQ* questionnaire (B.C. Ministry of Health 1978) prior to testing; individuals indicating any potential risk to health or safety were not included in the study. Participation was also dependent on completion of a fitness test (PWC_{170}; Astrand and Rodahl 1977) indicating a reasonable level of fitness.

Fig. 2.1. Subject seated in east end turnabout. (a) During the sitting phase of the experiment. (b) Completing a *PETER* test. Note the pack support.


a
b

Subject characteristics. Subject characteristics are summarized in Table 2.1. Fitness level was established using a submaximal bicycle ergometer test and aerobic capacity (Vo_{2max}) estimated from predictive tables based on cardiac frequency (Astrand and Rodahl 1977: 351). Height [HT], weight [WT], and skinfold measures were recorded for each subject. Mean skinfold thickness [MSK] was the average value of skinfold measurements taken at six standard sites: triceps [TRI], subscapular [SUB], suprailiac [SUP], abdominal [ABD], thigh and calf. Percentage body fat [$\%BF = 5.783 + (TRI + SUB + SUP + ABD) \times 0.153$] (Yuhasz 1962), surface area [$SA = (.202 \times WT^{0.425}) \times HT^{0.725}$] (Dubois and Dubois 1916: cited in Davies et al. 1986), and surface area:volume ratio [$SVR = (SA \cdot 10^{5} \cdot WT^{-1}$] (Graham 1983) were calculated as additional indices of possible relationships between thermoregulatory responses and anthropometric characteristics.

2.2.3. Clothing

Subjects dressed in a standard set of clothing: T-shirt (Stanfield's; 100% cotton); light flannel work shirt (Delta Brand; 100% cotton); a soft, lightweight, non-waterproof, unlined nylon "windbreaker" (Galliano CAD0018; 100% nylon taffeta); cotton briefs; jeans; wool socks (Hanson *Wigwam*); and leather work boots (Kodiak *Badlanders*), the latter serving as hiking boots. All clothing, except the jeans and briefs, was provided for the subjects. The dry weight of an average set of clothing was approximately 3.0 kg (wet weight 5.2 kg), with an estimated clo value of 1.2, based on comparative sets of clothing (Pugh 1966b).

2.2.4. Backpack

The insulated foam/fiberglass backpack carried by subjects in this experiment (Fig 2.1; Appendix E2) weighed 9.1 kg when fully loaded. In wet conditions, it was covered with a waterproof nylon packcover for additional

Table 2.1. Subject characteristics (EXP_1: n = 31)

Characteristic	Mean ± SD
Age (yr)	21.4 ± 2.7
Height (cm)	174.0 ± 6.8
Weight (kg)	67.3 ± 7.2
Surface area (m^2)	1.80 ± 0.11
Area:volume ($cm^2 \cdot kg^{-1}$)	269.4 ± 14.7
Skinfold (mm)	8.9 ± 2.8
% Body fat	11.3 ± 1.8
VO_2max (ml $O_2 \cdot min^{-1} \cdot kg^{-1}$)	48.2 ± 8.3

protection. Although the pack provided some direct protection from the rain, water ran freely down subjects' backs.

2.2.5. Walking Pace

Walking Pace. Three different walking paces were studied, as well as a non-exercising control condition. Walking pace was based on time to complete a lap (50m). The three pace (P_X) equivalents were:

P_L	Low	50 m/60 sec, or 3.0 $km \cdot hr^{-1}$;
P_M	Moderate	50 m/40 sec, or 4.5 $km \cdot hr^{-1}$; and
P_H	High	50 m/30 sec, or 6.0 $km \cdot hr^{-1}$.

Indicators placed on a darkroom timer adjacent to the track in the observation area, visible both to the subject and experimenter, helped the subject to maintain the given pace. In the non-exercising control condition (P_0), subjects sat in the centre of the east turnabout throughout the experiment (Fig. 2.1).

Distance Walked. The total estimated distance walked during a complete experimental session varied with pace:

P_L - 8.9 km; P_M - 13.3 km; and P_H - 17.8 km. These distances have been adjusted to include the time required to stop for data recording (Appendix B1).

2.2.6. Protocol

Initially, subjects were randomly assigned to one of three paces (P_L, P_M, or P_H) or a non-exercising control condition (P_0) (Table 2.2), within experimental limitations. Due to subject attrition, equipment malfunctions, and additional recruitment of subjects, some balancing of subject assignment was done. Comparative non-rain control walks were completed by subjects who did a wet walk at the same pace. The order of occurrence was random. A review of the summary

Table 2.2. Experimental design (EXP_1)[1]

	Pace[2]			
Condition	P_0	P_L	P_M	P_H
Wet	5	8	9	10
Dry	2	2	2	2

[1] Number of subjects starting an experiment

[2] P_0 = 0 km/hr; P_L = 3 km/hr; P_M = 4.5 km/hr; P_H = 6 km/hr

of subject characteristics (Table 2.3) indicates no significant differences between groups.

The protocol is summarized in Table 2.4. Subjects walked an initial 90 minutes, rain beginning after 45 min. Following a 10-min rest, subjects completed two 50-min walking periods interposed by a rest stop, then sat for 60 min in their wet clothing before rewarming. *PETER* subtests were completed at the times indicated in Table 2.4.

2.2.7. Physiological Variables

Rectal temperature. Rectal temperature was initially measured with a REAKIT 3200D digital thermometer system (RAE Industrial Electronics Ltd, Burnaby, B.C.), using a type AD590JH thermosensor (coaxial cable) enclosed in heat shrink cap, inserted 15 cm beyond the anal sphincter; the digital display was carried in the pack. In later experimental trials, this was replaced with a YSI series 400 rectal thermistor (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). The telephone jack connector for the probe was carried in a waterproof container by the subject; at scheduled stops, the jack was removed from this container and connected to a YSI tele-thermometer for temperature readout.

Skin temperatures. Skin temperatures were recorded at four standard sites (arm, chest, calf, thigh), and mean skin temperature calculated using the weighted formula of Lund and Gisolfi (1974). Skin temperatures were measured using individual digital RAEKIT 3200D thermometers mounted in the plastic cases in the backpack (Appendix E2). The sensors (Appendix C1), were held in place on the skin with a 2.5-cm-square piece of Elastoplast waterproof adhesive tape.

Oxygen consumption/ventilation rate. Oxygen consumption and ventilation rate were measured with a portable Oxylog oxygen consumption meter (P.K.

Table 2.3. Subject characteristics (EXP_1), grouped by walking pace (mean ± SD)

Characteristic	Pace			
	P_0	P_L	P_M	P_H
n	5	8	8	10
Age (yr)	21.6 ± 4.2	21.9 ± 3.3	21.3 ± 2.4	21.1 ± 1.7
Height (cm)	173.4 ± 7.5	174.4 ± 5.6	171.7 ± 7.0	175.8 ± 7.7
Weight (kg)	68.1 ± 4.1	69.5 ± 8.8	63.4 ± 6.8	68.2 ± 7.0
Surface area (m^2)	1.81 ± 0.10	1.83 ± 0.13	1.74 ± 0.10	1.83 ± 0.11
Area:mass ($cm^2 \cdot kg^{-1}$)	265.8 ± 5.4	265.3 ± 16.9	276.0 ± 16.2	269.1 ± 14.8
Mean Skinfold (mm)	8.7 ± 3.1	8.8 ± 2.7	10.0 ± 3.4	8.3 ± 2.5
% Body Fat	11.4 ± 2.0	11.1 ± 2.0	11.6 ± 2.0	11.1 ± 1.7
VO_2max ($ml\ O_2 \cdot min^{-1} \cdot kg^{-1}$)	42.0 ± 5.3	48.3 ± 9.4	50.1 ± 7.5	49.7 ± 8.8

Note: Data for subject S_{M2} not included as subject stopped before protocol completed, and repeated experiment in P_0.

Table 2.4. Protocol for P_L, P_M AND P_H (EXP_1)[1]

t_{CUM} (min)	t_{ACT} (min)	Activity	Description
-10 - 0	10	SITTING	EQUILIBRATION/*PETER*$_1$
0 - 45 45 - 90	90	WALKING *(DRY)* WALKING *(WET)*[2]	Walking... ... rain at 45 min
90 - 100	10	SITTING	*PETER*$_2$
100 - 150	50	WALKING *(WET)*[2]	Walking in rain...
150 - 160	10	SITTING	*PETER*$_3$
160 - 210	50	WALKING *(WET)*[2]	Walking in rain...
210 - 270	10	SITTING	*PETER*$_4$ (210 - 220) *PETER*$_5$ (260 - 270)
	60	SITTING	Rewarming in hot bath
	10	SITTING	*PETER*$_6$ (in tent)

[1] Subjects in P_0 remain sitting during walking phases.

[2] In dry conditions, subjects continued walking according to set pace, but without rain

t_{CUM} = cumulative experiment time
t_{ACT} = activity time

Morgan Ltd., Chatham, Kent, England) mounted in the backpack. The subject wore an oronasal mask connected to the Oxylog. Minute oxygen consumption (VO_2) was read directly from the Oxylog at the scheduled data recording stops, and metabolic rate calculated in watts using the conversion factor of 20.2 $kJ \cdot l\, O_2^{-1}$ consumed (assuming an R.Q. of 0.83). Minute ventilation (V_E) was estimated from the change in total inspired volume over the five-minute period. In some experiments, VO_2 was calculated from cumulative O_2 consumption and V_E read directly from the Oxylog.

Heart rate. Cardiac activity was monitored by radio telemetry (Parks Electronics Laboratory, Beaverton, Oregon: ECG Telemetering Transmitter Model 27-1; ECG Telemetry Receiver Model RC-27) and heart rate extrapolated from the recorded time for 30 beats. The transmitter was carried in the backpack (Appendix E2). One sample was recorded every five minutes.

2.2.8. *PETER* Test

The *PETER* subtest (Appendix G1), supplied by the U.S. Naval Health Research Center (San Diego), was used to measure general cognitive function. Four tests – the Baddeley reasoning test, a coding test, a number comparison test, and a tapping test – were included in the package. The decision to include the test was made after the experiment had been designed; therefore, the tests were completed during scheduled 10-minute rest breaks and the sitting phase of the experiment (Table 2.4). During wet experiments, subjects put on elbow-length, waterproof nylon sleeves during completion of the test in order to protect the test from wetting.

The four tests required less than 10 minutes to complete: Baddeley test (1 min), coding test (4 min), number comparison test (3 min), and tapping test (36 sec).

Baseline. Two preliminary learning (baseline) tests were completed in the laboratory at the University of Victoria or at the *Wet Walk* prior to the walk. Generally, subjects were reminded to write the test as rapidly and accurately as possible. Any questions regarding the nature of the tests were clarified during these practice tests.

Experiment Test Periods. During the experiment, the *PETER* subtests were delivered 6 times (Table 2.4): *(1)* during equilibration prior to the initiation of walking; *(2)* after 90 minutes of walking, during the first rest break; *(3)* during the second rest break at 150 minutes; *(4)* at the beginning of the sitting period; *(5)* at the end of the sitting period; and *(6)* after rewarming. The final test was completed in the tent. The tests were forwarded to the U.S. Naval Health Research Center (N.H.R.C.) for analysis.

2.2.9. Procedures

Subjects were requested to maintain a normal diet, avoid alcohol consumption and refrain from exercise during the 24-h period preceding an experiment. As the experiment began in the late afternoon, subjects were asked to eat a light lunch. No food or water was given to subjects during an experiment. Subjects arrived at the *Wet Walk* at approximately 1600 hours. They were informed of the test conditions at this time, and familiarized with the *Wet Walk* and the pace at which they would be walking. Following application of temperature sensors and ECG electrodes, the subjects dressed in the supplied, standard clothing.

Subjects then proceeded to the sitting area at the west end of the *Wet Walk*, where they completed the first *PETER* test, and resting levels of rectal temperature, skin temperatures, oxygen consumption, ventilation rate and heart rate were recorded. After the equilibration period, final instructions were given to the subject and the walking phase of the experiment began at approximately 1700 hours. Subjects walked continuously for the next 90 minutes, stopping briefly (30 sec) at 5-minute intervals for thermal and metabolic data readings. The rain was turned on following the 45-minute reading. The experiment continued until the end of the final sitting period, as described in Table 2.4. During rest breaks, the rain was turned off; it was turned on again during the first lap of walking after the break. At the end of the walking period (210 min), the rain was turned off, and the subject sat for 60 minutes in his wet clothing, with data recording continuing at 5-minute intervals. At the conclusion of the sitting period, the subject proceeded to the tent for rewarming, food and drink.

2.2.10. Ambient Conditions

Ambient air temperature was monitored with a YSI general purpose thermistor suspended in the air opposite the observation area; relative humidity was measured with a sling psychrometer (Bacharach Model SAC) at the side of the track adjacent to the observation area. Observed wind movement was not a significant factor, ranging from "nil" to "negligible" ($< 0.5\ \text{m} \cdot \text{sec}^{-1}$). Wind speed was recorded with an air meter (WEATHERtronics Model 2410) held at chest level.

As evident in Tables 2.5 and 2.6, ambient temperatures exceeded experimental criteria in many experiments, although the average temperatures were within the acceptable limits. The mean temperatures for wet experiments at the initiation of rain were: $P_0 = 7.3 \pm 2.6°C$ (n = 5); $P_L = 6.7 \pm 2.3°C$ (n = 8); $P_M = 6.9 \pm 1.5°C$ (n = 9); and $P_H = 7.1 \pm 2.3°C$ (n = 10). These differences were not statistically significant, based on standard deviation overlap. Ambient temperatures were generally stable over the course of an experiment; the temperature range was 1°C or less in 25 of 32 wet walks.

2.2.11. Analysis of Results

Analysis was based on three criteria: *(1)* comparison of group (pace) data, based on completion of protocol and complete rectal temperature data; *(2)* comparison of individual data for subjects completing wet and dry walks at the same pace (n = 2 for walking paces); *(3)* individual data indicating typical or unusual responses.

Data are summarized as the mean ± standard deviation (SD), unless otherwise indicated. In graphs, significance was assumed when standard deviations did not overlap (Browne 1979; Rosenblood, pers. comm.).

2.3. Results

2.3.1. Subject Performance

Subject performance is summarized in Table 2.5 (wet walks) and Table 2.6 (dry walks). Walking-pace groups are based on the subject composition described below.

Two general statements can be made regarding subject performance during wet-cold exposures.

(1) No experimental sessions were terminated due to hypothermia (rectal temperature ≤ 35°C); in the exercise groups, only four subjects (S_{L4}, S_{M2}, S_{M4}, S_{M5}) had rectal temperatures below 36.5°C at the end of the walking phase, and only one (S_{M2}) below 36.0°C.

(2) Despite the absence of clinical hypothermia, subjects exhibited behaviours often used to describe hypothermia, including intense shivering, reduced motor abilities, loss of manual dexterity, mood depression and withdrawal. The relatively high rectal temperatures did not correlate with the level of cold stress experienced by subjects. One subject (S_{L4}) who had previously participated in an ice-water

Table 2.5. Summary of subject performance: wet walks (EXP_1)

S	t_{EXP}	T_{Re}	T_{Amb} (°C)		Description
	(hrs)	(°C)	T_{rn}	T_{end}	
P_0					
S_{01}	3.5	35.9	5.9	5.0	Complete
S_{02}	3.5	36.9	9.2	6.7	Complete
S_{03}	3.5	36.2	8.4	8.0	Complete
S_{04}	3.5	36.7	3.4	3.7	Complete
S_{05}	2.7	37.3	9.6	8.4	HR arrythmia
P_L					
S_{L1}	3.5	37.2	6.6	6.5	Complete
S_{L2}	3.5	36.9	9.6	8.1	Complete
S_{L3}	3.5	36.5	4.2	3.4	Complete
S_{L4}	3.5	36.0	3.6	2.9	Complete
S_{L5}	3.5	37.1	8.8	7.1	Complete
S_{L6}	3.5	36.8	9.2	9.4	Complete
S_{L7}	3.5	37.3	6.3	6.0	Complete
S_{L8}	3.5	37.7	5.2	5.4	Complete
P_M					
S_{M1}	3.5	37.4	9.2	8.3	Complete
S_{M2}	3.5	35.6	7.8	6.8	Complete
S_{M3}	3.5	36.5	5.7	3.4	Complete
S_{M4}	3.5	36.2	5.9	5.8	Complete
S_{M5}	3.5	36.3	4.8	3.2	Complete
S_{M6}	3.5	36.7	6.6	6.0	Complete
S_{M7}	3.5	36.7	8.5	8.6	Complete
S_{M8}	2.7	37.4	5.8	6.5	Muscle pain (leg)
S_{M9}[1]	3.5		8.1	8.0	Complete
P_H					
S_{H1}	3.5	37.4	5.2	4.6	Complete
S_{H2}	3.5	37.4	9.2	9.0	Complete
S_{H3}	3.5	36.7	7.2	7.0	Complete
S_{H4}	3.5	36.6	11.7	8.7	Complete
S_{H5}	2.7	37.2	8.0	5.1	Knee pain
S_{H6}	2.7	36.8	6.8	6.6	Intense shivering
S_{H7}	3.5	37.9	5.8	5.8	Equipment problems
S_{H8}	3.5	38.4	3.6	3.6	"Spitter"
S_{H9}	3.5	36.5	7.6	7.2	Slow pace
S_{H10}	3.5	37.8	6.0	5.0	"Spitter"

[1] Rectal thermometer malfunction

t_{EXP} = walking time; T_{Re} = rectal temperature at end of walking period; T_{Amb} = ambient temperature; T_{rn} = T_{Amb} at 45 min (rain on); T_{end} = T_{Amb} at end of walking period

Table 2.6. Summary of subject performance: dry walks (EXP_1)

S	t_{EXP} (hrs)	T_{Rc} (°C)	T_{Amb} (°C)		Description
			T_m	T_{end}	
P_0					
S_{01d}	3.5	36.7	4.3	3.6	Complete
S_{02d}	3.5	36.8	7.9	7.5	Complete
P_L					
S_{L1d}	3.5	37.6	7.2	6.7	Complete
S_{L2d}	3.5	37.8	3.0	3.5	Complete
P_M					
S_{M1d}	3.5	37.5	5.0	4.4	Complete
S_{M2d}	3.5	37.1	−1.5	−0.5	Complete
P_H					
S_{H1d}	3.5	38.1	8.8	7.0	Complete
S_{H2d}	3.5	38.6	5.0	5.4	Complete

t_{EXP} = walking time; T_{Rc} = rectal temperature at end of walking period; T_{Amb} = ambient temperature; T_m = ambient temperature at 45 min (*no* rain); T_{end}: = ambient temperature at end of walking period immersion study (Hayward and Eckerson 1984), stated that he would rather repeat the shorter cold water immersion experiment than repeat his *Wet Walk* experience.

P_0 (S_{01-04}: n = 4). Due to a persistent arrythmia, the experimental session of S_{05} was stopped at 150 min. Mean ambient temperature for the group was 6.7 ± 2.6°C (range 3.4 - 9.2°C) at the initiation of rain (t_{45}), decreasing to 5.9 ± 1.9°C (range 3.7 - 8.0°C) by the end of the rain exposure (t_{210}). Metabolic data do not include S_{03}.

P_L (S_{L1-L8}: n = 8). All subjects completed the experiment without complications. However, Oxylog data were incomplete or invalid in 3 cases. Therefore, metabolic data were based on 5 subjects (S_{L1-L3}, S_{L6-7}). The mean ambient temperature was 6.7 ± 2.3°C (range 3.6 - 9.6°C) at t_{45}, and decreased to 6.1 ± 2.2°C (range 2.9 - 9.4°C) by t_{210}.

P_M (S_{M1-M7}: n = 7). Data from seven of the nine experiments were used for the walking phase; rectal temperature data were not included for subject S_{M7} during the sitting phase (T_{Re} thermosensor malfunction). S_{M8} failed to complete the protocol due to pain and cramping in the thigh region; the rectal temperature of S_{M9} surged during the final walking period (to 39.3°C) for unknown reasons (suspected battery power loss). Metabolic data for S_{M6} and S_{M7} were not included (Oxylog malfunction). Mean ambient temperature was 6.9 ± 1.6°C (range 4.8 - 9.2°C) at t_{45}, decreasing to a mean temperature of 6.0 ± 2.1°C (range 3.2 - 8.6°C) at t_{210}.

P_H (S_{H1-H4}: n = 4). Only four of ten subjects completed the protocol according to plan. Subject S_{H5} was forced to stop at t_{150} due to knee pain. S_{H6} was shivering so severely at the beginning of the final walking phase ($t_{160-165}$) that he was unable to maintain the pre-established pace; the experiment was terminated for safety reasons. S_{H7}, S_{H8} and S_{H10} completed the protocol; however, extended interruptions in the protocol occurred in each case due to difficulties encountered with the rectal temperature sensor. Subject S_{H9} also completed the protocol but at a very slow and inconsistent pace; data for this subject are treated individually. Mean ambient temperature was 8.3 ± 2.8°C (range 5.2 – 11.7°C) at t_{45}, and decreased to 7.3 ± 2.0°C (range 4.6 – 9.0°C) by t_{210}.

2.3.2. Rectal Temperature (T_{Re})

Effects of exercise (t_{0-45}). Rectal temperatures were insignificantly different at t_0 (Table 2.7), ranging from a minimum group mean of 37.07 ± 0.33°C (P_0), to a maximum of 37.36 ± 0.35°C (P_L).

In the exercising groups, rectal temperature increased during the first 45 minutes of exercise, the increase being greatest in the high-pace, P_H group (Fig. 2.2). At t_{45}, the increase in P_H of 1.25 ± 0.22°C was significantly greater than that observed for the P_M group (+0.59 ± 0.25). However, no significant difference was observed between the P_M and P_L (+0.41 ± 0.22°C) groups. Rectal temperature declined in the non-exercising, P_0 group during this period (−0.35 ± 0.17°C), to a level significantly below that of the P_L group.

Effects of wet exposure (t_{45-210}). The effect of wetting on rectal temperature was analyzed between the initiation of wetting (t_{45}) and completion of exercise (t_{210}). There was a significant decrease in rectal temperature in the P_L, P_M and P_H groups, the amount of decrease inversely related to the rectal temperature at t_{45} (Fig. 2.2). No significant change in rectal temperature was observed in the non-exercising, P_0 group.

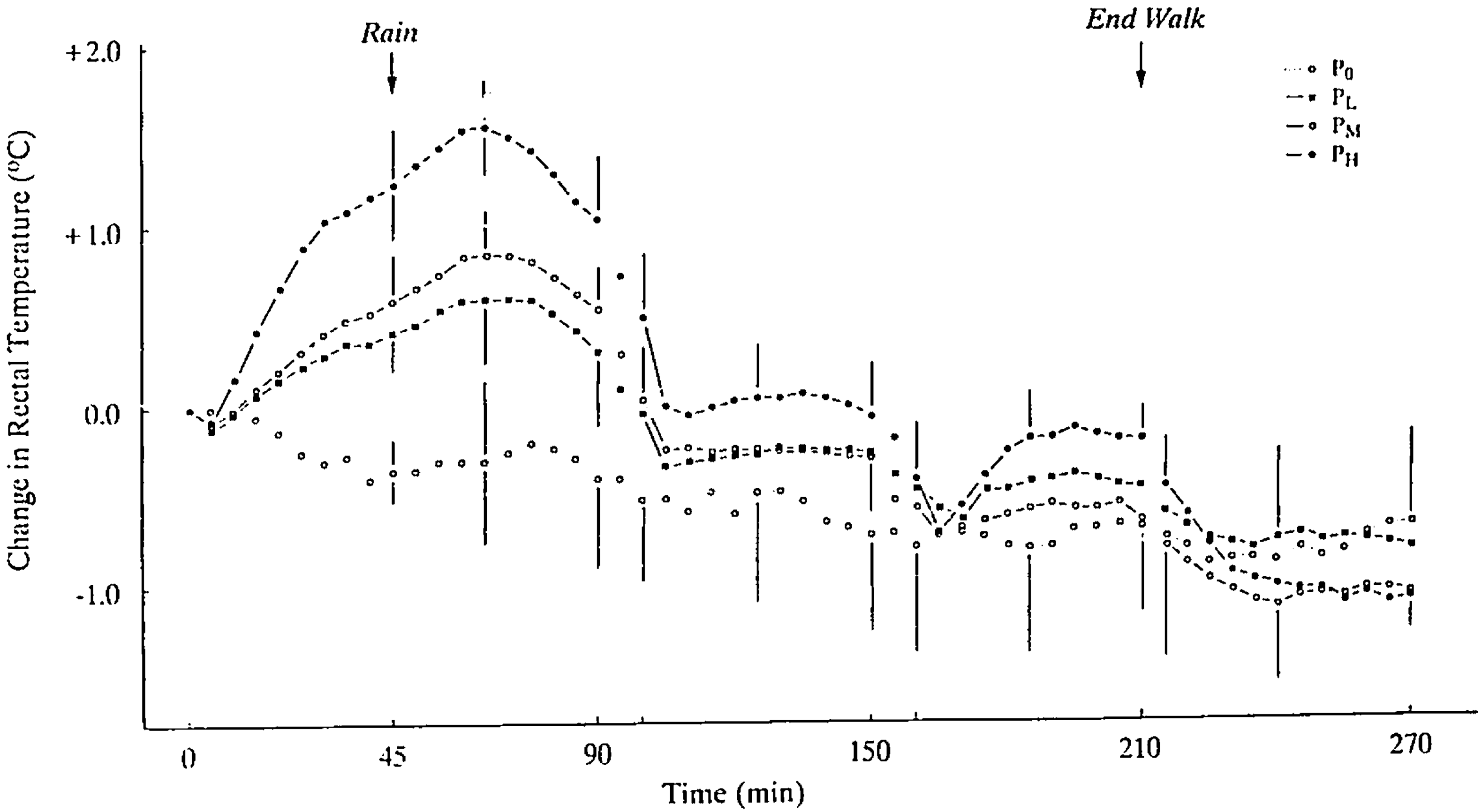
There were no significant differences in rectal temperature between the exercising groups at the completion of exercise, or between the exercising groups and the P_0 group (Table 2.7). Based on overlap of standard deviations, differences

Table 2.7. Changes in rectal temperature (°C) during exercise phase of wet walks (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Pre-exercise Rectal Temperature (°C)				
T_{Rc0}	37.07 ± 0.33	37.36 ± 0.35	37.16 ± 0.36	37.20 ± 0.22
Pre-rain Rectal Temperature (°C)				
T_{Rc0-45}	-0.35 ± 0.17	+0.41 ± 0.22	+0.59 ± 0.25	+1.25 ± 0.22
T_{Rc45}	36.72 ± 0.33	37.77 ± 0.17	37.74 ± 0.19	38.45 ± 0.17
Post-rain Rectal Temperature (°C)				
$T_{Rc45-210}$	-0.30 ± 0.39	-0.86 ± 0.54	-1.26 ± 0.42	-1.43 ± 0.36
T_{Rc210}	36.42 ± 0.46	36.91 ± 0.52	36.49 ± 0.55	37.02 ± 0.43
Minimum Observed Temperature (°C/Subject)				
	35.7 S_{01}	35.9 S_{L4}	35.6 S_{M2}	36.0 S_{H4}

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

Fig. 2.2. Change in rectal temperature (°C) as a function of walking pace: P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4).


Rain
End Walk
P_0
P_L
P_M
P_H
+2.0
+1.0
0.0
-1.0
Change in Rectal Temperature (°C)
0
45
90
150
210
270
Time (min)

between these groups were non-significant beginning in the second hour of exposure (after t_{100}), although the tendency was for the P_H group to have the highest mean rectal temperature and P_0, the lowest mean rectal temperature (Fig. 2.2). Variance increased in all groups during the wet exercise phase of the experiment, indicated by increases in standard deviation between t_{45} and t_{210} (Table 2.7). (It should be noted that three subjects in P_H not included in the analysis group, but who completed 2.5 h of wet exposure over an extended period due to protocol interruptions, had final exercising rectal temperatures significantly above 37°C (S_{H7}, 37.9; S_{H8}, 38.4; S_{H10}, 37.8).

During the final non-exercise phase ($t_{210-270}$), rectal temperature continued to cool, achieving stable levels 20–30 minutes after subjects began the rest period (Fig. 2.2). Change was greatest in the P_H group (−0.90 ± 0.26°C) and least in the P_0 group (−0.02 ± 0.28°C) (Table 2.8). At t_{270}, mean rectal temperatures were insignificantly different between groups; the highest mean temperature was observed in P_L (36.56 ± 0.23°C) and lowest in P_M (36.05 ± 0.41°C).

Two subjects in P_H sat for nearly 2 h in wet clothing, after they were required to stop exercising at t_{160} (S_{H5}, S_{H6}: Table 2.5). Both subjects showed the continued core cooling to rectal temperatures below 36°C, followed by stabilization and recovery (Fig. 2.3).

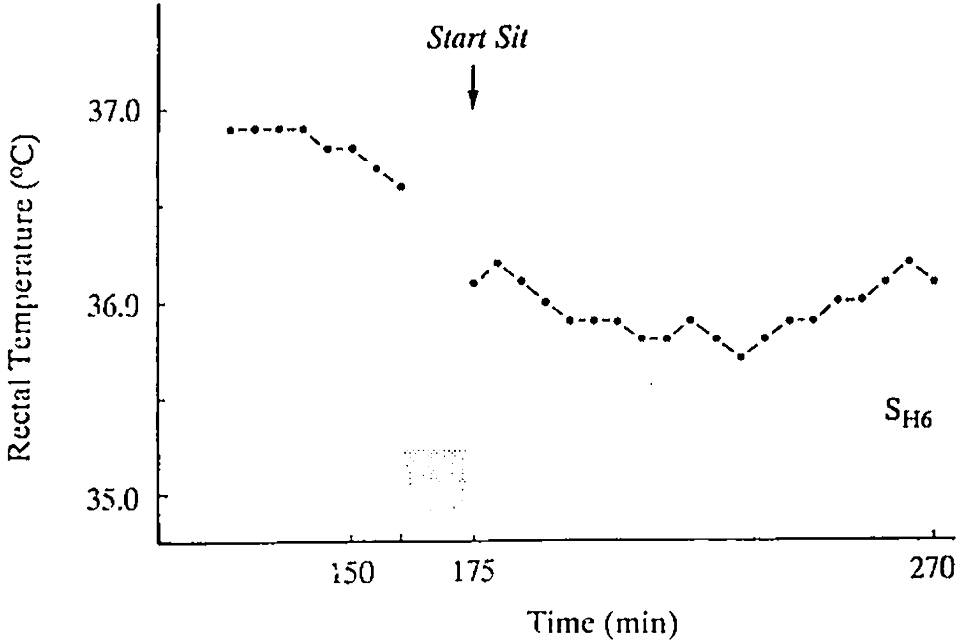
Three, general response-patterns were noted in rectal temperature during wetting: *(1)* an increase in rectal temperature following initiation of wetting, reaching a session maximum after approximately 20 minutes of rain; *(2)* a drop in rectal temperature when subjects began walking again after a rest break, followed by stabilization or recovery; and *(3)* a reduction in the rate of rectal temperature cooling over time (Fig. 2.2).

Table 2.8. Relative changes in rectal temperature (°C) during sitting phase of EXP_1 (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Change in rectal temperature during sitting phase (°C)				
$T_{Rc210-270}$	−0.02 ± 0.28	−0.35 ± 0.38	−0.40 ± 0.50	−0.90 ± 0.26
Rectal temperature at t_{270} (°C)				
T_{Rc270}	36.40 ± 0.29	36.55 ± 0.23	36.05 ± 0.41	36.12 ± 0.41

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 6); P_H (n = 4)

Fig. 2.3. Change in rectal temperature (°C) in subject S_{H6} during prolonged sitting period ($t_{175-270}$). The subject was unable to continue walking safely due to intense shivering (during period indicated by shading) after the $t_{150-160}$ rest.


Start Sit
37.0
36.0
35.0
Rectal Temperature (°C)
150
175
270
Time (min)
S_{H6}

Post-rain T_{Re} maxima (t_{45-90}). Rectal temperature increased in all exercising groups following initiation of the rain (Fig. 2.2). The increase was greatest in P_H (+0.35 ± 0.06°C), but not significantly higher than P_M (+0.27 ± 0.11°C) or P_L (+0.24 ± 0.16°C) (Table 2.9). Group mean maxima occurred at the 20-min reading (Fig. 2.2). An increase was also observed in the P_0 group (+0.23 ± 0.22°C), the P_0 mean maximum reached at t_{75}. The greatest range in group mean temperatures occurred at t_{65} min, from 36.77 ± 0.56°C for P_0 to 38.77 ± 0.22°C for P_H (Fig. 2.2).

Exercise-associated T_{Re} "afterdrop" and recovery. Rectal temperature declined in all groups during the rest stops (t_{90-100}; $t_{150-160}$), although little change was recorded in the non-exercising group.

A significant drop in rectal temperature also occurred during the first 5 minutes of walking after the first rest break in all exercising groups (Table 2.10), greatest in P_H (−0.50 ± 0.22°C). No such change in temperature was observed in the P_0 group. After the initial drop in temperature, the mean change in rectal temperature was ≤ 0.1°C over the next 45 minutes in the three exercising groups (Table 2.10), indicating stable conditions (Fig. 2.2). A small decline of approximately 0.25°C was seen in the P_0 group during the final 20 minutes of rain.

Similar decreases in rectal temperature were observed during the initial five minutes of walking after the second rest break ($t_{150-160}$). In the final 45 minutes of exercise, rectal temperatures increased slightly towards the t_{160} levels. This recovery was greatest in the P_H group (+0.55 ± 0.13°C), and the rectal temperature at the end of the walk (t_{210}) was similar to the t_{150} mean rectal temperature (Fig 2.2).

Decreasing Rate of Rectal Temperature Cooling. The change in rectal temperature between t_{90} and t_{150} was greatest in the P_H group (−1.10 ± 0.22°C), and least in the non-exercising, P_0 group (−0.33 ± 0.17) (Fig. 2.2).

Table 2.9. Post-t_{45} rectal temperature maxima (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Maximum rectal temperature (°C)				
T_{Remax}	36.95 ± 0.48	38.01 ± 0.14	38.01 ± 0.26	38.80 ± 0.22
Change in rectal temperature (°C)				
$T_{Re45\text{-}max}$	+0.23 ± 0.22	+0.24 ± 0.16	+0.27 ± 0.11	+0.35 ± 0.06

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

Table 2.10. Post-rest rectal temperature "afterdrop" and recovery (°C) (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
$T_{Re100\text{-}105}$	+0.10 ± 0.26	-0.30 ± 0.17	-0.27 ± 0.19	-0.50 ± 0.22
$T_{Re105\text{-}150}$	-0.33 ± 0.21	+0.06 ± 0.16	-0.06 ± 0.36	-0.05 ± 0.10
$T_{Re160\text{-}165}$	+0.08 ± 0.17	-0.11 ± 0.11	-0.17 ± 0.14	-0.32 ± 0.17
$T_{Re165\text{-}210}$	+0.05 ± 0.19	+0.13 ± 0.18	+0.06 ± 0.25	+0.55 ± 0.13

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

In each group, the change in rectal temperature between $t_{150-210}$ was less than that for the period t_{90-150} (Table 2.11), indicating a decreased rate of cooling. For example, in the P_H group, the $t_{150-210}$ change was −0.13 ± 0.17°C, in comparison to −1.10 ± 0.22°C during the preceding hour. The lower-pace groups reflected a similar trend. The mean change in the later period was positive in the P_0 group (+0.08 ± 0.13°C). An example of this trend is illustrated in Fig. 2.4.

Dry Walks. A comparison of rectal temperature changes for subjects completing both dry and wet walks is presented in Table 2.12. During the exercise phase of dry walks, there was little or no change in rectal temperature after 45 minutes. However, the decrease in rectal temperature in the sitting phase of dry walks was frequently greater than in the wet walk for that individual. The wet and dry walk rectal temperature data for subject S_{H1} are shown in Fig. 2.5. Characteristic response patterns are visible in the comparative plot, including the increase in rectal temperature after wetting, post-rest "afterdrop" and recovery, decreased rectal temperature cooling rate up to the end of exercise, and post-exercise cooling.

2.3.3. Skin Temperature (T_{MS})

Exercise Effect (t_{0-45}). Mean skin temperatures were insignificantly different at t_0 (Table 2.13), ranging from a group mean of 29.2 ± 1.1°C (P_0), to 29.9 ± 0.5°C (P_H).

In the exercising groups, mean skin temperature showed slight but insignificant changes during the pre-rain exercise period (Fig. 2.6), although the tendency was towards higher mean skin temperatures in higher pace groups. In contrast, mean skin temperature declined in the non-exercising P_0 group during this period (−1.8 ± 0.7°C), significantly below the initial level.

Table 2.11. Relative changes in rectal temperature (°C) over the period t_{90-210} in wet walks, comparing second and third walking periods (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
$T_{Re90-150}$	-0.33 ± 0.17	-0.59 ± 0.20	-0.81 ± 0.40	-1.10 ± 0.22
$T_{Re150-210}$	+0.08 ± 0.13	-0.19 ± 0.20	-0.39 ± 0.23	-0.13 ± 0.17

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

Fig. 2.4. Change in rectal temperature (°C) in subject S_{M2}, illustrating regulation of rectal temperature at a sub-normal level.

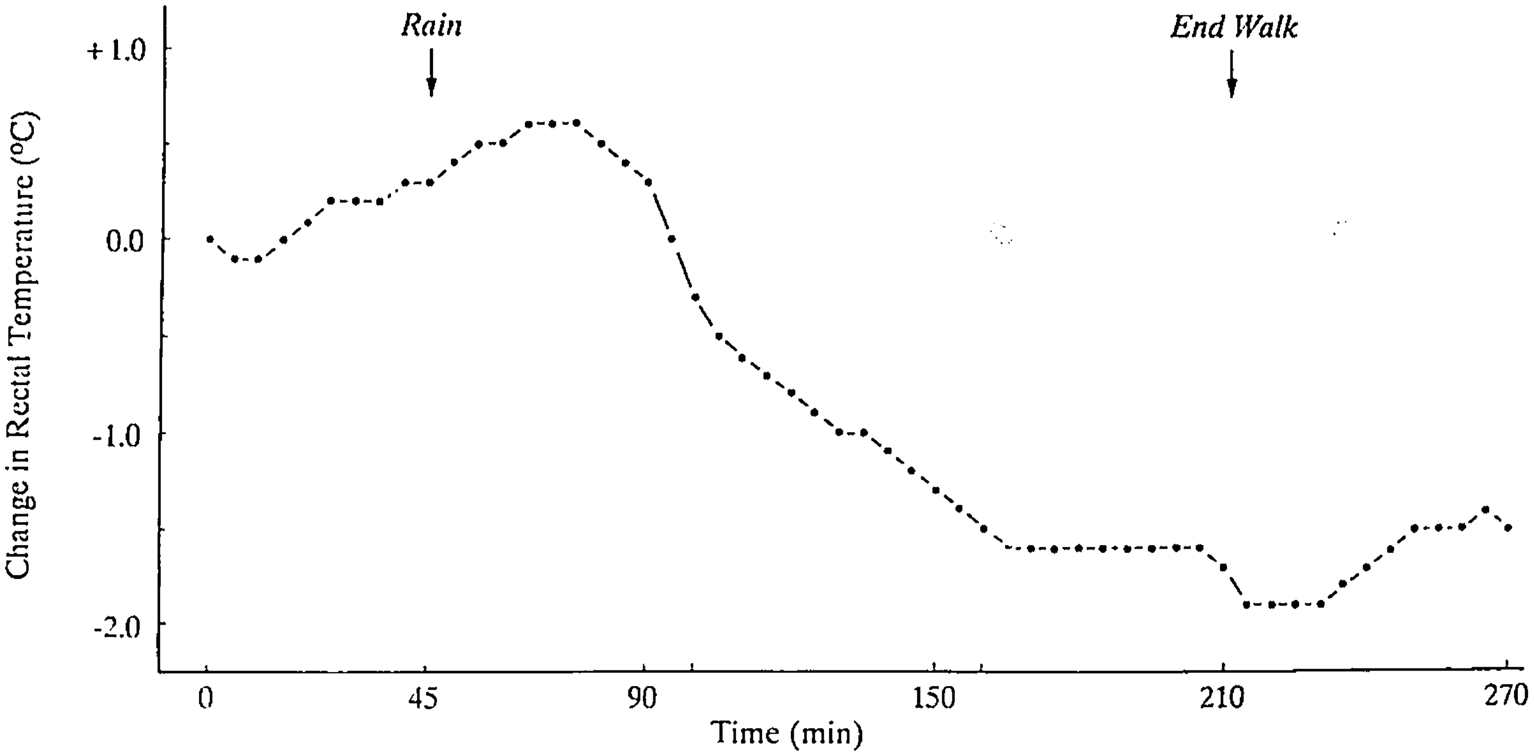

Rain
End Walk
+1.0
0.0
-1.0
-2.0
Change in Rectal Temperature (°C)
0
45
90
150
210
270
Time (min)

Table 2.12. Comparison of changes in rectal temperature (°C) in dry and wet walks

Subject	Dry	Wet
WALKING PHASE (t_{45-210})		
S_{01}	-0.4	-0.4
S_{L1}	0.0	-0.5
S_{L2}	-0.2	-0.5
S_{M1}	-0.4	-0.7
S_{M2}	-0.2	-2.0
S_{H1}	0.0	-1.2
S_{H2}	+0.3	-1.1
SITTING PHASE ($t_{210-270}$)		
S_{01}	-0.2	-0.3
S_{L1}	-0.8	-0.7
S_{L2}	-0.8	-0.2
S_{M1}	-0.4	-0.7
S_{M2}	-0.5	+0.2
S_{H1}	-1.8	-1.2
S_{H2}	-1.6	-0.8

Fig. 2.5. Change in rectal temperature (°C) in subject S_{H1}, comparing dry and wet walks. In the wet condition, note (a) elevation in rectal temperature after t_{45}, (b) post-rest "afterdrop" and recovery; and (c) stabilization of rectal temperature over time, up to end up walking phase.

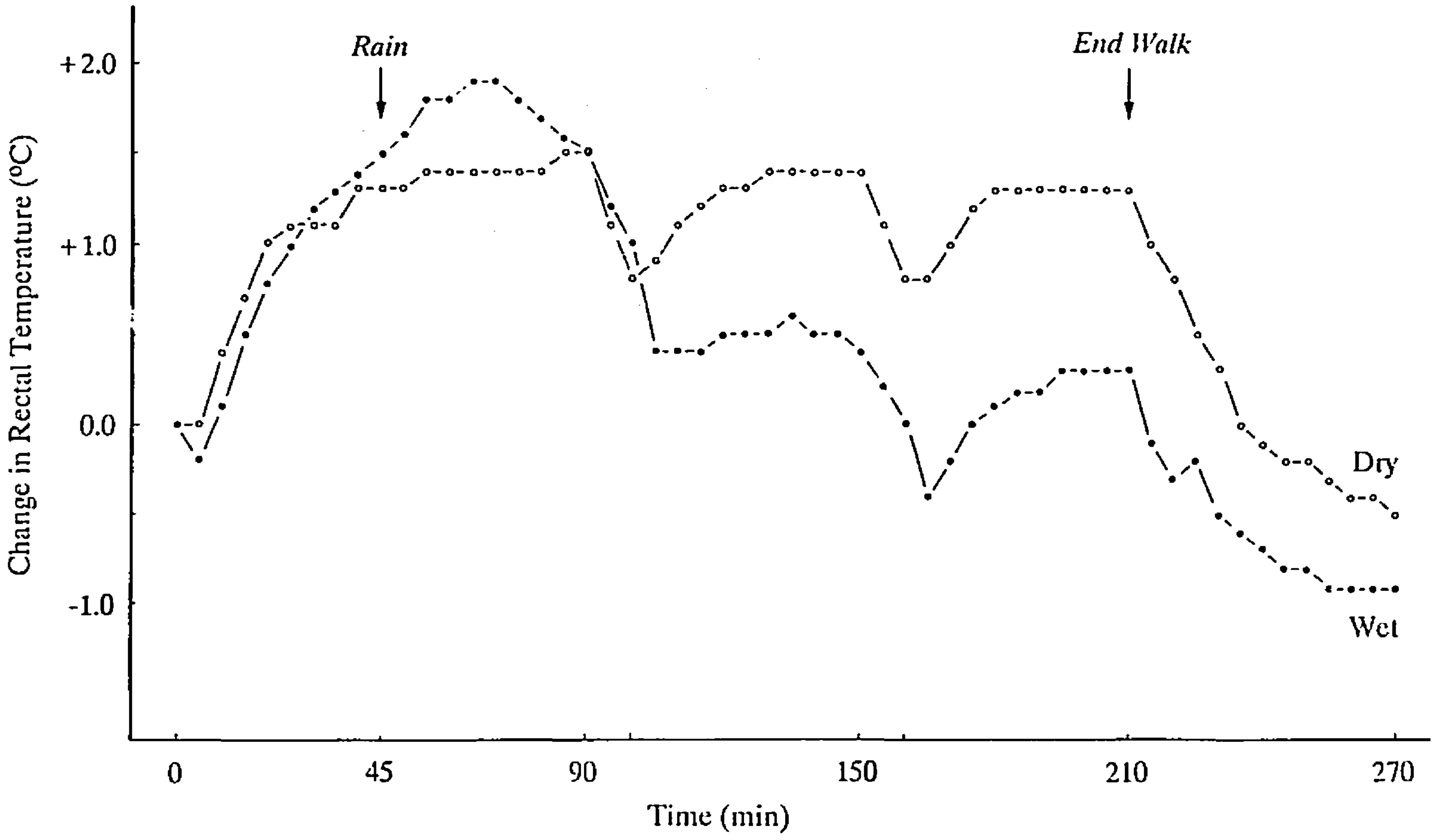
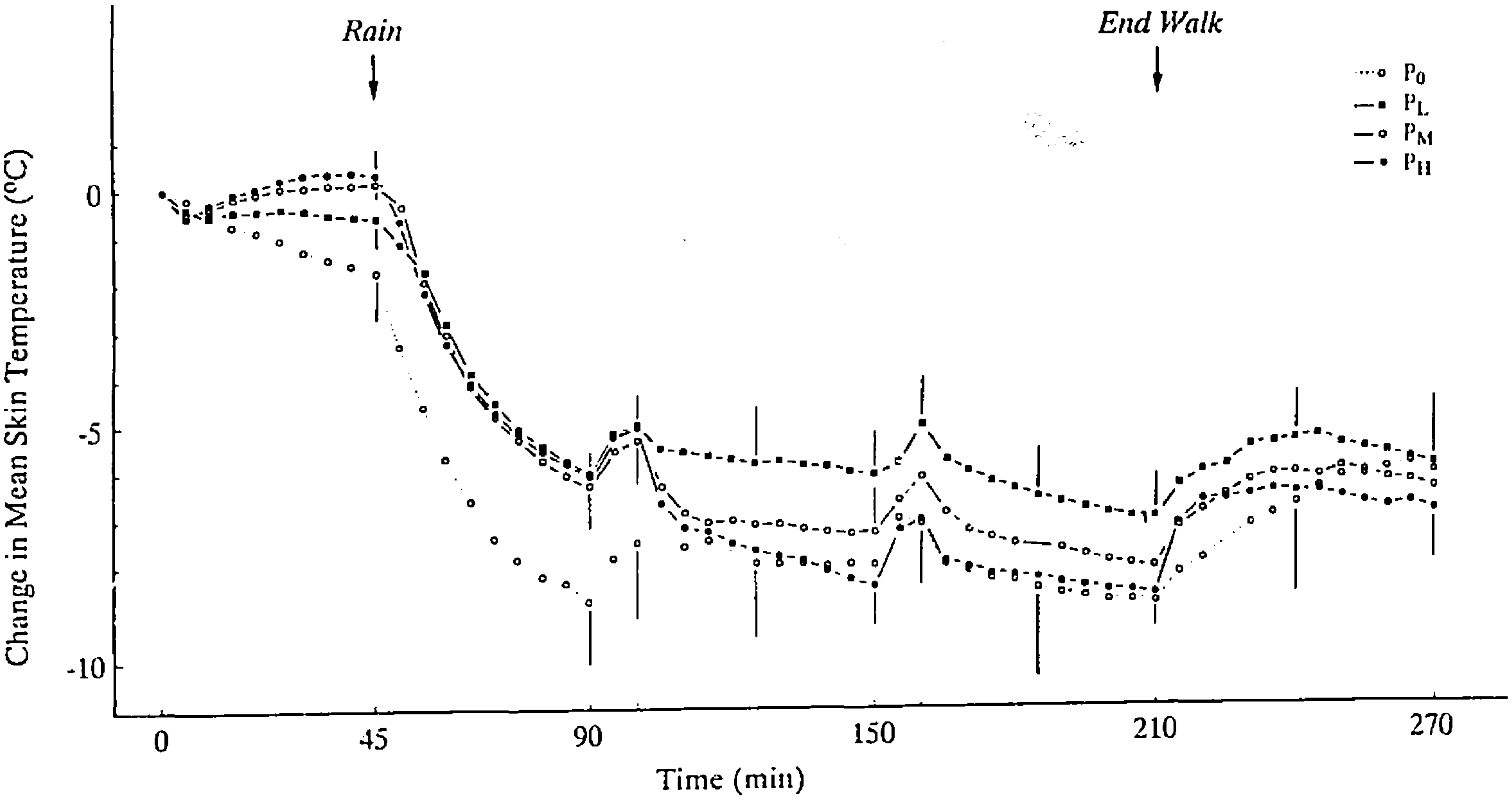

Rain
End Walk
+2.0
+1.0
0.0
-1.0
Change in Rectal Temperature (°C)
0
45
90
150
210
270
Time (min)
Dry
Wet

Table 2.13. Changes in mean skin temperature (°C) during exercise phase of wet walks (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Pre-exercise Mean Skin Temperature (°C)				
T_{MS0}	29.2 ± 1.1	29.6 ± 0.4	29.5 ± 1.5	29.9 ± 0.5
Pre-rain Mean Skin Temperature (°C)				
T_{MS0-45}	−1.8 ± 0.7	−0.6 ± 0.7	+0.2 ± 0.4	+0.3 ± 0.5
T_{MS45}	27.5 ± 1.0	29.1 ± 0.7	29.8 ± 1.5	30.2 ± 0.7
Post-rain Mean Skin Temperature (°C)				
$T_{MS45-210}$	-7.0 ± 2.4	-6.5 ± 0.7	-8.3 ± 1.6	-9.0 ± 0.8
T_{MS210}	20.5 ± 1.6	22.7 ± 1.2	21.5 ± 2.5	21.2 ± 0.5
Minimum Observed T_{MS} during Exercise Phase (°C)/Subject				
T_{MSmin}	18.4 S_{01}	20.8 S_{L8}	18.9 S_{M2}	20.4 S_{H4}

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

Fig. 2.6. Change in mean skin temperature (°C) as a function of walking pace: P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4).


Rain
End Walk
P$_0$
P$_L$
P$_M$
P$_H$
Change in Mean Skin Temperature (°C)
0
-5
-10
0
45
90
150
210
270
Time (min)

Effects of Wet Exposure (t_{45-210}). There was a significant decrease in mean skin temperature in all groups between t_{45} and t_{210}, the decrease inversely related to the walking pace (Table 2.13). The mean decrease of −9.0 ± 0.8°C in P_H was significantly greater than in P_L (−6.5 ± 0.7°C); otherwise, no significant differences were observed in mean skin temperature at the completion of this phase of the experiment.

During the final non-exercise phase, there was an increase in mean skin temperature, similar to increases observed during the rest breaks (Table 2.14). At t_{270}, mean skin temperatures averaged 23°C in all groups.

Dry Walks. During the exercise phase of dry walks, mean skin temperatures showed minor decreases across all walking paces (Table 2.15), and were about 6–7°C higher than levels recorded in comparative wet walks. During the sitting phase, mean skin temperature decreased in all dry walks, in contrast to T_{MS} increases observed in wet walks.

2.3.4. Metabolic Rate (MR)

Exercise Effect. No significant differences were observed in pre-exercising MRs (Table 2.16). Metabolic rate increased with exercise, and P_H metabolic rate (8.60 ± 0.47 W·kg^{-1}) was significantly higher than MRs observed in the mid-range exercising groups, the differences between the latter insignificant. Both the mid-range groups were significantly greater than the non-exercising group (Table 2.16; Fig 2.7). On average, P_H metabolic rate was equivalent to about 50% of subject VO_2max, and between 25–30% at the lower paces (Table 2.17). A slight but insignificant increase was observed between t_5 and t_{45} MR in P_0.

Effects of Wet Exposure (t_{45-210}). There was a significant increase in MR in all groups over this period (Table 2.17), averaging 30–40% by the final hour of

Table 2.14. Relative changes in mean skin temperature (°C) during resting and sitting phases of EXP_1 (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Rest Stops (*PETER* Subtest)				
$T_{MS90-100}$	+1.2 ± 0.6	+1.0 ± 0.8	+1.0 ± 0.7	+1.1 ± 0.3
$T_{MS150-160}$	+0.8 ± 0.2	+1.0 ± 0.8	+1.2 ± 0.6	+1.4 ± 0.6
Sitting Phase				
$T_{MS210-270}$	+2.8 ± 1.8	+0.8 ± 1.3	+1.3 ± 1.6	+1.7 ± 0.5
Mean Skin Temperature at t_{270}				
T_{MS270}	23.2 ± 0.8	23.7 ± 1.1	23.1 ± 1.2	22.9 ± 1.0

[1] P_0 (n = 4); P_L (n = 8); P_M (n = 7); P_H (n = 4)

Table 2.15. Comparison of changes in mean skin temperature (°C) in dry and wet walks

Subject	Dry	Wet
WALKING PHASE (t_{45-210})		
S_{01}	−1.6	−5.0
S_{L1}	−0.8	−7.6
S_{L2}	−1.3	−6.7
S_{M1}	−0.6	−6.7
S_{M2}	−2.0	−8.4
S_{H1}	−1.4	−8.7
S_{H2}	−1.0	−8.0
SITTING PHASE ($t_{210-270}$)		
S_{01}	−0.8	+2.4
S_{L1}	−1.8	+0.6
S_{L2}	−0.7	+1.9
S_{M1}	−1.1	−0.2[1]
S_{M2}	−0.5	+1.5
S_{H1}	−1.4	+1.7
S_{H2}	−0.2	+2.0

[1] T_{MS} of this subject increased steadily during the sitting period until t_{260} (+1.2°C), when T_{MS} fell 1.4°C during completion of the *PETER* subtest.

Table 2.16. Metabolic rates ($W \cdot kg^{-1}$) during walking phase of wet walks (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
Pre-rain metabolic rates ($W \cdot kg^{-1}$)				
Resting MR	1.2 ± 0.2	1.6 ± 0.4	1.7 ± 1.1	1.6 ± 0.3
MR_{45}	1.5 ± 0.1	3.9 ± 0.8	5.1 ± 1.0	7.5 ± 0.6
Post-rain metabolic rates ($W \cdot kg^{-1}$)				
MR_{90}	2.3 ± 1.2	5.0 ± 1.2	6.1 ± 1.6	8.6 ± 0.5
MR_{MAX1}	2.6 ± 1.9	6.1 ± 1.0	7.3 ± 1.8	9.6 ± 1.8
MR_{150}	2.4 ± 0.6	5.4 ± 1.6	6.6 ± 1.4	9.6 ± 1.4
MR_{MAX2}	2.9 ± 1.4	6.0 ± 1.4	7.5 ± 1.7	10.5 ± 1.4
MR_{210}	1.8 ± 0.7	5.7 ± 1.5	7.1 ± 1.1	9.4 ± 1.1

MR_{MAX1} = maximum mean metabolic rate during period $t_{105-150}$
MR_{MAX2} = maximum mean metabolic rate during period $t_{165-210}$

[1] P_0 (n = 3); P_L (n = 5); P_M (n = 5); P_H (n = 4)

Fig. 2.7. Comparison of metabolic rates (W • kg^{-1}) between pace groups: P_0 (n = 3); P_L (n = 5); P_M (n = 5); P_H (n = 4).

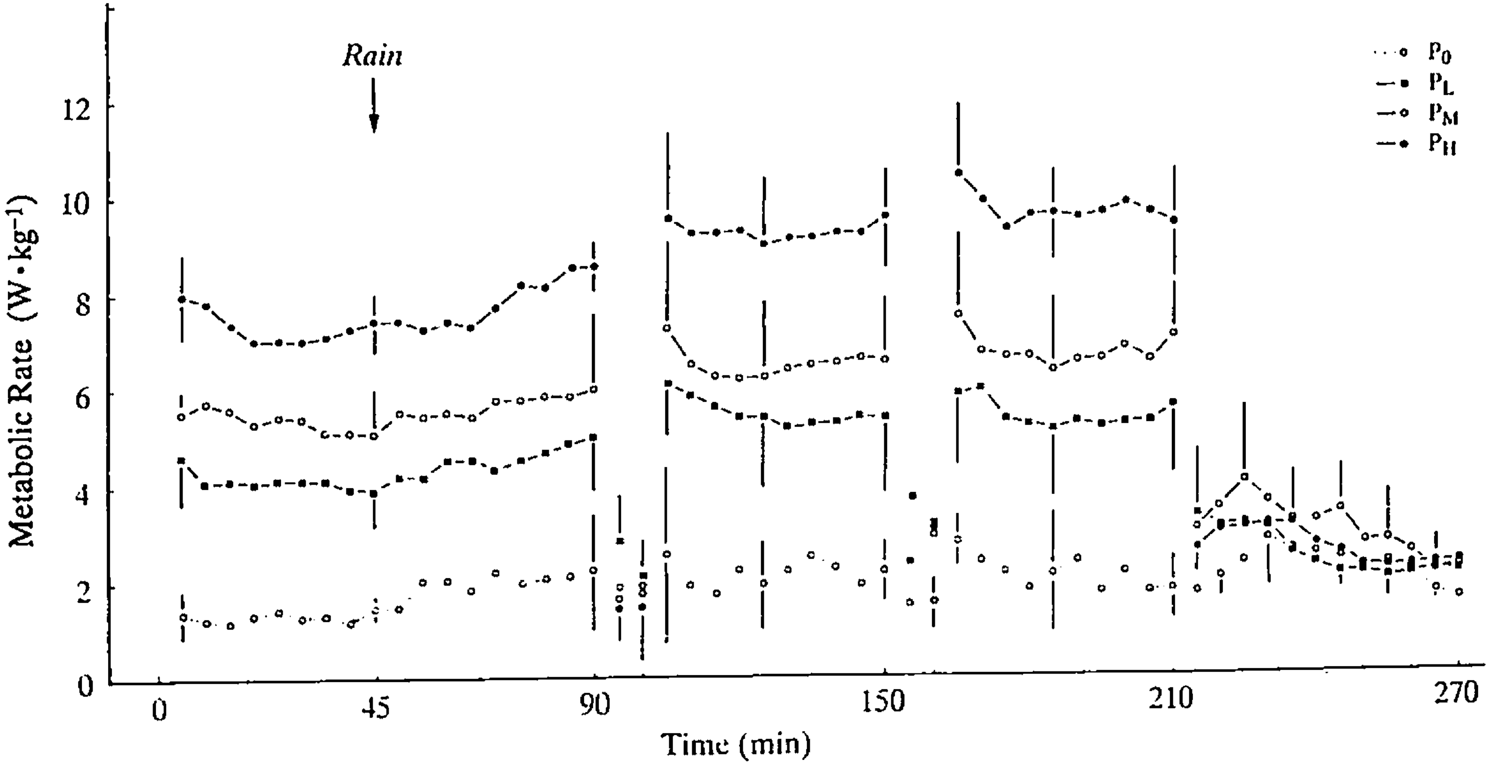

Rain
Metabolic Rate (W•kg^{-1})
0
2
4
6
8
10
12
Time (min)
0
45
90
150
210
270
P_0
P_L
P_M
P_H

Table 2.17. Relative mean changes in metabolic rates during walking phase of wet walks (mean ± SD[1])

Variable		Pace		
	P_0	P_L	P_M	P_H
Pre-rain metabolic rate ($W \cdot kg^{-1}$)				
MR_{45}	1.5	3.9	5.1	7.5
	± 0.1	± 0.8	± 1.0	± 0.6
$\%V_{O2max}$	10	25	31	49
	± 1	± 4	± 7	± 12
Relative Change in MR				
MR_{90}				
Change (%)	85	+23	+18	+18
	± 87	± 23	± 11	± 14
(Range)	(29–185)	(12–44)	(8-36)	(2–36)
$\%V_{O2max}$	16	32	36	56
	± 10	± 7	± 9	± 9
MR_{150}				
Change (%)	85	+30	+29	+31
	± 52	± 17	± 9	± 20
(Range)	(29–132)	(12-47)	(17–40)	(3–59)
$\%V_{O2max}$	15	35	39	62
	± 6	± 9	± 7	± 7
MR_{210}				
Change (%)	49	+37	+40	+30
	± 58	± 13	± 14	± 23
(Range)	(-14–99)	(18-52)	(24–61)	(4–53)
$\%V_{O2max}$	12	37	43	61
	± 6	± 9	± 7	± 9

[1] P_0 (n = 3); P_L (n = 5); P_M (n = 5); P_H (n = 4)

walking in P_L, P_M and P_H. However, the absolute increase in MR was significant only in P_H (Table 2.16). Maximal metabolic rates in the final two walking stages occurred during the initial 5 min of walking (Fig. 2.7; Table 2.16), concomitant with the observed drop in rectal temperature (Fig. 2.2) (except for P_L at t_{165}).

The increase in MR with wetting showed considerable range within groups (Table 2.17). In P_H, for example, S_{H4} had an MR increase of less than 10%, in comparison to the 50+% MR increase exhibited by S_{H3}.

No significant differences were observed in the P_0 group's mean MR, in association with significant variation; however, individuals within this group did show significant MR increases. For example, S_{01}'s MR increase averaged more than 100% over the $t_{100-150}$ period.

Upper body shivering was observed during the walking phases of the experiment, and was particularly evident when subjects stopped walking (i.e., rest breaks, 5-min data-recording stops). Shivering was visible in some subjects during walking activity, particularly in the first 5 min of the second and third walking stages.

Subject S_{H6}, as previously mentioned, was unable to continue the experiment following the second break ($t_{150-160}$) because of intense, whole-body shivering. The subject shook violently as he stumbled along the *Wet Walk*, several times coming in contact with the arch framework; rectal temperature was 36.6°C at the begining of this activity, and fell less than 0.5°C over the following 10 min. The walking phase of the experiment was terminated for reasons of safety, and the subject continued sitting for the remainder of the experiment time without incident (Fig. 2.3). Metabolic data were not available during this high-intensity shivering activity; however, prior to the rest break (t_{150}), MR was not unusually high for this pace (9.2–9.5 $W \cdot kg^{-1}$), although strong shivering was present. S_{L6} shivered uncontrollably during the first 20 min of sitting, MR slowly decreasing from 5.9 to 4.1 $W \cdot kg^{-1}$. This was followed by spasmodic phases of shivering over the final 75 min.

In the final non-exercise phase ($t_{210-270}$), MR did not significantly differ between groups (Fig. 2.7). Shivering was visible, although its intensity varied over time and between subjects.

The relationship between metabolic rate and rectal temperature for one subject during the sitting phase is shown in Fig. 2.8; the peak MR was associated with visible shivering and verbal complaints.

Dry Walks. Comparison of metabolic rates between individual dry and wet walks is shown in Table 2.18. With one exception (S_{H1}), there was no increase in MR after t_{45} in dry walks. Five of six subjects in walking conditions showed increases in MR above 20% after t_{45} in wet walk; S_{M1} had an MR increase of about 15% during this time period. Atypically, mean MR in S_{04} decreased during the wet exposure (suspected equipment malfunction).

2.3.5. Ventilation Rate (V_E)

Ventilation rate estimates are summarized in Table 2.19. The relationship between walking pace and V_E was similar to the relationship observed for MR. P_H V_E at t_{45} (34.4 ± 4.1 $l \cdot min^{-1}$) was significantly greater than P_M and P_L V_Es; there was no difference between P_M and P_L V_Es, averaging 20–25 $l \cdot min^{-1}$. The mean P_0 V_E was significantly less than that observed in the exercising groups.

Effects of Wet Exposure (t_{45-210}). Wetting produced a significant increase in V_E in all groups, except P_M (Table 2.19). The proportionate increase in V_E from t_{45} to t_{210} was inversely related to walking pace. In P_0, V_E rose from a mean value of 8.4 ± 1.2 $l \cdot min^{-1}$ at t_{45} to 21.1 ± 4.4 $l \cdot min^{-1}$ at t_{210}, an increase of approximately

Fig. 2.8. Relationship between change in rectal temperature (°C) and metabolic rate ($W \cdot kg^{-1}$) in subject S_{H3} during sitting phase. Intense, whole body shivering occurred concomitant with peak metabolic activity in the sitting period; the subject expressed his displeasure regarding experimental conditions at this time.

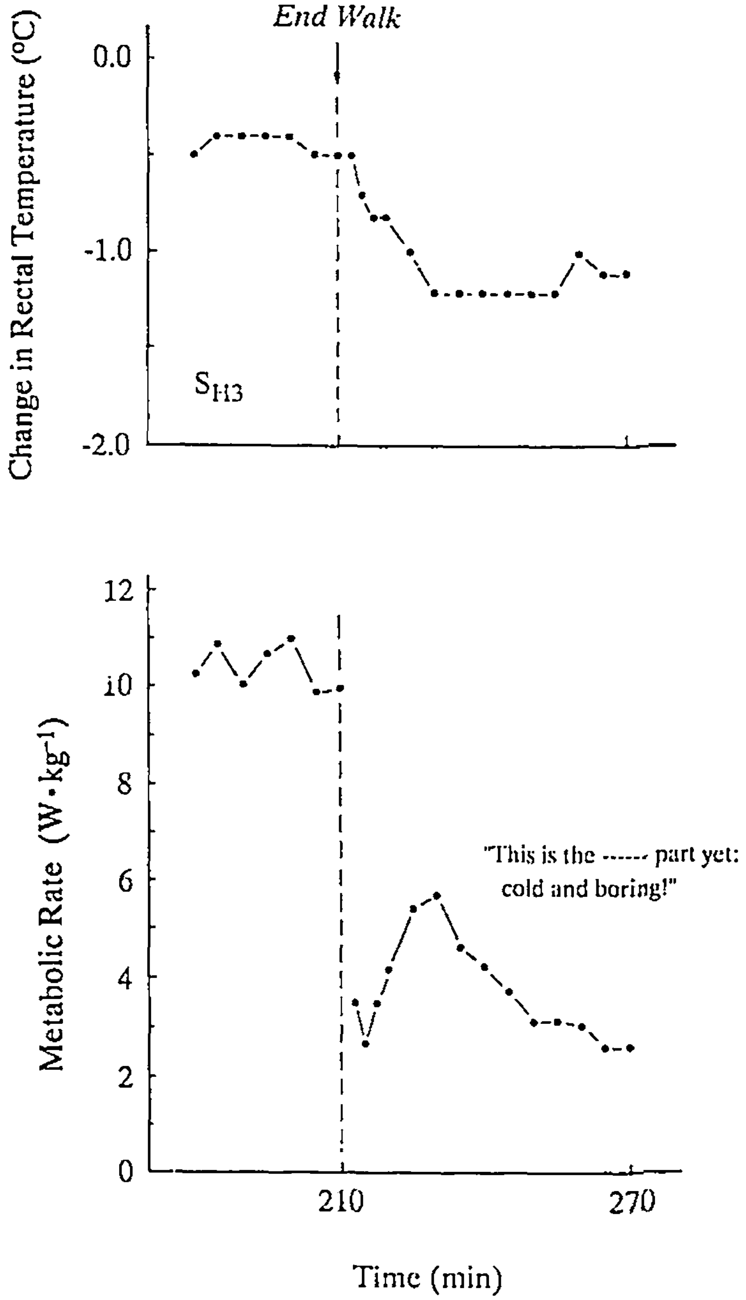

End Walk
Change in Rectal Temperature (°C)
0.0
-1.0
-2.0
S_H3
Metabolic Rate (W•kg-1)
12
10
8
6
4
2
0
"This is the ------ part yet: cold and boring!"
210
270
Time (min)

Table 2.18. Comparison of metabolic rates (W • kg^{-1}) in wet and dry walks, (a) before t_{45} (pre-rain in wet walks), and (b) final 25 min of walking (mean ± SD, n = 5)

Subject	Wet	Dry
S_{01}		
t_{20-45}	1.6 ± 0.1	1.4 ± 0.1
$t_{185-210}$	1.5 ± 0.4	1.2 ± 0.2
S_{L1}		
t_{20-45}	4.6 ± 0.3	4.8 ± 0.2
$t_{185-210}$	6.3 ± 0.1	4.6 ± 0.1
S_{L2}		
t_{20-45}	4.6 ± 0.1	4.5 ± 0.1
$t_{185-210}$	6.6 ± 0.3	4.4 ± 0.1
S_{M1}		
t_{20-45}	6.0 ± 0.2	6.0 ± 0.1
$t_{185-210}$	7.0 ± 0.2	6.1 ± 0.2
S_{M2}		
t_{20-45}	5.5 ± 0.4	5.3 ± 0.6
$t_{185-210}$	7.5 ± 0.6	5.8 ± 0.6
S_{H1}		
t_{20-45}	7.8 ± 0.1	7.1 ± 0.2
$t_{185-210}$	9.5 ± 0.3	8.2 ± 0.3
S_{H2}		
t_{20-45}	7.4 ± 0.2	8.3 ± 0.1
$t_{185-210}$	10.3 ± 0.3	8.5 ± 0.1

Table 2.19. Ventilation rates (l • min^{-1}) in different pace groups during walking and sitting phases of wet walks (mean ± SD[1])

Variable	Pace			
	P_0	P_L	P_M	P_H
V_{E0}	9.5 ± 1.2	10.1 ± 1.5	11.2 ± 1.9	9.8 ± 2.4
V_{E45}	8.4 ± 1.2	21.3 ± 2.4	24.9 ± 4.3	34.4 ± 4.1
V_{E90}	17.1 ± 5.9	27.0 ± 4.6	29.3 ± 4.6	36.4 ± 4.6
V_{E150}	19.2 ± 6.9	34.1 ± 4.9	31.7 ± 5.4	42.8 ± 3.3
V_{E210}	21.1 ± 4.4	31.4 ± 4.3	30.7 ± 6.5	43.1 ± 4.0
V_{E245}	17.1 ± 1.8	13.1 ± 2.0	16.6 ± 4.6	14.8 ± 3.3
V_{E270}	14.5 ± 2.4	13.3 ± 1.8	14.4 ± 2.1	15.0 ± 1.7

[1] P_0 (n = 3); P_L (n = 8); P_M (n = 5); P_H (n = 4)

150%; V_E increased by about 35% in P_L and less than 25% in P_H over the same period of time.

During the sitting phase, V_E was similar between pace groups (Table 2.19), and was significantly greater than the pre-walk values only in P_0.

Dry Walks. Comparison of V_E in individual wet and dry walks supports observations of increased V_E with wetting observed in the pace group data (Table 2.20). No increases in V_E were observed after t_{45} in dry walks; however, significant increases (25–35%) in V_E occurred during this period in wet walks (with the exception of S_{M1}).

2.3.6. Heart Rate (HR)

Heart rate responses are summarized in Table 2.21. Considerable variation in heart rate was evident during the exercise periods.

Effects of Wet Exposure (t_{45-210}). A significant change in group HR occurred only in P_0, heart rate increasing from 76.3 ± 9.0 bpm at t_{45} to 101.3 ± 12.7 bpm at t_{210}. No significant difference was observed between the non-exercising group (P_0) and the low-pace walking group (P_L).

Mean heart rates were similar between groups during the sitting phase (Table 2.21). In the exercising groups, mean HRs were slightly, but insignificantly, above pre-exercise resting levels at t_{270}.

Dry Walks. Heart rate data collected from individual dry and wet walks (Table 2.22) reflect the small increases in HR observed during wet walks. S_{H2}, for example, shows a significantly greater increase in HR during the final phase of his dry walk, than in his wet walk.

Table 2.20. Comparison of V_E ($l \cdot min^{-1}$) in wet and dry walks, (a) before t_{45} (pre-rain in wet walks), and (b) final 25 min of walking (mean ± SD, n = 5)

Subject	Wet	Dry
S_{01}		
t_{20-45}	7.8 ± 0.8	8.7 ± 1.3
$t_{185-210}$	15.5 ± 1.4	8.8 ± 1.3
S_{L1}		
t_{20-45}	21.7 ± 0.4	21.2 ± 1.9
$t_{185-210}$	28.2 ± 1.4	21.4 ± 0.5
S_{L2}		
t_{20-45}	18.1 ± 0.6	17.3 ± 1.2
$t_{185-210}$	29.1 ± 0.7	14.9 ± 1.6
S_{M1}		
t_{20-45}	24.1 ± 0.8	23.2 ± 0.8
$t_{185-210}$	27.7 ± 0.5	23.6 ± 1.1
S_{M2}		
t_{20-45}	19.9 ± 1.0	19.5 ± 0.5
$t_{185-210}$	30.2 ± 2.1	19.7 ± 0.6
S_{H1}		
t_{20-45}	30.2 ± 0.4	27.1 ± 2.0
$t_{185-210}$	41.2 ± 1.5	27.4 ± 0.4
S_{H2}		
t_{20-45}	32.7 ± 0.8	32.5 ± 0.6
$t_{185-210}$	40.4 ± 0.9	33.2 ± 0.7

Table 2.21. Heart rates (bpm) in different pace groups during walking and sitting phases of wet walks (mean ± SD[1])

Variable	Pace			
	P$_0$	P$_L$	P$_M$	P$_H$
HR$_0$	84.5	78.3	78.0	74.3
	± 9.8	± 9.4	± 10.7	± 13.8
HR$_{45}$	76.3	101.6	113.0	131.3
	± 9.0	± 9.1	± 5.6	± 17.2
HR$_{90}$	93.5	103.9	114.3	133.3
	± 10.4	± 7.3	± 8.4	± 17.8
HR$_{150}$	99.0	111.4	116.2	131.5
	± 8.3	± 11.4	± 7.2	± 17.4
HR$_{210}$	101.3	112.4	119.5	142.5
	± 12.7	± 11.3	± 8.7	± 17.9
HR$_{245}$	90.3	73.3	77.7	84.0
	± 15.7	± 12.6	± 7.2	± 20.8
HR$_{270}$[2]	83.0	88.8	85.5	85.7
	± 5.0	± 18.0	± 5.6	± 18.9

[1] P$_0$ (n = 4); P$_L$ (n = 8); P$_M$ (n = 6); P$_H$ (n = 4)

[2] P$_H$: t$_{265}$ (n = 2)

Table 2.22. Comparison of HR (bpm) in wet and dry walks, (a) before t_{45} (pre-rain in wet walks), and (b) final 25 min of walking (mean ± SD, n = 5)

Subject	Wet	Dry
S_{01}		
t_{20-45}	93.3 ± 1.9	86.4 ± 3.2
$t_{185-210}$	106.4 ± 3.2	78.0 ± 2.0
S_{L1}		
t_{20-45}	91.4 ± 3.3	
$t_{185-210}$	103.4 ± 0.8	
S_{L2}		
t_{20-45}	115.2 ± 4.1	102.4 ± 2.7
$t_{185-210}$	130.8 ± 2.8	103.4 ± 3.4
S_{M1}		
t_{20-45}	116.4 ± 2.7	
$t_{185-210}$	120.4 ± 0.8	
S_{M2}		
t_{20-45}	108.0 ± 1.1	
$t_{185-210}$	114.4 ± 1.0	109.4 ± 2.2
S_{H1}		
t_{20-45}	128.6 ± 0.5	119.4 ± 1.2
$t_{185-210}$	148.8 ± 1.6	134.2 ± 4.2
S_{H2}		
t_{20-45}	115.6 ± 1.9	115.2 ± 1.6
$t_{185-210}$	118.8 ± 1.9	143.6 ± 2.7

2.3.7. Variables Affecting Cooling Rate

There were no apparent general relationships between changes in rectal temperature, anthropometric characteristics, aerobic fitness, and ambient temperature. The "average" qualities of subjects, concomitant with small sample sizes, precludes complex (multivariate) statistical analysis. Simple comparative analysis of "likely-probability" scenarios, such as a slower cooling rate observed in an individual with more body fat exercising in a higher ambient temperature (Fig. 2.9), appears to support general expectations of relationships between cooling rate and physical factors. However, these "predictable" relationships are found alongside other data that do not demonstrate these stereotypical relationships. For example, low-fitness-rated subject S_{H4} had greater tolerance (longer exposure) for wet-cold than another individual (S_{H5}) who had a significantly higher aerobic fitness level. Subject S_{H1} walked (wet) at an ambient temperature of about 5°C, and completed the walking phase of the experiment with a higher rectal temperature than S_{H2} (comparable fitness and anthropometric ratings), who completed his walk at 9°C.

2.3.8. *PETER* Subtest

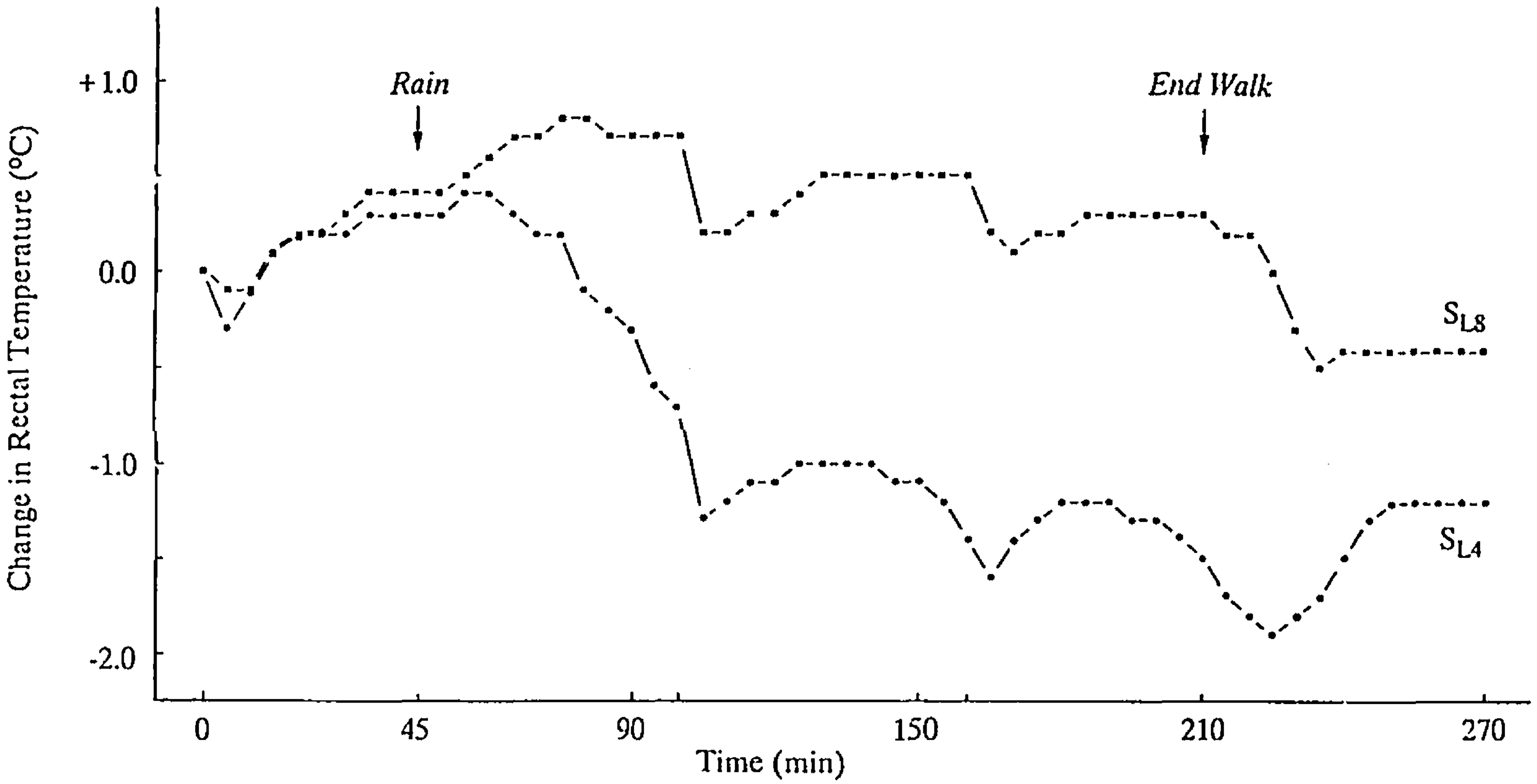
The *PETER* subtest was analyzed independently by N.H.R.C. A review of the results, published in an N.H.R.C. report (Hord and Thompson 1983), is presented in this section.

Comparative performance was measured by calculation of a derived score (D) using an equation typically used for scoring mutliple choice tasks,

$$D = C - (A - C)/(N - 1),$$

where C is the number of correct responses, A is the number of attempts, and N is the number of possible alternative answers. Change in performance was tested by comparing the pooled *PETER* D-scores on the pre-walk test (t_0) to the end-walk

Fig. 2.9. Comparison of changes in rectal temperature (°C) between two P_L subjects: S_{L8} was a larger (83 kg), more insulated (mean skinfold 11.5 mm) subject ($T_{amb} \approx 5.5°C$); S_{L4} was a smaller (57 kg), leaner (mean skinfold 6.7 mm) subject ($T_{amb} \approx 3°C$).


Rain
End Walk
Change in Rectal Temperature (°C)
+1.0
0.0
-1.0
-2.0
0
45
90
150
210
270
Time (min)
S_{L8}
S_{L4}

test (t_{210}). This analysis indicates a significant performance decrement ($p < 0.01$) in three of the four tests (mean ± standard deviation): code substitution test (−42.0 ± 19.6); number comparison test (−17.5 ± 8.8); and tapping test (−16.2 ± 8.7). No significant change was observed in the Baddeley reasoning test (−0.8 ± 3.9).

A survey of the graphic comparison of correct responses versus the number of attempts for each test shows no change in the mean accuracy performance of subjects during wet-cold exposures (Hord and Thomson 1983). In the three tests showing significant performance decrements, the mean accuracy score appears to be maintained at nearly 100%. However, there is a significant change in the number of attempts.

A correlation matrix of two thermal variables (change in T_{Rc}, change in T_{MS}), a fitness measure ($VO_{2}max$), two anthropometric variables (skinfold thickness and surface area) and the four *PETER* subtests was generated in order to investigate relationships between cognitive performance and physiological parameters. No significant relationships were observed.

Analysis of these results should also reference the following general observations of subject behaviour during completion of the *PETER* tests: *(1)* reduction in writing ability, associated with cold, stiff hands; *(2)* disruption of mechanical efficiency by intense shivering, and *(3)* apparent low subject motivation.

Many subjects had difficulty holding onto a pencil during the wet-cold exposure tests; some subjects used both hands to hold the pencil while writing. Subjects reported their hands as feeling "cold", "stiff" or "numb". Subjects S_{M9} and S_{H2} expressed doubts that they would be able to hold a pencil, at the beginning of mid-walk tests. The former subject reported that he felt his cognitive ability had not been affected, but that his coordination and dexterity had been impaired; subject S_{L2} stated that he felt he knew the answer but that it was hard to write.

General and local intense shivering spasms were also a problem for subjects during the *PETER* tests. In some instances, the shivering was so strong that a subject would momentarily be unable to continue the test. Shivering in the arms and hands interfered with writing ability. Subject S_{M5} reported that he was concentrating more on shivering than the tests, while S_{H2} did not look forward to the tests because he would start shivering.

Finally, many subjects found the *PETER* tests "boring" or "tedious", and at least three subjects stated that they "hated" the tests. This was not a universal feeling, however. Several subjects stated that they looked forward to the tests (S_{L8} "kind of fun").

2.4. Discussion

During 2.5 hours of walking in rain, and a further hour of sitting in wet clothing in the cold, not one case of clinically-defined hypothermia was observed in 27 wet-cold exposures. Only one subject had a rectal temperature below 36°C at the end of the walking phase of the experiment (S_{M2}, 35.6°C). Only 4 of 23 subjects ended this phase of the experiment with rectal temperatures below 36.5°C (4 of 27 subjects, including S_{H7-10} under modified conditions) (Table 2.7). Four other subjects sat in rain for the same period of time, with similar non-hypothermic results: only 1 of these four subjects ended the rain phase of the experiment with a rectal temperature below 36°C (S_{01}, 35.9°C).

The absence of hypothermia under these conditions was unexpected particularly given behavioural indications suggestive of hypothermia – including intense shivering, reduction in motor abilities and mood depression – according to descriptions of hypothermia symptoms found in popular outdoor-recreation magazines (Del Guercio 1989) and medically-related texts (Maclean and Emslie-Smith 1977).

The general relationship between faster walking pace and increased rectal temperature occurred during the dry, pre-rain period as expected, although no significant differences were observed between the P_M and P_L groups. However, the lack of significant differences between P_0, the intermediately-placed P_M and P_L, and P_H groups at the end of the rain exposure was not expected (although, as noted in the Results, subjects S_{H7}, S_{H8}, and S_{H10} finished with rectal temperatures well above 37°C). This would suggest that there is no thermal advantage to walking at a relatively high pace under these conditions, with the exception of covering more distance, and perhaps reaching shelter and safety (assuming such a haven *can* be reached). The higher energy costs might have deleterious effects on an individual who stops walking, with lower energy reserves available for shivering after exercise is completed. Pugh (1966a) noted that individuals caught out in wet and cold conditions often survive a night of exposure if they stop and find shelter prior to exhaustion, in contrast to cases of hypothermia fatalities where people walk until in a state of exhaustion. The viability of the former strategy is enhanced by the results of *Wet Walk* subjects sitting through 2 hours of rain, without developing hypothermia.

Changes in rectal temperature were generally consistent with those observed by Pugh (1967), in subjects exercising in wet clothing at 5°C, and exposed to a 15 $km \cdot hr^{-1}$ wind. For example, subjects working at a light rate (400 $kg \cdot m \cdot min^{-1}$) showed an initial rectal temperature increase to 37.55°C, followed by a decrease to 36.5°C during exercise in wet clothing, comparable to responses of subjects in paces

P_L and P_M (no measures of variation are presented by Pugh, and means appear to include multiple measures on at least one of his three subjects). Subjects in a non-exercising condition showed a mean decrease −0.6°C (mean T_{Re} 36.6°C); no details are provided regarding the length of exposure, however. Non-exercising *Wet Walk* subjects had a t_{210} rectal temperature of 36.4 ± 0.5°C.

However, comparison of relative changes in rectal temperature between pace groups suggests opposite trends to the data of Pugh (1967). Pugh demonstrated a decreasing difference in rectal temperature between wet and dry conditions as pace increased. The *Wet Walk* data suggest the opposite is happening. Decreases in rectal temperature from pre-rain values were greater in the higher pace group (Table 2.7), at least for S_{H1-4}, although the eventual rectal temperature was not less than the other group means. This may result because of higher core-environment temperature gradients in P_H subjects, enhancing heat loss. Greater relative thermal stress during exercise may be indicated by the significantly lower mean skin temperatures observed in the P_H group in comparison to P_L.

The trend towards stabilization of rectal temperature over time is similar to asymptotic cooling observed in subjects exposed to moderated cold-water immersion, as in indiviuals wearing survival suits (Hayward and Eckerson 1984) and in divers during prolonged cold-water dives (Vaughan 1975). Asymptotic cooling was also illustrated by Pugh (1967) for one subject.

The rectal temperature "afterdrop" shown by subjects as they returned to exercise in rain after a brief 10-minute rest was also observed by Hong and Nadel (esophageal temperature) as subjects began to exercise in a cool environment (10°C) after a 60-minute period of rest. Similar to observations made in this experiment, the drop in esophageal temperature, accompanied by increased oxygen consumption, was followed by an increase in core temperature. The magnitude of the esophageal temperature decrease, the extent of "recovery", and increase in oxygen consumption were related to the intensity of exercise. These observations were also similar to trends observed in this experiment (Table 2.10).

Increases in heat production were observed in all walking pace groups, as well as in the non-exercising group, although absolute differences in heat production appear to be significant only in the P_H group (Table 2.16). However, relative increases in heat production, averaging 30–40% in the walking groups, were significant (Table 2.17). These data lend credence to the concept that exhaustion or fatigue occurs sooner during exercise in cold than in warmer conditions, at similar exercise levels (Adolph and Molnar 1946; Pugh 1967).

The relative work rates after 2.5 hours of wet-cold exposure further implicate the effects of walking rate and exhaustion on progression into hypothermia. Over the final stages of the wet-cold exposure, heat production was equivalent to about 60% of VO_{2max} in P_H, a pace that is difficult to maintain over a prolonged period (Gollnick 1982).

Intense shivering was observed during the cold-wet exposure period, and sitting phase that followed. Shivering was most visible during data-recording stops, but was also visible during walking, particularly in the hands. As described in the results, one subject was shivering so intensely that his walking was impaired, forcing the termination of the walking phase of that experimental session. The observed increase in oxygen consumption should not be wholly attributed to shivering, however. The increased work load imposed by increased clothing weight, particularly the boots (Legg and Mahanty 1986), and the possible increased metabolic costs associated with walking on a wet trail (Pandolf et al. 1976), would also account for an undefined amount of the observed increase in heat production. Nonetheless, the increase in heat production, regardless of cause, appears sufficient to maintain rectal temperatures above 35°C during exercise (and rest) in rain, at ambient temperatures around 5°C.

However, the relationship suggested by Pugh (1967), that excess oxygen consumption above equivalent exercise levels in dry conditions decreases with increasing exercise level, was not supported by my results. Heat production increased by similar, if not higher levels, in subjects walking at fast pace (Table 2.17). The higher-than predicted relative increase in heat production at the high pace may be explained in part by relatively greater metabolic costs of carrying an increased load (wet clothing), in wet hiking boots on wet terrain, compared to the slower paces. Pedalling a bicycle, and wearing clothing that is drying out (Pugh 1967), does not represent the natural hiking or mountaineering experience in this respect.

The decrement in cognitive performance on three of four tests is consistent with expectations (Teichner 1958; Baddeley et al. 1975), based not only on the significant difference scores, but also on physiological and behavioural observations. However, the interpretation of performance decrements due to cold distraction is only partially applicable. As described in the results, most subjects suffered significant dexterity impairment, to the point where some subjects required the use of both hands to manipulate the pencil. Therefore, in conjunction with a reduction in mechanical efficiency due to interference from shivering (Kissen et al. 1964), performance decrements may also be explained simply as a result of slower writing capabilities (particularly in light of no observed change in accuracy score). As previously noted, at least one subject directly stated he knew the answer, but could not write as fast he could think. Secondly, based on subject comments, possibly one-half of the subject pool found the tests boring; therefore, reduction in motivation is an additional consideration for explaining observed cognitive performance decrements. Shifts in mood (motivation effects) and fatigue (greater energy costs of exercising in wet-cold) may also contribute to a general decline in performance. General mood depression was common among subjects during wet-cold (although not always present). Nonetheless, under these circumstances of prolonged wet-cold exposure, there was a reduction in the ability to complete the tests as quickly as in dry conditions, for whatever cause(s).

The lack of correlation between thermal variables and performance decrements reported in Hord and Thompson (1983) is misleading. The general decline in performance between the test at t_0 and the test completed at the end of the wet-walking phase (t_{210}) is associated with significant decreases in skin and rectal temperature (except P_0). The lack of correlation is possibly due to an expectation that absolute levels of skin temperature will predict cognitive performance; that skin temperature did not predict cognitive performance may be explained in part by the limited range of changes in skin temperature, 56% (15/27) of subjects showing decreases within a 1.6°C range (−7.1 to −8.7°C), and 78% (21/27) within a 3°C range. Furthermore, prediction of a significant relationship between skin temperature and performance within this narrow range suggests an expectation that subjects will consistently interpret wet-cold based on some absolute levels of skin temperature; such an expectation does not allow for individual differences.

An alternate approach is to assume that individuals respond with typical behaviour patterns reflecting a level of discomfort relative to a general physiological state. In this case, the general physiological pattern elicited by prolonged exposure to wet, cold conditions might be described as a "wet-cold syndrome" (Vanggaard 1975). Minor differences in physiological measurements may be buried within the singular, overwhelming perception of the event for a given individual. Thus, two individuals with similar physiological responses may both show cognitive decrements, but with differences in performance attributable to personal differences in interpretation of similar physiological events.

Generally, observations of subject behaviour during wet-cold stress demonstrated the potential variance of psychological responses to this intense level of exposure. These observations are based on impressions of subjects' moods, feelings and attitudes, as well as overt behaviours. No quantitative methods were available to record these observations.

Generally, there was no apparent relationship between physiological and psychological variables during cold stress. In other words, a subject appearing to cope well in the wet-cold stress did not show warmer skin and rectal temperatures, as might be expected for less thermal stress. For example, Kissen et al. (1964) did not observe any difference in skin temperatures in subjects between hypnotic and non-hypnotic cold-exposure (5°C) sessions. Variance in general psychological and behavioural responses suggested individual differences in coping ability. Anecdotal evidence, as Cameron (1982), suggests that attitude, such as the "will to live", may positively affect a survival outcome. "Premature" cold water immersion deaths - deaths occurring before a predicted physiological limit (as defined in Hayward et al. 1975b) - may in some cases result from inappropriate psychological and behavioural responses that directly (although unintentionally) cause acceleration of cooling rate.

In summary, the results of EXP_1 demonstrated that human subjects were able to tolerate 2.5 hours of exercise in rain at ambient temperatures near 5°C without becoming hypothermic. However, changes in behaviour observed during the prolonged phase of wet-cold exposure were indicative of "hypothermia", based on descriptions found in popular and medically-related texts.

Chapter 3. INTERACTIONS OF THERMAL BALANCE, MOTOR PERFORMANCE AND BEHAVIOUR DURING PROLONGED EXERCISE IN A WET, COLD ENVIRONMENT (EXP_2)

3.1. Introduction

Despite substantial peripheral cooling (average decrease in skin temperature 8.5°C) accompanied by behavioural signs suggestive of hypothermia, including intense shivering, no cases of clinical hypothermia were observed in EXP_1 wet-cold exposures. However, rectal temperatures decreased significantly from levels maintained in dry conditions. Changes were observed in both motor and psychological behaviours during wet exposures. Subject performance on the *PETER* subtests decreased significantly, although these changes may be attributed to reduced attention or distraction from cold discomfort (Teichner 1958; Vaughan 1977) and/or impairment in motor function (unable to hold a pencil). Typically, many subjects showed a general depression of mood, often accompanied by expressions of hostility, irritability or resignation not observed in dry walks. The overall impression of perceived impairment in performance was comparable to descriptions of hypothermia symptoms (Maclean and Emslie-Smith 1977). This suggested that there was a possible discrepancy between the signs of cold exposure and symptoms of hypothermia.

Vaughan (1975), following an investigation of diver performance during prolonged cold water immersion, concluded that rectal estimates of core temperature were insensitive indices of cold stress above clinically critical values, as rectal temperature "did not reflect the severity of cold stress as observed by medical and scientific personnel or as reported by the divers." Vanggaard (1975) stated that the early signs of hypothermia may be in fact attributable to the effects peripheral cooling, and that early diagnoses of hypothermia may be premature since collapse or invalidation occurs before significant general body cooling can occur.

These observations suggested that investigation of pre-hypothermic changes in motor and psychological behaviour would enhance understanding of the overall significance of extended wet-cold exposure. Decrements in motor performance associated with local peripheral cooling are well-established (Clarke et al. 1958; Lockhart 1966; Fox 1967), and research indicates that performance decrements in cold are more closely allied to peripheral thermal states than to core temperature (Davis et al. 1975; Baddeley et al. 1975). Given that peripheral cooling precedes hypothermia, and that mild core cooling is associated with decreased performance (Bergh and Ekblom 1978, 1979), it is possible that wet-cold exposure may result in incapacitating injuries during participation in outdoor activities, such as mountain climbing (American Alpine Club 1982), at near-normal core body temperatures. Analogies may be drawn to cold water immersion in which the official cause of death is given as drowning. Moderate body cooling (mild hypothermia) may result in impairment of normal motor function, leading to inhalation of water and drowning (Keatinge 1969).

Tests of motor performance and objective measures of psychological experience were therefore included in the investigation. The duration (4 hr) and severity (wind) of cold stress were also increased in order to enhance the probability of inducing hypothermia during wet-cold exposures.

3.2. Methods

Pilot studies were carried out in the autumn preceding EXP_2 to establish a single, representative walking pace (Appendix B2). Several other preliminary walks were conducted in order to evaluate the protocol, motor performance tests, and windspeed effects.

3.2.1. The *Wet Walk*

Extensive changes were made to the area surrounding the *Wet Walk*, including the addition of fans, a second observation shelter, and improved lighting. Fig. 1.2 reflects the status of the *Wet Walk* in EXP_2.

3.2.2. Subjects

Experimental procedures were approved by the Committee for Research on Human Subjects at the University of Victoria. Each subject was informed of his right to withdraw from the experiment at any time; subjects were reminded of this right prior to the beginning of an experimental session. An experiment was normally terminated if *(a)* rectal temperature reached 35°C or *(b)* a subject requested to withdraw from the experiment. The experimenter also reserved the right to terminate an experiment if he felt there was risk to the subject's health and/or well-being.

Subject selection. Twenty male subjects volunteered to participate in the experiment (several subjects had taken part in EXP_1). Additional subjects were recruited for participation in pilot studies. Informed consent was obtained from each subject after he had been familiarized with the purpose and procedures of the study. Subjects also completed a medical history questionnaire and the *ParQ* questionnaire (B.C. Ministry of Health 1978) prior to testing; individuals with characteristics indicating any potential risk to their own health or safety were not included in the study. Participation in the study was also dependent on completion of a fitness test (PWC_{170}; Astrand and Rodahl 1977) indicating a reasonable level of fitness.

Subject characteristics. Subject characteristics are summarized in Table 3.1. Fitness level was established using a submaximal bicycle ergometer test and aerobic capacity (V_{O_2max}) estimated from predictive tables based on cardiac frequency (Astrand and Rodahl 1977: 351). Height and weight, and skinfold measures were recorded for each subject. Mean skinfold thickness (mm) was the average value of skinfold measurements taken at six standard sites: triceps, subscapular, suprailiac, abdominal, thigh and calf. Per cent body fat, surface area, and surface area:mass ratio were calculated as described in chapter 2. Additionally, Heath-Carter somatotyping (Heath and Carter 1967) was also completed and a relative index calculated (Hayward et al. 1978).

3.2.3. Clothing

Subjects dressed in the standard set of clothing described in the previous chapter (section 2.2.3).

3.2.4. Backpack

The backpack containing measurement instrumentation (Fig 1.7) is described in Appendix E3. The loaded pack weighed 7.7 kg. During wet exposures, the pack was covered by a protective neopprene cover.

3.2.5. Walking Pace

Subjects walked the track at a constant rate of 35 $sec \cdot lap^{-1}$ (50 m), equivalent to a walking pace of 5.15 $km \cdot hr^{-1}$. This pace had been selected, in part, on the results of the pilot study previously described. An electronic pacing device (Appendix B3) allowed the subject and observers to monitor the pace on a lap-by-lap basis. Subjects demonstrated a consistent ability to maintain a constant pace, after a brief learning period. The total estimated distance walked, adjusted for scheduled stops, was 22.1 km over the complete 5-hour experiment (Appendix B4).

Table 3.1. Subject characteristics (EXP_2: n = 18)

Characteristic	Mean	± SD
Age (yr)	21.3	± 2.7
Height (cm)	177.3	± 4.1
Weight (kg)	69.2	± 7.6
Surface area (m^2)	1.85	± 0.10
Area:volume ($cm^2 \cdot kg^{-1}$)	268.9	± 15.8
Skinfold (mm)	9.2	± 2.7
% Body fat	11.2	± 2.0
Somatotype[1]		
Endomorphy	2.5	± 0.9
Mesomorphy	3.9	± 1.0
Ectomorphy	3.2	± 1.1
Index[2]	0.45	± 0.33
VO_2max (ml $O_2 \cdot min^{-1} \cdot kg^{-1}$)	48.0	± 5.5

[1] Heath-Carter somtatotype

[2] Ectomorphy/(Endomorphy•Mesomorphy)

3.2.6. Protocol

A simplified design was selected in order to increase the effective sample size. All subjects (n = 18) walked in rain and wind conditions (R_1W_1); nine of these subjects also completed a control walk (no rain/wind: R_0W_1). Additionally, two other subjects completed a non-wind wet walk (R_1W_0).

The protocol is described in Table 3.2. Following equilibration, subjects walked 60 minutes in dry conditions; after the 60-minute reading, the rain and wind were turned on. Subjects continued to walk for 4 hours under these conditions, then sat for 90 minutes in their wet clothing on the ground in protected area about 3 m north of the observation area. When the experiment ended, subjects rewarmed in a therapeutic, warm-water bath. Tests of motor behaviour and psychological status were included throughout the experiment as indicated in Table 3.2. Identical procedures were followed in dry conditions, with the exception of rain.

3.2.7. Physiological Variables

Rectal temperature. Rectal temperature was measured with a YSI series 400 rectal thermistor (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). The telephone jack connector for the probe was carried in a waterproof container by the subject; at scheduled data stops, the jack was removed from this container and connected to a YSI tele-thermometer. A small surgical tube plug was devised which was inserted onto the probe at the 15-cm mark in order to reduce the probability of the probe slipping out of the rectum during an experimental exposure.

Skin temperatures. Skin temperatures were recorded at four standard sites (arm, chest, calf, thigh), and mean skin temperature calculated using the weighted formula of Lund and Gisolfi (1974). Mean skin temperature was estimated as the unweighted mean when data from only three thermosensors were available. Skin

Table 3.2. Protocol (EXP_2)

t_{CUM} (mins)	t_{ACT} (mins)	Activity	Description
−30 – −15	15	SITTING	Equilibration; $POMS_1$, $BADDELEY_1$ (tent)
−15 – 0	15	*MOTOR TESTS*	$BALANCE_1$, $TARGET_1$ $GRIP_1$, $THREAD_1$
0 – 60	60	WALKING *(DRY)*	Walking (5.2 km/hr)
0			*SENSORY*
10			*RPE*
60 – 300	240	WALKING *(WET)*[1]	Rain/wind at 60 min
60			*SENSORY, RPE*
90	4		*SENSORY, RPE;* $THREAD_2$, $GRIP_2$
100	6		$BALANCE_2$, *TARGET2*
120			*SENSORY, RPE*
180	4		*SENSORY, RPE* $THREAD_3$, $GRIP_3$
190	6		$BALANCE_3$, $TARGET_3$
240			*SENSORY, RPE*
270	4		$THREAD_4$, $GRIP_4$
280	6		$BALANCE_4$, $TARGET_4$
300			*SENSORY, RPE*
310 – 400	90	SITTING	Sitting in wet clothing
320			$BADDELEY_2$, $POMS_2$
390			$BADDELEY_3$, $POMS_3$
405 – 420	15	*MOTOR TESTS*	$BALANCE_5$, $TARGET_5$ $GRIP_5$, $THREAD_5$
	60	SITTING *RECOVERY TESTS*	Rewarming in hot bath $BADDELEY_4$, $POMS_4$ (tent) $BALANCE_6$, $TARGET_6$ $GRIP_6$, $THREAD_6$

[1] In dry condition, subjects continue walking without rain.

t_{CUM} = Cumulative experiment time; t_{ACT} = Activity time temperatures were measured using individual digital RAEKIT 3200D thermometers mounted in balsawood cases in the backpack (Appendix E3); current-source sensors, insulated with an epoxy resin cap (Appendix C2), were held in place with a 2.5-cm-square piece of Elastoplast waterproof adhesive tape.

Oxygen consumption/ventilation rate. Oxygen consumption and ventilation rate were measured with a portable Oxylog oxygen consumption meter (P.K. Morgan Ltd., Chatham, Kent, England) mounted in the backpack. The subject wore an oronasal mask connected to the Oxylog. Minute oxygen consumption (VO_2) was read directly from the Oxylog at the scheduled data recording stops, and metabolic rate calculated in watts using the conversion factor of 20.2 $kJ \cdot l \, O_2^{-1}$ consumed (assuming an R.Q. of 0.83). Minute ventilation (V_E) was estimated from the change in total inspired volume over the ten-minute period.

Heart rate. Cardiac activity was monitored by radio telemetry (Conestoga Medical Electronics, Model SCT-1; Tektronix Physiological Monitor Type 410) and heart rate extrapolated from the recorded time for 30 beats. Three 30-beat samples were taken every ten minutes; the second sample was used in calculation of means.

Core temperature comparison. In some experiments, other non-invasive estimates of core temperature were recorded. Urine temperature was measured with a low-reading clinical thermometer (Zeal) placed in the urine stream using the *TeePee* (Appendix C5), a modified version of the Uritemp bottle described by Fox et al. (1973), and used for urine collection. Axillary and oral temperature were measured with YSI thermistors during the post-exercise sitting phase. Data are not included in the dissertation.

Urine sanpling. Urine samples were collected principally to measure urine temperature, as previously described, and urine flow rates. Samples were immediately analyzed for protein, glucose and pH (Ames Combistix), and small samples were retained for osmolality analysis. Data analyses are not included in the dissertation.

3.2.8. Motor Behaviour Tests

Two sets of motor performance tests were delivered at 90-minute intervals during the exercise phase, and briefly interrupted walking (Fig. 3.1). Grip strength and dexterity tests (average stopping time 4 minutes) were administered at 90, 180 and 270 minutes; balance beam and target shoot (average time 6 minutes) were administered at 100, 190 and 280 minutes. The tests were delivered in vicinity of the *Wet Walk*; subjects remained standing throughout the tests.

Grip Strength (Fig. 3.1a). A subject was instructed to place the dynamometer (Narragansett; Appendix F1) comfortably in the palm of his preferred hand. He then raised his arm to level of the head, with a 90° flexion at elbow. When the subject was ready, he brought his hand down parallel to his body, squeezing as hard as possible; subjects were not allowed to use their bodies for leverage. Maximum pull was measured in lb and converted to kg. The test was done on the track adjacent to the observation area, and always followed completion of the threading test described below. The grip strength test was completed seven times (Table 3.2):

(1) three practice pulls before the experiment; (2) at the beginning of the walk ($Grip_1$); (3–5) three times during the walking phase of the experiment [($Grip_2$ (90 min); $Grip_3$ (180 min); $Grip_4$ (270 min)]; (6) at the end of the sitting phase ($Grip_5$); and (7) following recovery ($Grip_6$). The dynanometer was kept warm, and the subjects hand patted (not rubbed) dry prior to testing. During the test, the oronasal mask was removed, in order to minimize interference with the test process.

Fig. 3.1. The four motor performance tests of EXP_2: (a) threading test, (b) grip strength, (c) target shoot, and (d) balance beam walking.


a
b
c
d

Threading Test (Fig. 3.1b). A threading test (Appendix F2) was designed to test manual dexterity. Subjects were required to transfer 5 different-sized nuts from one set of fixed bolts to another; the bolts were attached to the lid of a small plastic utility box. The box was attached to a bench at the side of the track in the observation area (height 92 cm). Subjects were instructed to transfer the bolts as quickly as possible. The threading test was completed seven times, at similar times to the grip strength test; the threading test always preceded the grip strength test (Table 3.2):

(1) five practice trials prior to the experiment; (2) at the beginning of the walk (Thread$_1$); (3–5) three times during the walking phase of the experiment [(Thread$_2$ (90 min); Thread$_3$ (180 min); Thread$_4$ (270 min)]; (6) at the end of the sitting phase (Thread$_5$); and (7) following recovery (Thread$_6$).

The oronasal mask was removed during performance of this test. The time required to complete the transfer of the 5 nuts was recorded; the number of dropped nuts was also tabulated.

Balance Beam (Fig. 3.1d). A balance beam test was included to measure general motor ability. The test was based on a test described in Johnson and Nelson (1969). A 3.05 m length of 2 × 6-in kiln-dried fir was supported on edge by split log half-rounds (Appendix F3). The balance beam was located on level ground on the south side of the *Wet Walk* towards the west end (Fig. 1.4). Subjects completed four traverses of the beam in each test:

(1) walk straight along the beam from east to west;

(2) a return circuit from west to east;

(3) walk westward along the beam to the halfway mark, rotate to the right, and sidestep to the end;

(4) return eastward in a normal walk to the halfway mark, rotate to the left, and sidestep to the end.

The time for each circuit was recorded. Subjects always started on and stepped off onto marker plates placed at the ends of the beam. The timer was started when a subject stepped onto the beam, and stopped as he contacted the marker plate. Subjects were instructed to proceed across the balance beam as quickly and safely as possible; the goal was to get across the beam as rapidly as possible with out "falling". Safety was emphasized. A subject was asked to step off the beam if he felt he was losing control of his balance, and then to continue (no falls occurred during this experiment). The number of times a subject stepped off the beam was recorded. The balance beam test was completed six times (Table 3.2), always prior to the target shoot:

(1) five practice trials prior to the experiment; (2) at the beginning of the walk (Balance$_1$); (3–5) three times during the walking phase of the experiment [(Balance$_2$ (100 min); Balance$_3$ (190 min); Balance$_4$ (280 min)]; (6) at the end of the sitting phase (Balance$_5$); and (7) following recovery (Balance$_6$). The oronasal mask was removed during the balance beam test. Analysis of the balance beam data was not completed fot the dissertation.

Target Shoot (Fig. 3.1c). A "target shoot" test was devised as a means of measuring general body coordination. A single-lens reflex camera (Asahi Spotmatic II; Takumar 105 mm macro lens) was attached to a rifle stock (Appendix F4). A piece of clear film with a cross-hair scratched in the center was placed over the film plate in the camera; when a frame of film was exposed, a fine white cross-hair was also recorded in the center of the negative. The target was a black circle on a white plexiglass background, the image oi which filled the focussing ring of the lens; a white-cross hair was centered on the black circle. The target cross-hair was recorded as a distinct black cross-hair on the negative. Therefore, the relative accuracy of a given shot could be assessed by measuring the deviation of the camera center (white negative cross-hair) from the target center (black cross-hair).

The subject was instructed to take 10 "shots" in sequence as quickly and as accurately (centered image) as possible. The time to complete the 10 shots was recorded. The shoot was completed at six times (Table 3.2), following the balance beam test:

(1) five practice trials prior to the experiment; (2) at the beginning of the walk (Target$_1$); (3-5) three times during the walking phase of the experiment [(Target$_2$ (100 min); Target$_3$ (190 min); Target$_4$ (280 min)]; (6) at the end of the sitting phase (Target$_5$); and (7) following recovery (Target$_6$). The oronasal mask was removed for the test.

Analysis of the target shoot was not completed. Analysis of individual negatives required excessive time, and was complicated by out-of-focus images.

Achilles tendon reflex. The achilles tendon reflex was measured (Burdick FM-1 Photomotograph; Sanborn VISO 100 electrocardiograph) four times during an experiment: (1) before the subject began walking; (2) at the end of the walking phase of the experiment; (3) after completion of the 90-minute sitting phase; and (4) following rewarming. Analysis of the achilles tendon reflex was not completed for the dissertation.

3.2.9. Psychological Tests

Several measures of psychological status were completed by subjects. Some of these tests were provided (and anaylzed) by N.H.R.C.

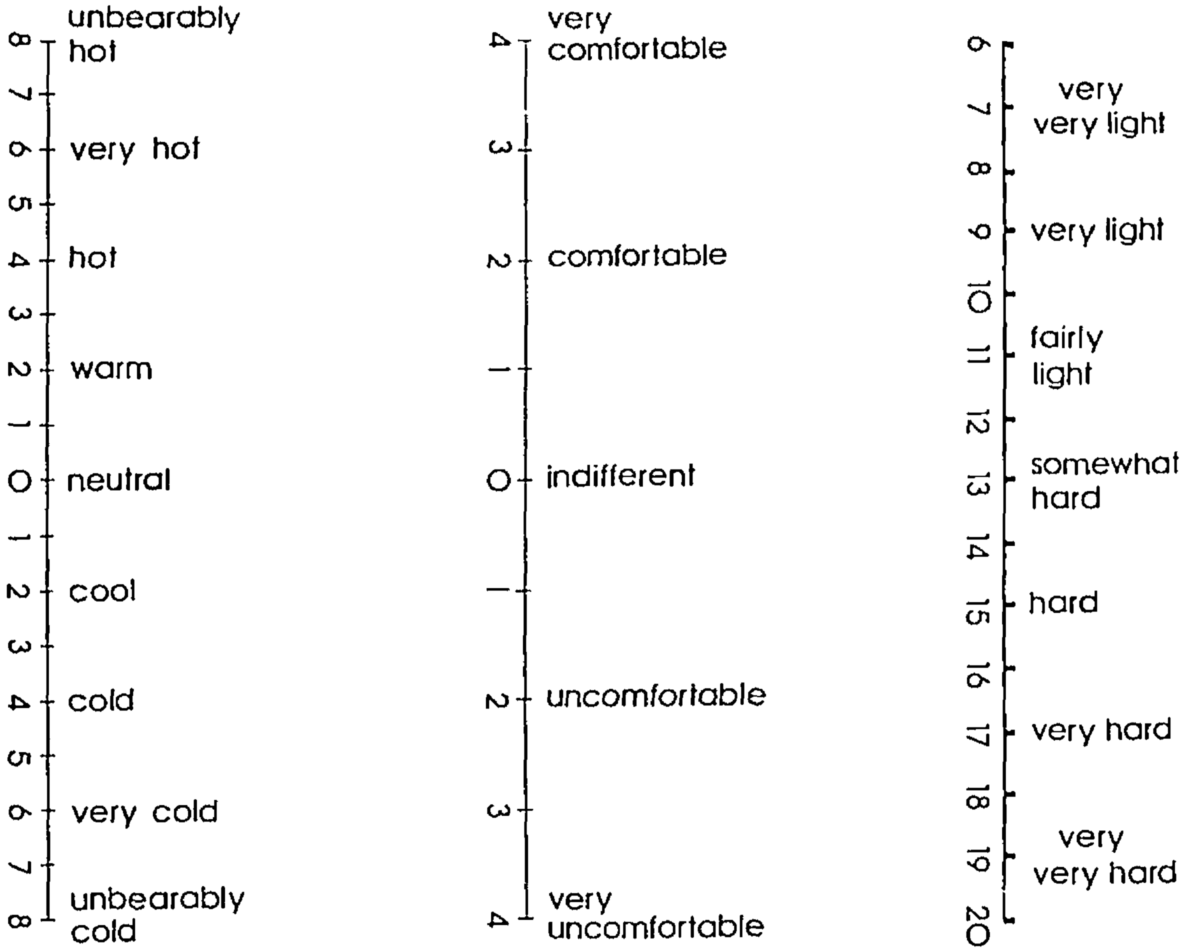
Baddeley test. A version of the Baddeley reasoning test (Appendix G2) was completed by subjects before and after the walking phase of the experiment (Table 3.2). This test was selected from the *PETER* battery (EXP_2) because (a) no complex fine motor-control was involved, and (b) it was disliked (high frustration) by subjects in the previous experiment. The Baddeley test was generated by N.H.R.C. Initial analysis suggested problems with the structure of the test; the issues have not been resolved.

POMS. The *Profile of Mood States* (Educational and Industrial Testing Service 1971) was completed by subjects at similar times as the Baddeley test. This test measures changes in mood according to six scales: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, and Confusion-Bewilderment. The test was included in an attempt to objectify previous observations of apparent change in mood in EXP_1. Analysis of POMS was not completed for the dissertation.

Self-rating scales. Three perceptual scales were completed by subjects at regular intervals during the cold exposure (Table 3.2). These were (Fig. 3.2):
(1) rating of perceived exertion (RPE) (Borg 1973);
(2) thermal comfort (Hardy 1970); and
(3) thermal sensation (Marcus and Belyavin 1978; Hardy 1970).

The latter scale was modified after Marcus and Belyavin (1978) to include the "unbearable" classification.

Fig. 3.2. The self-reporting sensory scales. From top to bottom: RPE (rating of perceived exertion), RTC (rating of thermal comfort), and RTS (rating of thermal sensation).


8 unbearably hot
7
6 very hot
5
4 hot
3
2 warm
1
0 neutral
1
2 cool
3
4 cold
5
6 very cold
7
8 unbearably cold
4 very comfortable
3
2 comfortable
1
0 indifferent
1
2 uncomfortable
3
4 very uncomfortable
6
7 very very light
8
9 very light
10
11 fairly light
12
13 somewhat hard
14
15 hard
16
17 very hard
18
19 very very hard
20

These scales were presented to subjects in a special weatherproof tray (Appendix G3) located on a bench in the observation area. A sliding indicator arrow for each scale could be manipulated easily with cold hands.

Each scale was explained to the subject during the orientation period at the beginning of the experiment.

Personality tests. Two personality inventories were completed by subjects in the lab at the University of Victoria. These were the *Motivational Analysis Test* (Cattell et al. 1964) and *Test of Attention and Interpersonal Style* (Nideffer 1977). Analysis of these tests was beyond the scope of the thesis, and results are not presented here. Cursory review of the results did not suggest significant relationships between personality and performance (Hord, pers. comm.).

3.2.10. Procedures

Subjects were requested to maintain a normal diet, avoid alcohol consumption and refrain from exercise during the 24-hour period preceding the experiment. Subjects reported to the *Wet Walk* at approximately 1300 hours, and changed into the standard clothing after the temperature sensors and ECG electrodes were applied. The baseline series of performance tests was completed, and subjects familiarized with the walking pace and experimental routine. The preparation period required about 1.5 hours. Subjects then sat quietly in a heated tent (15–20°C) adjacent to the *Wet Walk* and resting values of rectal temperature, skin temperature, metabolic rate, ventilation rate and heart rate were recorded. After the equilibration period, subjects performed the initial battery of performance tests, then rested briefly while final instructions were given. The walking phase of the experiment began at approximately 1630 hours. Subjects walked continuously for the next five hours, stopping briefly (35 sec) at 10-minute intervals for thermal and metabolic data readings, unless the experiment was suspended for reasons previously stated. Administration of the motor tests resulted in longer stops at 90, 100, 180, 190, 270 and 280 minutes. After the 60-minute reading, rain and wind (R_1W_1) or wind (R_0W_1) was initiated, and continued unabated until the end of the walking phase of the experiment. After a 5-minute break, subjects then sat on the ground in a sheltered area adjacent to the *Wet Walk* for the required 90 minutes, data recording continuing at 10-minute intervals. During this period, axillary and oral temperaturea were periodically measured in some subjects. At the end of the sitting phase, subjects completed another battery of motor performance tests before being rewarmed in a hydrotherapy bath. Urine samples were collected when subjects were able to donate. Psychological tests and other measures were completed as indicated in Table 3.2.

3.2.11. Ambient conditions

The mean dry bulb temperature (mean ± SD, $n = 18$) at the start of wet exposure experiments was 5.2 ± 1.6°C, falling slightly to 4.7 ± 1.8°C at the end of the exercise phases. The change in ambient was more than 1°C in only 5 of the 18 wet exposures. Mean ambient temperatures for the group of five subjects completing the protocol (described below) were 5.7 ± 0.8°C in R_1W_1 and 2.7 ± 4.3°C in R_0W_1, at t_{60}. Air temperature was recorded with a mercury thermometer placed in a Stevenson weather screen adjacent to the Wet Walk (Fig. 1.2). Ambient relative humidity averaged 80% (Bacharach Model SAC sling psychrometer). Although limits on ambient wind were also established ($8\ km \cdot hr^{-1}$), observed wind movement was not a significant factor, ranging from "nil" to "negligible" ($< 0.5\ m \cdot sec^{-1}$). Wind speed was recorded with an air meter (WEATHERtronics Model 2410) held at chest level.

3.2.12. Analysis of Results

Data analysis was complicated by subject attrition (Table 3.3). Therefore, data analysis was based on three criteria: (1) comparison of wet and dry conditions for subjects completing the established protocol (n = 5); (2) comparison of data for subjects continuing at least 180 minutes (n = 16); (3) reference to individual data where appropriate. Data are presented as the mean ± SD, unless otherwise indicated. In figures, significance was assumed when standard deviation did not overlap (Browne 1979). Statistical tests were used only to test specific hypotheses. Paired-comparison t-tests were used to test for the effects of wetting between t_{60} and t_{180}. Correlations were applied to analysis of relationships between anthropometric, fitness and physiological variables.

3.3. Results: Physiology

3.3.1. Subject Performance

R_1W_1. Only five (S_{W1-5}) of the eighteen subjects in this condition were able to complete the experimental protocol (four hours of wet-cold exposure) (Table 3.3). These five subjects repeated the experiment in dry conditions (see R_0W_1). At the end of the rain exposure (t_{300}), no subject in this group had a rectal temperature near hypothermia; the lowest observed rectal temperature was 36.0°C (S_{W4}). The degree of fatigue experienced by these subjects varied, ranging from "not all that tired" (S_{W3}: the subject stated that he'd "never walked so long in my life") to "*very* tired" (S_{W2}: stated he felt "more tired than cold"; T_{Re} dropped to 35.1°C during post-walk sit). Four other subjects were able to tolerate at least 3 hours of rain and wind exposure. One of these subjects (S_{W7}) developed hypothermia at t_{270}, at which time the experiment was stopped. Seven of the remaining nine subjects walked for 2 to 2.5 hours in the rain and wind; most of these walks were terminated for reasons

Table 3.3. Summary of subject performance (EXP_2)

S	t_{EXP} (hr)	T_{Re} (°C)	T_{Amb} (°C) T_{rw}	 T_{end}	Description
R_1W_1					
S_{W1}	5.0	36.9	4.5	4.5	Complete
S_{W2}	5.0	36.2	6.5	6.4	Complete
S_{W3}	5.0	36.9	6.4	6.8	Complete
S_{W4}	5.0	36.0	5.4	5.0	Complete
S_{W5}	5.0	36.2	5.5	4.5	Complete
S_{W6}	4.5	37.2	6.3	4.6	Fatigue
S_{W7}	4.5	35.3	5.6	6.7	Hypothermia
S_{W8}	4.0	37.8	3.3	4.0	Respiratory stress
S_{W9}	4.0	37.3	5.4	3.0	Muscle pain (leg)
S_{W10}	3.5	36.0	3.3	1.5	Muscle pain (leg)
S_{W11}	3.5	36.6	4.7	2.9	Muscle pain (leg)
S_{W12}	3.3	36.8	6.4	6.5	Muscle pain (leg)
S_{W13}	3.2	37.2	7.5	7.4	Lost ECG signal
S_{W14}	3.0	37.3	2.9	3.0	Pain/nausea
S_{W15}	3.0	35.9	5.5	4.9	Cold/dizzy
S_{W16}	3.0	36.8	6.6	6.8	Muscle pain (leg)
S_{W17}	2.3	36.9	1.8	2.0	Muscle pain (leg)
S_{W18}	2.3	35.1	3.5	3.7	Hypothermia
R_1W_0					
S_{W20}	3.5	36.6	0.8	0.0	Cold intolerance
S_{W21}	3.0	36.5	5.4	5.6	Muscle pain (leg)
R_0W_1					
S_{D1}	5.0	38.0	5.5	5.3	Complete
S_{D2}	5.0	37.7	3.8	3.6	Complete
S_{D3}	5.0	38.2	6.1	5.4	Complete
S_{D4}	5.0	37.8	−4.7	−4.1	Complete
S_{D5}	5.0	38.1	2.6	0.8	Complete
S_{D7}	5.0	38.4	4.2	3.5	Complete
S_{D8}	5.0	38.0	−0.5	−0.8	Complete
S_{D15}	5.0	37.7	5.1	3.9	Complete
S_{D18}	5.0	37.3	2.0	1.0	Complete

t_{EXP} = walking time
T_{Re} = rectal temperature at end of walking period
t_{Amb} - ambient temperature
t_{rw} = ambient temperature at 60 min (rain/wind on)
T_{end} = ambient temperature at end of walking period

associated with peripheral cooling (Table 3.3). Subject S_{W17} was forced to stop exercising due to pain in the hip region, and S_{W18} became hypothermic (details of this case are discussed later).

Two general observations were made regarding subject performance in this experiment.

(1) Hypothermia developed in only 2 of 18 wet-cold exposures during exercise. In the other 16 walks, only one subject had a rectal temperature below 36°C (S_{W15}, 35.9°C). A third case of hypothermia was observed in the sitting phase following exercise (S_{W2}, 35.1°C).

(2) General complaints of cold stress, as well as signs and symptons suggestive of hypothermia, were commonly reported by and observed in subjects before the second hour of exposure was completed. For example, as early as t_{80}, S_{W6} stated that he was "f------ cold", subject S_{W16} described himself as a case of "advanced misery" (t_{120}), and subject S_{W15} reported feeling "light-headed" at t_{150}. The first signs of the hip/groin problem associated with the premature termination of six experimental exposures appeared before t_{180} in several subjects. Generally, shivering was first apparent 30–40 minutes after the initiation of wetting, and usually during data-recording stops. The *Wet Walk* shuffle observed in EXP_1 was also exhibited by subjects in this experiment.

R_1W_0. Two subjects participated in wet walks without wind. However, both of these no-wind exposures were terminated early due to non-hypothermia factors (Table 3.3). Ambient temperatures dipped to freezing in S_{W20}'s walk (the experiment was terminated when I noticed an ice crust on the walking surface, and icicle formation on the protective screen in front of the fans).

R_0W_1. Nine of the R_1W_1 subjects also completed dry walks; order of presentation was random, except in a few cases when subjects who had completed wet walks were asked to repeat the experiment in dry conditions. Subjects completed the dry walks without incident, although they were tired at the completion of these walks. The dry-walk data of subjects S_{D1-D5} were compared to the wet walks completed by these subjects; in the other cases, the data were compared to wet walks on an individual basis.

3.3.2. Physiological Responses to 2 Hours of Wet-Cold

Data for the period t_{0-180} are presented as the means of subjects S_{W1-16}. The experimental sessions of subjects S_{W17} and S_{W18} were stopped at t_{140}; the initial physiological responses of these two subjects were similar to the those of the larger group (see Fig. 3.3).

Pre-rain responses to exercise. Rectal temperature rose 0.96 ± 0.18°C, from an initial resting value of 37.07 ± 0.31°C, to a mean T_{Re} of 38.03 ± 0.27°C at t_{60} (Fig. 3.3). Mean skin temperature showed a slight but insignificant decrease of −0.3 ± 1.2°C during this time period, reaching a mean level of 30.3 ± 1.6°C at t_{60} (Table 3.4). Hand temperature also showed a small but insignificant decrease (−1.6 ± 5.4°C), although the responses were highly variable.

The average resting metabolic rate was 1.4 ± 0.3 $W \cdot kg^{-1}$. At t_{60}, the exercising metabolic rate averaged 6.4 ± 0.4 $W \cdot kg^{-1}$, equivalent to 39 ± 5% of V_{O_2max}. Average, exercising V_E was 30.1 ± 3.0 $l \cdot min^{-1}$, about 3 times the resting value of 10.3 ± 1.7 $l \cdot min^{-1}$, and heart rate averaged 112.1 ± 9.6 bpm prior to the initiation of wind and rain (Table 3.4).

First 30 Minutes of Wet-Cold (t_{60-90}). Almost all subjects exhibited an initial increase in rectal temperature, typically within 20 min of wetting; the average

Fig. 3.3. Change in rectal temperature (°C) for all subjects up to t_{180} (2 hours of wet-cold exposure). Data are presented as (a) mean ± SD of 16 subjects completing protocol to t_{180}, and individual plots for (b) S_{W17} and (c) S_{W18}.

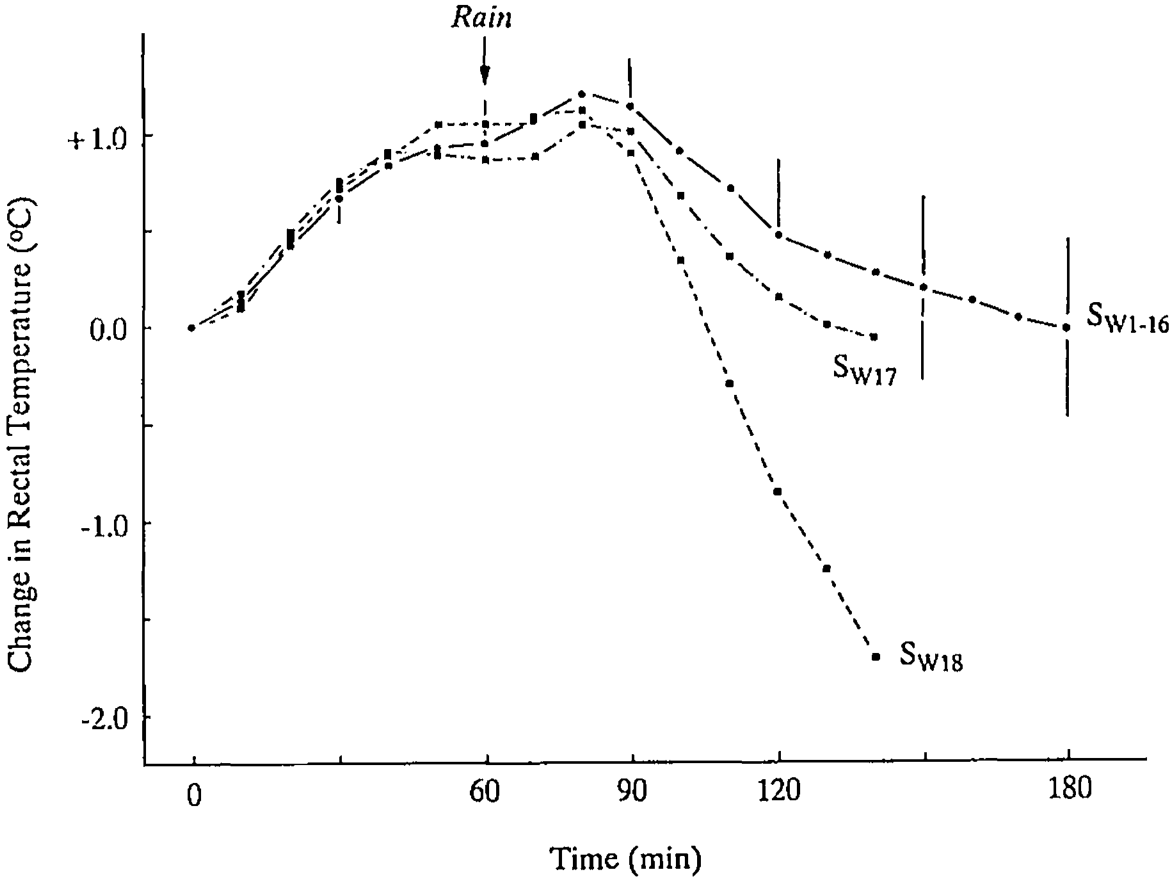

Rain
Change in Rectal Temperature (°C)
+1.0
0.0
-1.0
-2.0
0
60
90
120
180
Time (min)
$S_{W1\text{-}16}$
S_{W17}
S_{W18}

Table 3.4. Summary of physiological responses to wet-cold for all subjects walking to t_{180} ($n = 16$, mean ± SD)

Variable	Mean ± SD
Rectal Temperature (°C)	
t_0	37.07 ± 0.31
t_{60}	38.03 ± 0.27
t_{120}	37.55 ± 0.41
t_{180}	37.06 ± 0.47
Mean Skin Temperature (°C)	
t_0	30.5 ± 1.3
t_{60}	30.2 ± 1.5
t_{120}	23.4 ± 2.2
t_{180}	23.0 ± 2.3
Metabolic Rate ($W \cdot kg^{-1}$)[1]	
t_0	1.4 ± 0.3
t_{60}	6.4 ± 0.4
t_{120}	9.2 ± 1.6
t_{180}	9.7 ± 1.3
Ventilation Rate ($l \cdot min^{-1}$)[1]	
t_0	10.3 ± 1.7
t_{60}	30.1 ± 3.0
t_{120}	38.9 ± 5.4
t_{180}	42.0 ± 4.5
Heart Rate (bpm)	
t_0	64.9 ± 9.6
t_{60}	112.1 ± 9.6
t_{120}	121.4 ± 13.0
t_{180}	130.9 ± 15.4

[1] t_{120}, $n = 14$; t_{180}, $n = 13$

increase in rectal temperature after t_{60} was +0.26 ± 0.14°C. At t_{90}, prior to the first set of motor performance tests, mean rectal temperature was 38.17 ± 0.31°C. Mean skin temperature showed a significant decrease of 5.9 ± 1.8°C, as did hand temperature (−8.1 ± 3.8°C). At t_{90}, mean hand temperature was 12.1 ± 2.9°C.

Metabolic rate rose moderately, to 7.8 ± 1.0 $W \cdot kg^{-1}$ (an average increase of 21 ± 10%); there was no visible shivering, although subjects were thoroughly wetted by this time, and complaints of cold discomfort were not uncommon. Both V_E (34.2 ± 4.8 $l \cdot min^{-1}$) and heart rate (116.9 ± 11.0 bpm) also showed slight but insignificant increases.

Changes During Performance Tests (t_{90-120}). Cooling of rectal temperature was first observed at the t_{100}. The mean decrease in rectal temperature during this 30-min period was −0.67 ± 0.43°C, a cooling rate equivalent of 1.5°C/hr. This value does not include the data of subject S_{W18}, who showed a decrease of 1.75°C in this period (the mean decrease without this subject was only slightly less than −0.67°C). Mean skin temperature continued to cool, but at a slower rate, decreasing by an average of 0.8 ± 0.8°C. Hand temperature, however, decreased by a further 2.7 ± 1.5°C.

Metabolic rate continued to increase during this period, concomitant with the first indications of shivering, including subject reports and visible signs. By t_{120}, metabolic rate had increased to 9.2 ± 1.6 $W \cdot kg^{-1}$. Again, V_E increased moderately, to a mean level of 38.9 ± 5.4 $l \cdot min^{-1}$ (a 25% increase above pre-rain levels). A moderate increase was also observed in heart rate (121.4 ± 13.0 bpm).

2nd Hour of Wet-Cold ($t_{120-180}$). Two subjects dropped out of the experiment prior to the second set of behaviour tests, S_{W18} (T_{Rc} 35.15°C) and S_{W17} (T_{Rc} 36.90°C). Cooling of rectal temperature continued during this hour, at a slower rate, dropping by an average ($n = 16$) of -0.49 ± 0.20°C between $t_{120-180}$ (Fig. 3.3). The average rectal temperature at t_{180} was 37.06 ± 0.47°C. This value was significantly below the pre-rain rectal temperature of 38.02 ± 0.26°C ($p < 0.0001$), but no different from the initial rectal temperature (Table 3.4). There was no significant change in mean skin temperature during this 60-min period (-0.17°C ± 0.8°C); at t_{180}, the mean skin temperature was 23.0 ± 2.3°C, an average of 7.3 ± 2.2°C below the initial resting level ($p < 0.0001$). Hand temperature also showed no significant change during this time (-0.9 ± 1.6°C:), reaching a mean value of 8.4 ± 2.8°C just prior to the second set of manual performance tests. The overall decrease in hand temperature from t_{60} was significant ($p < 0.0001$).

The steady increase in metabolic rate continued; intense, whole-body shivering was visible during data-recording stops in some subjects. At t_{180}, the mean metabolic rate was 9.7 ± 1.3 $W \cdot kg^{-1}$, an average increase of 52 ± 15% ($p < 0.0001$) above the pre-rain exercising MR. This "exercise" level was equivalent to 54 ± 9% of $\dot{V}O_{2max}$. V_E reached a mean level of 42.0 ± 4.5 $l \cdot min^{-1}$ at this time, a significant, 33% increase above pre-rain values ($p < 0.0001$). Heart rate (although the mean value had increased to 130.0 ± 15.4 bpm) was insignificantly different from the pre-rain value, based on standard deviation overlap; however, the relative change in heart rate (+ 18.0 ± 11.2 bpm) was significant ($p < 0.0001$).

3.3.3. Physiological Responses to 4 Hours of Wet-Cold: Exercise Phase.

To investigate the physiological responses to prolonged wet-cold exposure, a subset of 5 subjects (S_{W1-5}) was selected, based on completion of the experimental protocol. Physiological data of other subjects who were unable to complete the protocol were generally similar to the data of S_{W1-5} (with noted exceptions), as will be demonstated later. Therefore, the S_{W1-5} data are presented as typical of individuals able to tolerate prolonged (4 hours) of wet-cold exposure without becoming hypothermic, as defined by the *Wet Walk* conditions. These five subjects also completed walks under dry conditions (R_0W_1).

Rectal Temperature (T_{Re}). During the 60 min of exercise prior to the onset of rain and wind (t_{0-60}), the increase in core temperature was similar in both conditions (R_1W_1, +1.02 ± 0.13; R_0W_1, +1.00 ± 0.25) (Fig. 3.4). Wetting produced a rise in rectal temperature in R_1W_1 (+0.20 ± 0.13°C) (Table 3.5), the mean T_{Re} reaching a maximum after 20 minutes of wetting.

Significant cooling of rectal temperature began after t_{90} (Fig. 3.4). Over the next 30 minutes, following completion of the behaviour tests, rectal temperature decreased by 0.61 ± 0.10°C, equivalent to a cooling rate of approximately 1.2°C/hr. In the 60 min period between t_{120} and t_{180}, the rate of cooling decreased, evidenced by a mean drop of 0.63 ± 0.15°C; rectal temperature reached a mean level of 37.10 ± 0.29°C at t_{180}, representing a significant mean decrease of 1.04 ± 0.25°C below the pre-rain value ($p < 0.0007$). There was no change in R_0W_1 rectal temperature over the same 2-hr period (−0.06 ± 0.18°C). During the 30-min period within which the second battery of performance tests were completed ($t_{180-210}$), R_1W_1 mean rectal temperature decreased by 0.3°C (Fig. 3.4).

In contrast to significant rectal temperature cooling observed in the hour preceding t_{180}, there was no effective change in rectal temperature over the 60-min $t_{210-270}$ period (−0.07 ± 0.12°C) (Fig. 3.4), similar to R_0W_1 (−0.02 ± 0.12°C) (Table 3.5). Prior to the completion of the third set of performance tests (t_{270}, t_{280}), mean R_1W_1 rectal temperature was 36.72 ± 0.41°C, a mean difference of −0.39 ± 0.36°C from the initial resting rectal temperature, but nearly 1.3°C below R_0W_1 mean

Fig. 3.4. Comparison of change in rectal temperature (°C) between wet (R_1W_1) and dry (R_0W_1) walks for subjects completing protocol (mean ± SD, n = 5).

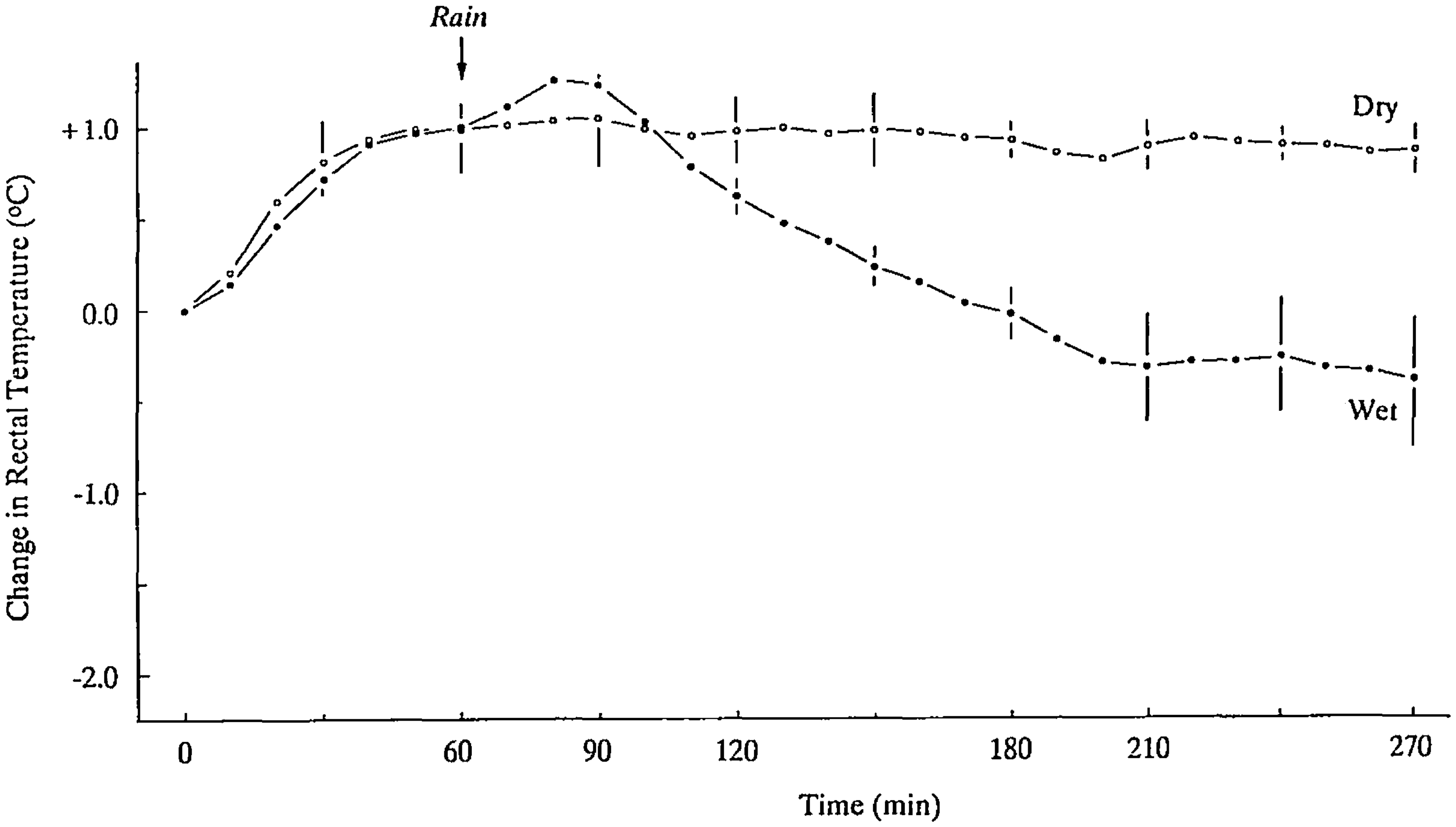

Rain
Dry
Wet
+1.0
0.0
-1.0
-2.0
Change in Rectal Temperature (°C)
0
60
90
120
180
210
270
Time (min)

Table 3.5. Comparison of changes in rectal and mean skin temperature during wet (R_1W_1) and dry (R_0W_1) walks (n = 5, mean ± SD)

Variable	R_1W_1	R_0W_1
Rectal Temperature (°C)		
T_{Re0}	37.11 ± 0.29	37.09 ± 0.14
T_{Re0-60}	+1.02 ± 0.13	+1.00 ± 0.25
$T_{Re60-90}$	+0.20 ± 0.13	+0.04 ± 0.09
$T_{Re90-120}$	-0.61 ± 0.10	-0.06 ± 0.11
$T_{Re120-180}$	-0.63 ± 0.15	-0.05 ± 0.13
$T_{Re210-270}$	-0.07 ± 0.12	-0.02 ± 0.12
T_{Re270}	36.72 ± 0.41	37.99 ± 0.23
Mean Skin Temperature (°C)		
T_{MS0}	31.5 ± 1.7	30.8 ± 1.5
T_{MS60}	31.5 ± 1.6	29.4 ± 1.3
$T_{MS60-90}$	-6.3 ± 1.8	-1.0 ± 0.3
$T_{MS90-120}$	-1.2 ± 0.6	-0.1 ± 0.3
$T_{MS120-180}$	-0.4 ± 0.7	-0.1 ± 0.3
$T_{MS210-270}$	+0.3 ± 0.4	-0.2 ± 0.6
T_{MS270}	23.2 ± 1.6	28.2 ± 1.4

rectal temperature at t_{270}. During the 30-min period in which performance tests were completed, rectal temperature decreased about 0.3°C in R_1W_1.

None of these five subjects developed clinically-defined hypothermia during the exercise phase; the lowest recorded rectal temperature in R_1W_1 was 36.0°C (t_{300}) (data for the final 30 minutes of walking are shown on the graph illustrating changes in rectal temperature during sitting: Fig. 3.7).

Mean Skin Temperature (T_{MS}). There was no significant difference in mean skin temperatures between R_1W_1 and R_0W_1 at the beginning of the walk, or after 60 min of walking prior to the applied stress (Table 3.5). In the first 30 min of wetting, R_1W_1 mean skin temperature dropped steeply (Fig. 3.5), decreasing by 6.3 ± 1.8°C. The rate of cooling decreased in the next 30-min period (−1.2 ± 0.6°C), T_{MS} reaching a level of 24.0 ± 1.4°C by t_{120}.

Over the following 2.5 hours, mean skin temperature decreased less than 1°C, similar to responses observed in R_0W_1 (Table 3.5). By t_{180}, mean skin temperature had dropped an average of 7.9 ± 2.8°C, significantly ($p < 0.003$) below the pre-rain temperature. At t_{270}, prior to the final exercise-phase performance test series, R_1W_1 T_{MS} was 23.2 ± 1.6°C, about 5°C less than the R_0W_1 mean skin temperature (Table 3.5).

Metabolic Rate (MR). No significant difference in MR was apparent between subjects in the R_1W_1 and R_0W_1 conditions during equilibration or the the initial 60-min walking period (Table 3.6; Fig. 3.6). R_1W_1, pre-rain MR was 6.4 ± 0.4 $W \cdot kg^{-1}$, compared to a R_0W_1 mean value of 6.2 ± 0.8 $W \cdot kg^{-1}$. This level of metabolic rate was equivalent to slightly less than 40% of V_{O_2max}. R_1W_1 metabolic rate steadily increased after wetting was initiated, reaching levels above 9 $W \cdot kg^{-1}$ within 2 hours (t_{180}); this represented a significant increase ($p < 0.0007$) of 49%

Fig. 3.5. Comparison of change in mean skin temperature (°C) between wet (R_1W_1) and dry (R_0W_1) walks for subjects completing protocol (mean ± SD, n = 5).

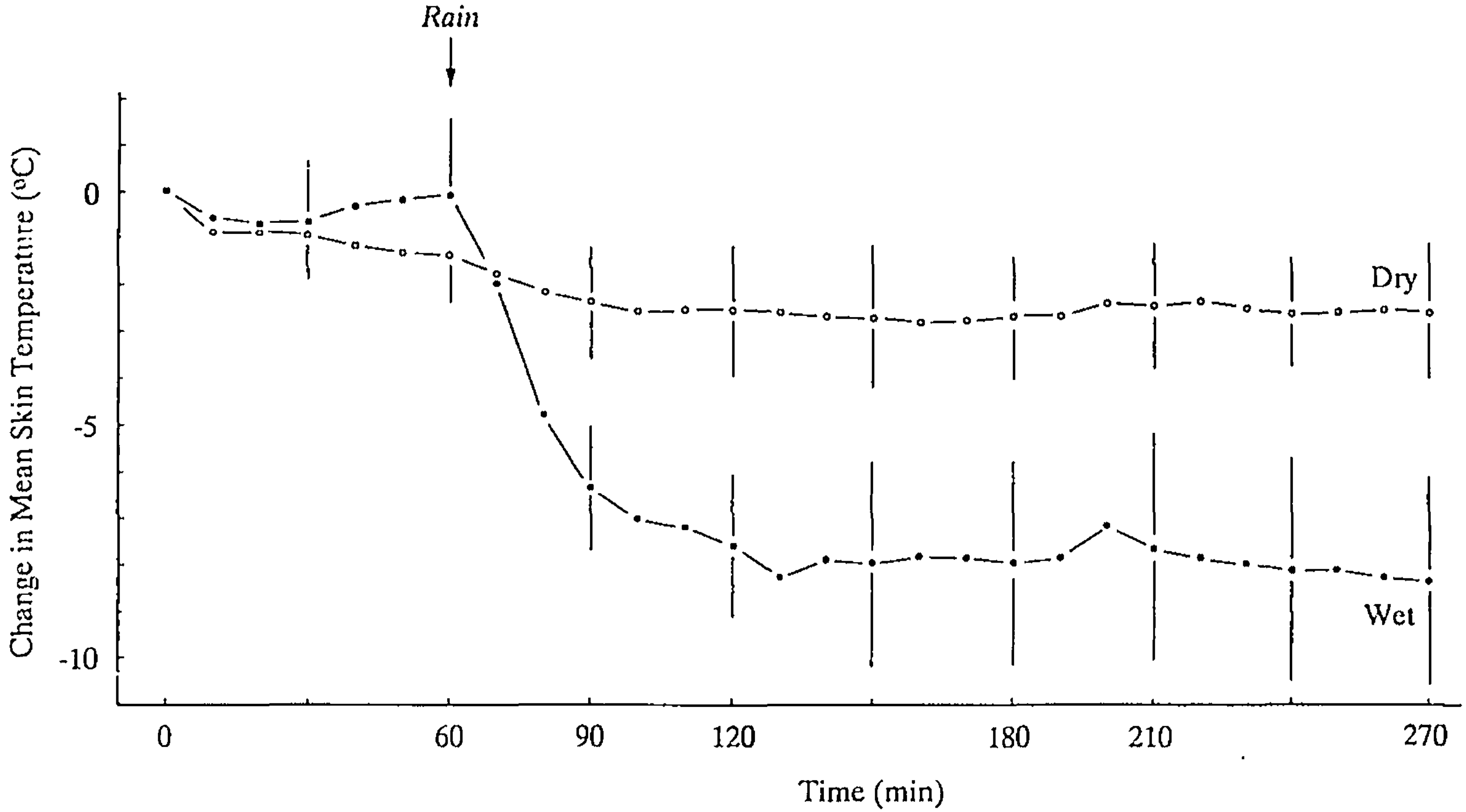
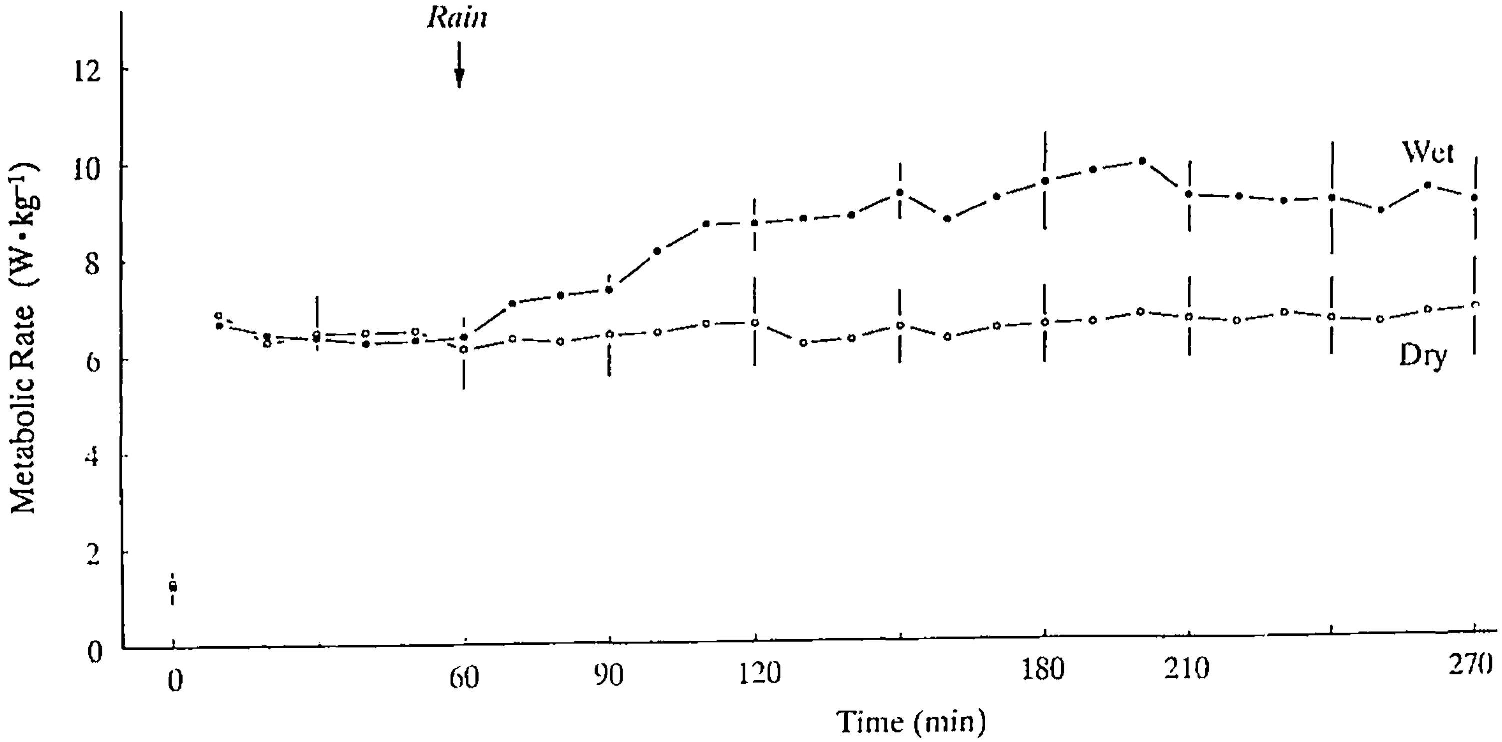

Rain
0
-5
-10
Change in Mean Skin Temperature (°C)
0
60
90
120
180
210
270
Time (min)
Dry
Wet

Table 3.6. Comparison of metabolic rate (MR) during wet (R_1W_1) and dry (R_0W_1) walks (n = 5, mean ± SD)

Variable	R_1W_1	R_0W_1
Metabolic Rate ($W \cdot kg^{-1}$)		
MR_0	1.3 ± 0.4	1.4 ± 0.1
MR_{60}	6.4 ± 0.4	6.2 ± 0.8
MR_{90}	7.3 ± 0.3	6.4 ± 0.9
MR_{120}	8.7 ± 0.5	6.6 ± 0.8
MR_{180}	9.5 ± 1.0	6.6 ± 0.8
MR_{210}	9.2 ± 0.7	6.7 ± 0.8
MR_{270}	9.1 ± 0.9	6.9 ± 1.1
MR_{300}	8.7 ± 0.8	6.5 ± 0.6
Relative Metabolic Rate (% increase above MR_{60})		
MR_{90}	14.4 ± 2.9	0.2 ± 6.0
MR_{120}	38.2 ± 4.4	3.4 ± 8.2
MR_{180}	49.9 ± 12.8	2.9 ± 7.8
MR_{210}	44.4 ± 9.6	4.8 ± 8.0
MR_{270}	42.6 ± 9.7	7.6 ± 11.8
Relative Oxygen Consumption (%$VO_{2}max$)		
t_{60}	39. ± 5.	37. ± 7.
t_{90}	44. ± 4.	39. ± 8.
t_{120}	53. ± 5.	40. ± 8.
t_{180}	58. ± 9.	40. ± 8.
t_{210}	55. ± 8.	41. ± 8.
t_{270}	55. ± 8.	42. ± 10.

Fig. 3.6. Comparison of metabolic rate ($W \cdot kg^{-1}$) between wet (R_1W_1) and dry (R_0W_1) walks for subjects completing protocol (mean ± SD, n = 5).


Rain
Wet
Dry
Metabolic Rate (W•kg-1)
0
2
4
6
8
10
12
0
60
90
120
180
210
270
Time (min)

above the pre-rain MR, and was equivalent to approximately 55% oı $\dot{V}O_{2max}$ (Table 3.5). There was no meaningful change in R_0W_1 over the same period of time.

During the 1-hour period $t_{210-270}$, MR remained at steady levels just above 9 W•kg⁻¹. R_0W_1 metabolic rate stabilized around pre-rain values; at t_{270}, mean MR was 6.9 ± 1.1 W•kg⁻¹ (relative O_2 consumption 42 ± 10% $\dot{V}O_{2max}$), significantly below the mean R_1W_1 metabolic rate (Fig. 3.6).

Ventilation Rate (V_E). Prior to the onset of rain and wind (t_{260}), mean estimated V_Es were insignificantly different (R_1W_1, 28.9 ± 1.4 l•min⁻¹; R_0W_1, 28.1 ± 2.3 l•min⁻¹) (Table 3.7). Mean R_1W_1 V_E increased steadily in the first hour of wetting to 38.0 ± 2.3 l•min⁻¹. In the next hour, V_E increased slightly, stabilizing around 40 l•min⁻¹ (Table 3.7), a significant ($p < 0.004$) 50% increase above the pre-rain value. R_0W_1 ventilation rates remained stable throughout this period; at t_{180}, average V_E was 27.4 ± 0.7 l•min⁻¹.

During the hour-long period after the second battery of performance tests ($t_{210-270}$), V_E decreased slightly; at t_{270}, average V_E was 37.7 ± 3.7 l•min⁻¹. R_0W_1 V_E remained in the neighbourhood of pre-rain values, t_{270} V_E at 28.0 ± 1.4 l•min⁻¹ (Table 3.7).

Heart Rate (HR). Mean heart rates were insignificantly different at t_{60} (R_1W_1, 108.8 ± 7.4 bpm; R_0W_1, 108.4 ± 11.4 bpm) (Table 3.7). After 2 hours of wet-wind exposure (t_{180}), mean heart rate had steadily increased to 122.6 ± 6.7 bpm in R_1W_1, compared to a mean rate of 114.0 ± 10.6 bpm in R_0W_1 (Table 3.7). The R_1W_1 mean increase of 13.8 ± 4.1 bpm between t_{60} and t_{180} was significant ($p < 0.0016$). There was no significant change in heart rate after t_{180} in R_1W_1 (Table 3.7). However, R_0W_1 heart rate continued to increase steadily, and at t_{270}, heart rates were similar between wet and dry conditions (Table 3.7).

Table 3.7. Comparison of V_E and heart rate responses during walking phase of wet (R_1W_1) and dry (R_0W_1) walks (n = 5, mean ± SD)

Variable	R_1W_1	R_0W_1
Ventilation Rate (l•min^{-1})		
V_{E0}	9.6 ± 1.5	9.0 ± 1.0
V_{E60}	28.9 ± 1.4	28.1 ± 2.3
V_{E90}	32.6 ± 3.5	27.1 ± 0.6
V_{E120}	36.0 ± 4.3	29.4 ± 4.0
V_{E180}	40.0 ± 3.1	27.4 ± 0.7
V_{E210}	41.1 ± 3.0	28.5 ± 1.9
V_{E270}	37.7 ± 3.7	28.0 ± 1.4
Heart Rate (bpm)		
HR_0	66.2 ± 6.7	66.0 ± 9.2
HR_{60}	108.8 ± 7.4	108.4 ± 11.4
HR_{90}	112.8 ± 5.5	109.2 ± 11.7
HR_{120}	114.0 ± 7.6	112.0 ± 12.5
HR_{180}	122.6 ± 6.7	114.0 ± 10.6
HR_{210}	124.0 ± 8.3	117.0 ± 11.1
HR_{270}	124.2 ± 10.0	120.6 ± 9.7

3.3.4. Physiological Responses to 4 Hours of Wet-Cold: Sitting Phase.

Data for the final 30 minutes of walking are shown on graphs of physiological changes occurring during the sitting phase (Fig. 3.7 - 3.9).

Rectal Temperature. During the final non-exercise phase ($t_{310-400}$), rectal temperature continued to cool after exercise, achieving stable levels in R_1W_1 20-30 minutes after subjects began the rest period (Fig. 3.7). Cooling was greatest in R_0W_1 during this phase, and the difference between groups was not significant in the final 30 min of sitting (Fig. 3.7). Subject S_{W2} became hypothermic during the sitting phase; details of this case are described below.

Mean Skin Temperature. After the exercise period, mean skin temperature rose by approximately 2°C in R_1W_1, and was maintained at a steady level about 25°C; R_0W_1 mean skin temperature increased by about 1°C after exercise, but showed a slight decline over the 90-min sitting period (Fig. 3.8).

Metabolic Rate. At the beginning of the sitting phase, R_1W_1 mean MR (4.1 ± 1.3 $W \cdot kg^{-1}$) was almost double that of R_0W_1 (2.2 ± 1.0 $W \cdot kg^{-1}$); however, these differences were assumed to be insignificant based on overlap of standard deviations (Fig. 3.9), but hints at meaningful physiological difference. No subject in the R_0W_1 condition showed an MR as high as an MR value observed in R_1W_1 during the initial 20 minutes of the sitting phase. The tendency was for R_1W_1 MR to decrease over time, as R_0W_1 MR increased.

Ventilation Rate. Wet subjects maintained consistent V_Es in the 13-14 $l \cdot min^{-1}$ range, higher than those observed in dry conditions (Table 3.8). However, large variation in the R_1W_1 condition eliminated significant differences. For example, after 30 minutes of sitting, R_1W_1 V_E was 14.8 ± 5.4 $l \cdot min^{-1}$, compared to a

Fig. 3.7. Comparison of change in rectal temperature (°C) between wet (R_1W_1) and dry (R_0W_1) walks, during final 30 minutes of walking ($t_{270-300}$) and sitting phase (t_{S0-S90}) (mean ± SD, n = 5).

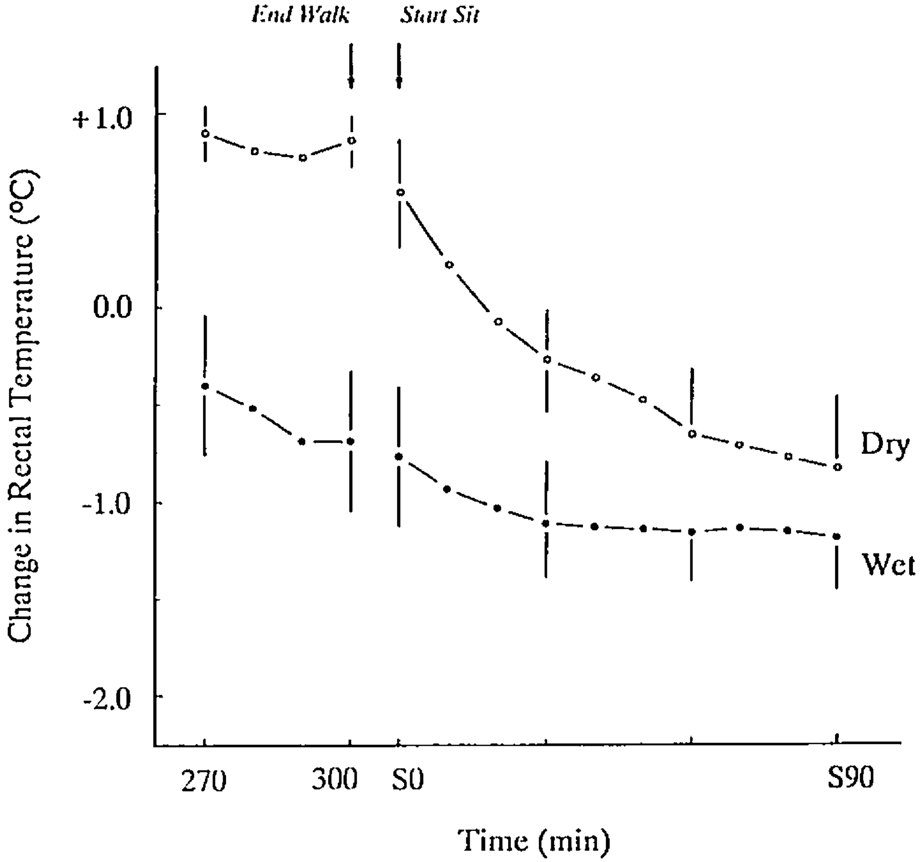

End Walk
Start Sit
+1.0
0.0
-1.0
-2.0
Change in Rectal Temperature (°C)
270
300
S0
S90
Time (min)
Dry
Wet

Fig. 3.8. Comparison of change in mean skin temperature (°C) between wet (R_1W_1) and dry (R_0W_1) walks, during final 30 minutes of walking ($t_{270-300}$) and sitting phase (t_{S0-S90}) (mean ± SD, n = 5).

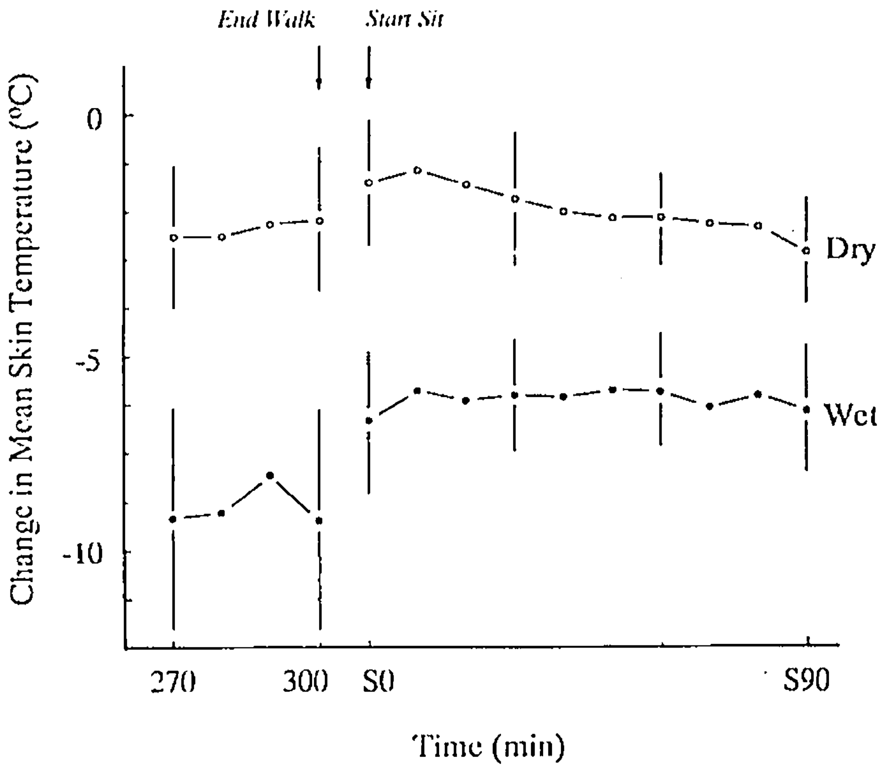

End Walk
Start Sit
Change in Mean Skin Temperature (°C)
0
-5
-10
Dry
Wet
270
300
S0
S90
Time (min)

Fig. 3.9. Comparison of metabolic rate ($W \cdot kg^{-1}$) between wet (R_1W_1) and dry (R_0W_1) walks, in final 30 minutes of walking ($t_{270-300}$) and sitting phase (t_{S0-S90}) (mean ± SD, n = 5).

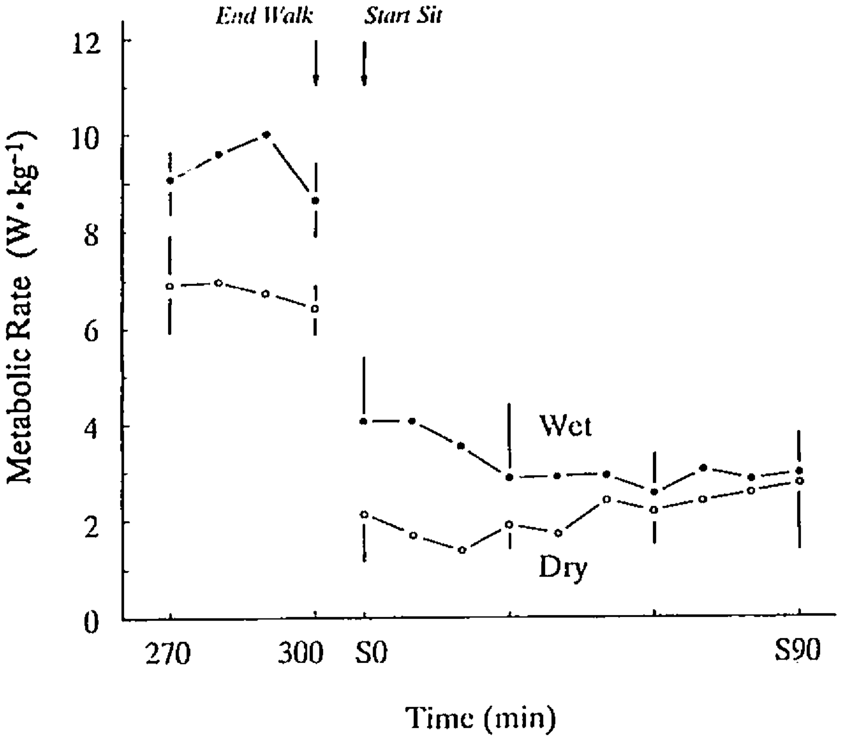

End Walk
Start Sit
Metabolic Rate (W•kg-1)
12
10
8
6
4
2
0
Wet
Dry
270
300
S0
S90
Time (min)

Table 3.8. Comparison of V_E and heart rate responses during sitting phase of wet (R_1W_1) and dry (R_0W_1) walks (n = 5, mean ± SD)[1]

Variable	R_1W_1	R_0W_1
Ventilation Rate ($l \cdot min^{-1}$)		
V_{E0}	9.6 ± 1.5	9.0 ± 1.0
$V_{E/S30}$	14.8 ± 5.4	8.5 ± 1.5
$V_{E/S60}$	14.2 ± 2.3	10.8 ± 3.7
$V_{E/S90}$	11.8 ± 2.8	11.5 ± 3.8
Heart Rate (bpm)		
HR_0	66.2 ± 6.7	66.0 ± 9.2
HR_{S30}	84.8 ± 13.3	78.5 ± 8.4
HR_{S60}	86.0 ± 11.0	78.3 ± 10.2
HR_{S90}	87.6 ± 10.7	80.3 ± 14.7

[1] R_0W_1 n = 4 during sitting phase

dry value of 8.5 ± 1.0 l•min^{-1}. The tendency was for R_1W_1 V_E to remain constant, and in R_0W_1, to increase (Table 3.8).

Heart Rate. Heart rates appeared slightly (but insignificantly) higher in the R_1W_1 condition (Table 3.8).

3.3.5. Hypothermia

Three subjects exhibited rectal temperatures near the level of clinical hypothermia (35°C), two during exercise and one during the final, sitting phase of the experiment.

S_{W7}. At t_{240}, the subject reported that he was "feeling very tired." There were noticeable drops in heart-rate samples recorded over the following 10-min period, average counts dropping from above 140 bpm to approximately 130 bpm. VO_2 also showed a downward shift, decreasing from values above 2 l•min^{-1} to about 1.7 l•min^{-1}, at the 240- and 250-min data-recording stops, despite the fact that the subject maintained the established walking pace (Fig. 3.10). At this time, rectal temperature, which had been decreasing slowly since the t_{210} recording, began to decrease at an accelerated rate (Fig. 3.11). By t_{260}, rectal temperature had fallen to 35.8°C, and the subject was finding it very difficult to maintain the pace. Just prior to the t_{270} readings, S_{W7} staggered slightly as he came around the east turnabout towards the observation area. He was immediately stopped, and the rectal temperature recorded (35.3°C). The subject stated that he felt dizzy and nauseous; he looked pale, and his general behaviour was consistent with his reported feelings. The subject was *not* shivering.

He was immediately taken to the tent, and, after his wet clothing was removed, was immersed in the warm-water bath. He entered the bath less than 10 minutes after he had stopped walking. His rectal temperature at this time was

Fig. 3.10. Comparison of metabolic rate ($W \cdot kg^{-1}$) for S_{W7} in wet (R_1W_1) and dry (R_0W_1) walks. Note decline in metabolic in wet condition after t_{210}.

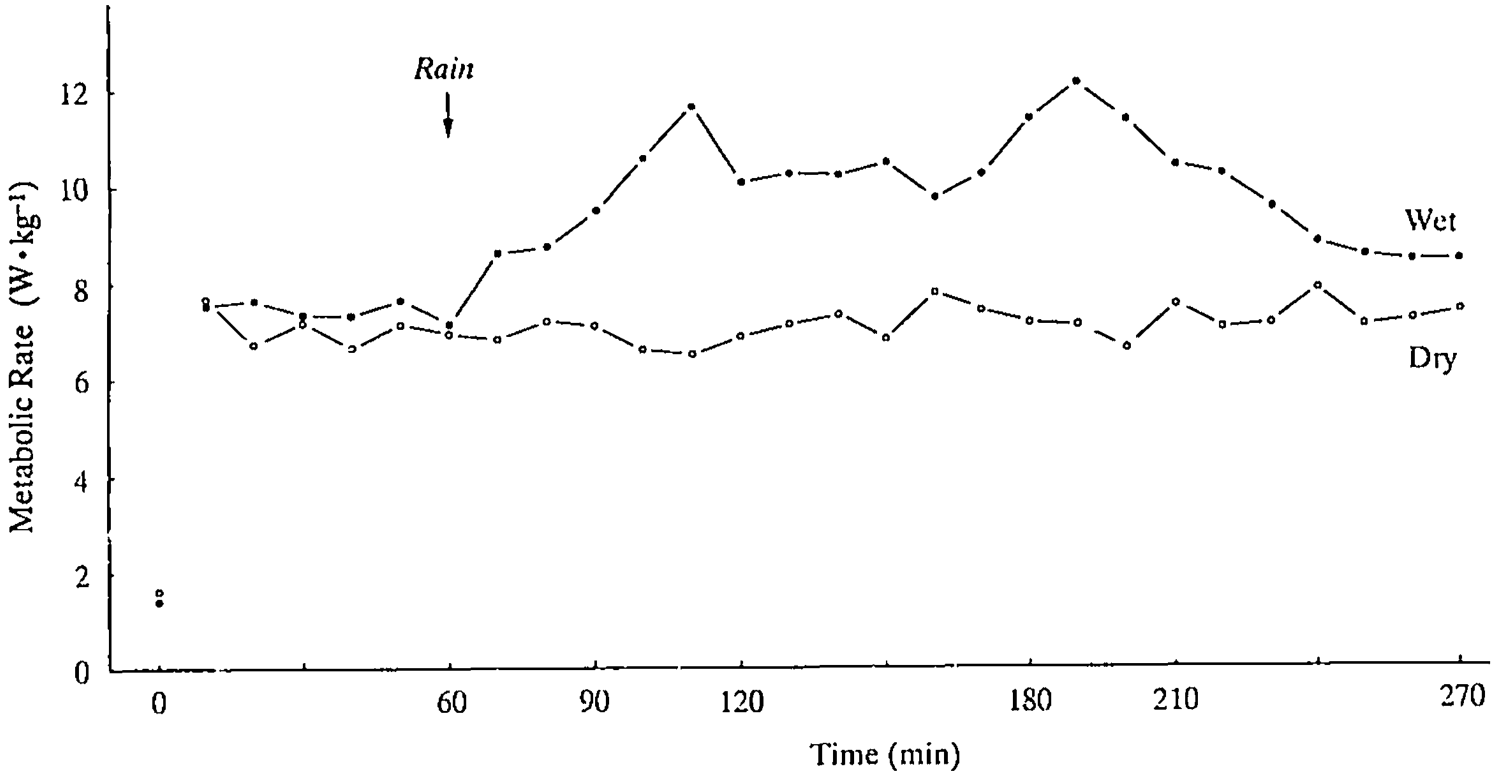
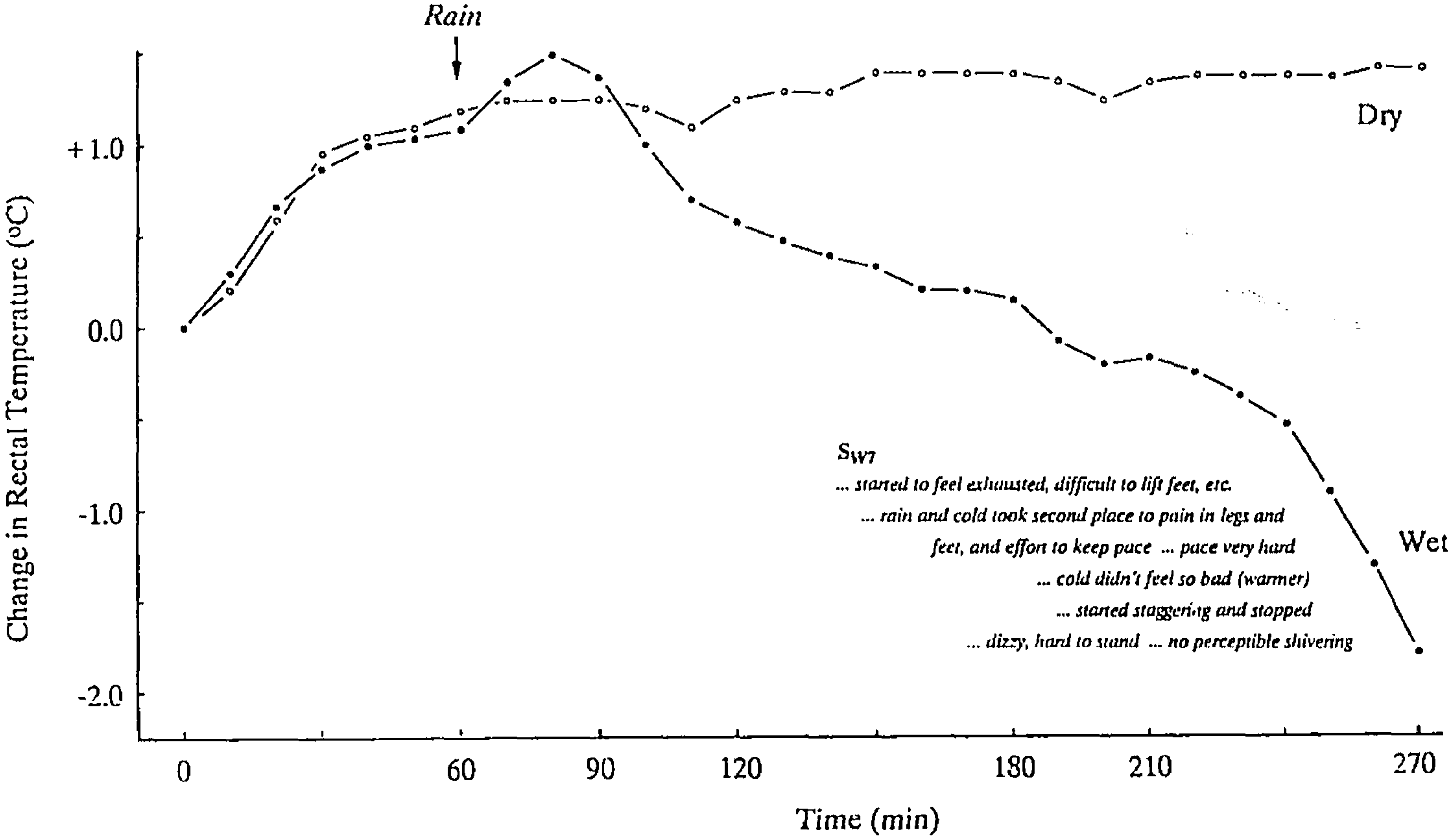

Rain
Wet
Dry
Metabolic Rate (W•kg⁻¹)
0
2
4
6
8
10
12
0
60
90
120
180
210
270
Time (min)

Fig. 3.11. Comparison of change in rectal temperature (°C) for S_{W7} in wet (R_1W_1) and dry (R_0W_1) walks. Note decline in rectal temperature in wet condition after t_{210}.



S$_{W7}$

... started to feel exhausted, difficult to lift feet, etc.

... rain and cold took second place to pain in legs and feet, and effort to keep pace ... pace very hard

... cold didn't feel so bad (warmer)

... started staggering and stopped

... dizzy, hard to stand ... no perceptible shivering

34.9°C; it dropped to a minimum level of 34.3°C within 5–10 minutes. Normally a relaxed and talkative individual, S_{W7} sat quietly in the bath, staring directly ahead; it appeared to take about 30 minutes for the subject to return to a normal communicative state.

The symptoms exhibited by this subject were not seen in any other *Wet Walk* subject, including hypothermic individuals. It is difficult to describe this experience in objective terms; there was, in my view, a unique quality about this event that symptoms do not appropriately define.

The subject, on his own volition, wrote down a summary of his experiences during the final 30 minutes of walking (some of these have been added to Fig. 3.11). Just prior to the time that significant decreases in $V\text{O}_2$ occurred, the subject started to feel exhausted. He specifically stated that "the rain and cold took second place to the pain in my legs and feet, and to my effort to keep pace." Towards the end of his walk, he felt the "cold didn't feel so bad (warmer?)", and at the end of the walk, again felt "almost warm." The subject could not perceive any shivering. He also wrote that he "couldn't think clearly – no decisions on simple questions – very muddled", but that his "mind cleared when warmed."

A comparison of rectal temperature cooling after t_{210} of S_{W7} with the S_{W1-5} group is shown in Fig. 3.12. The rectal temperature of S_{W7} at t_{210} was 36.9°C, compared to the S_{W1-5} mean of 36.8 ± 0.4°C.

S_{W18}. Within 20 minutes of the initiation of the rain and wind, S_{W18} began to slow his pace and exhibit the *Wet Walk* shuffle. There was only a small increase in rectal temperature after t_{60} (+0.05°C) and after t_{80}, rectal temperature began to decrease (Fig. 3.13). By t_{90}, his pace was consistently slow, but concomitant with visible shivering, metabolic rate was elevated above the pre-rain level (+50%).

Fig. 3.12. Comparison of change in rectal temperature (°C) after t_{210} between S_{W7} and S_{W1-5} (mean ± SD, n = 5) in wet (R_1W_1) walks.

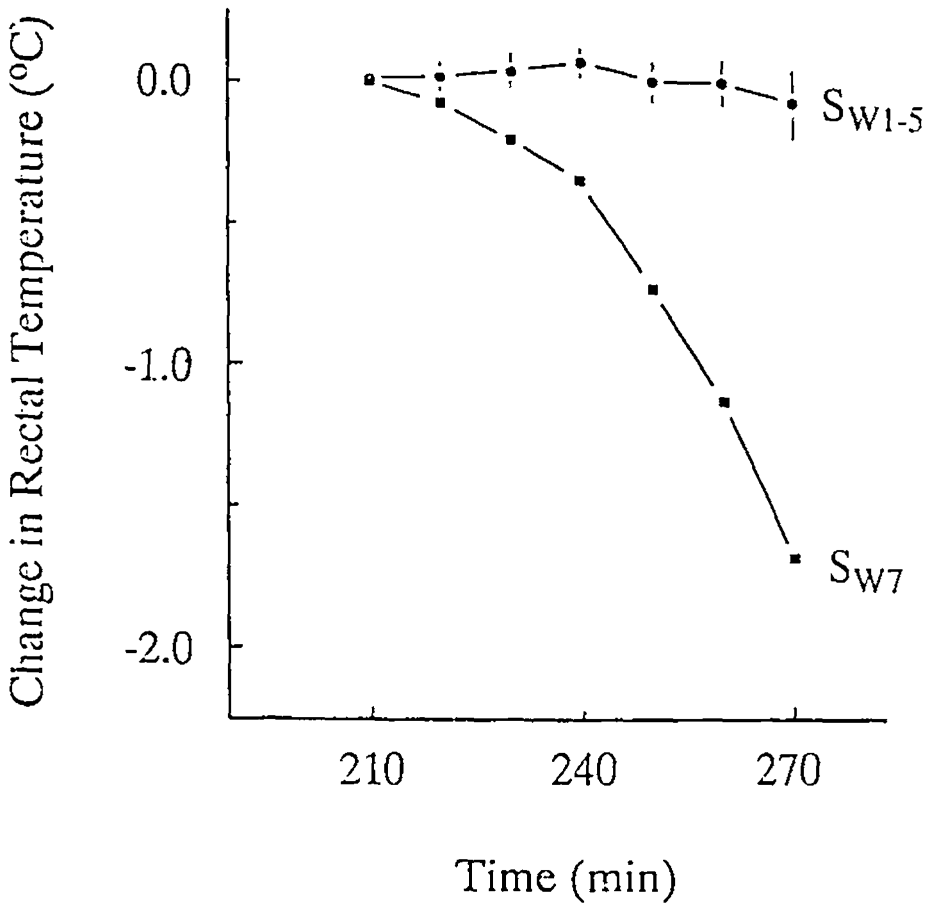
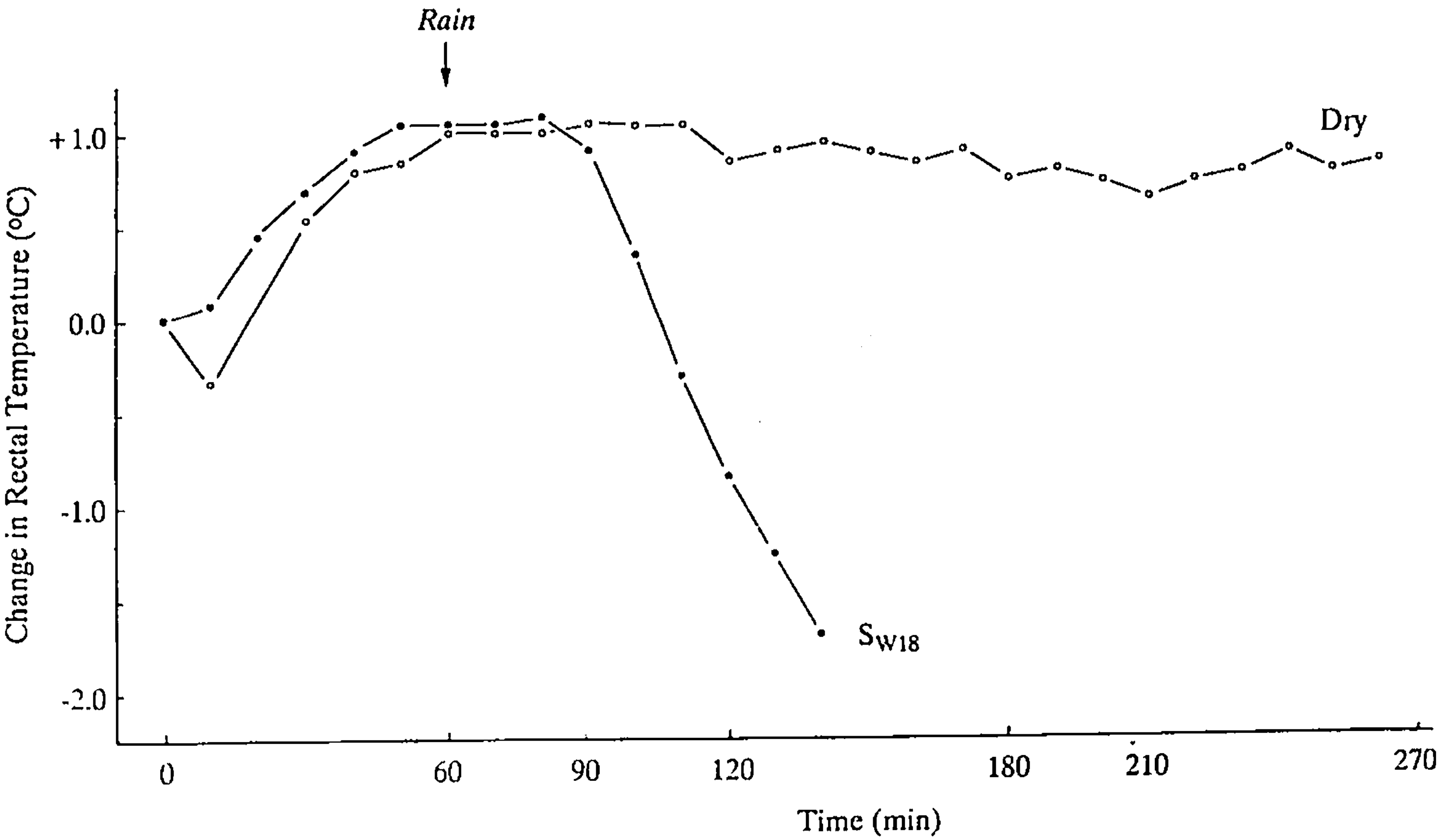

Change in Rectal Temperature (^oC)
0.0
-1.0
-2.0
210
240
270
Time (min)
S_{W1-5}
S_{W7}

Fig. 3.13. Comparison of change in rectal temperature (°C) for S_{W18} in wet (R_1W_1) and dry (R_0W_1) walks.

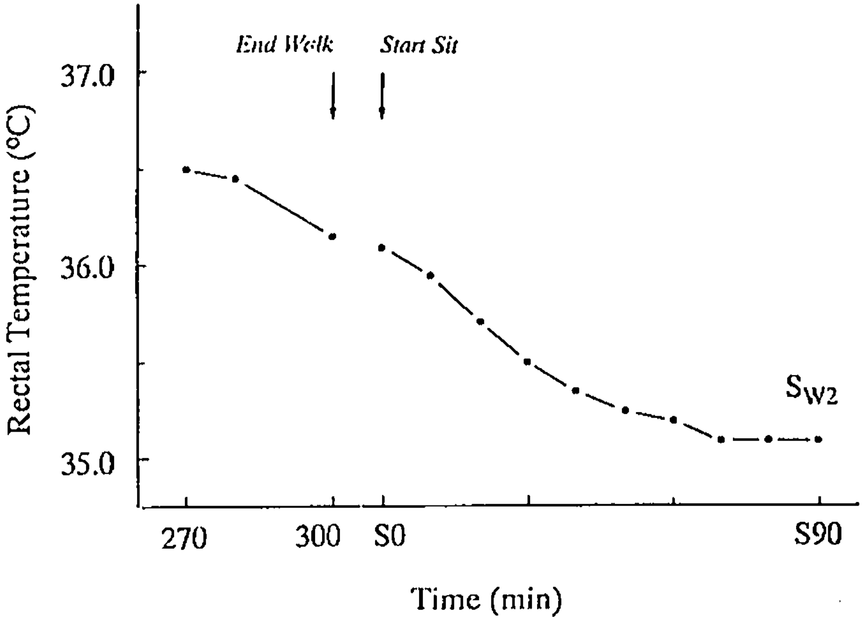

Rain
Dry
SW18
+1.0
0.0
-1.0
-2.0
Change in Rectal Temperature (°C)
0
60
90
120
180
210
270
Time (min)

Rectal temperature fell steeply over the period of the performance tests. After t_{100}, his pace had slowed considerably, as he "tottered" stiffly along the track. Walking speed was estimated to be less than 1 km•hr^{-1}. There was no indication of fatigue. (This subject had previously completed a dry walk (Fig. 3.13); although fatigued after 5 hours of walking, he had been able to maintain the pace over this length of time.) At this reduced pace, metabolic rate fell from a peak of 9.6 W•kg^{-1} at t_{90}, to an average about 7.5 W•kg^{-1} over the final 30 minutes of exposure. During this period, T_{Rc} decreased by 1.4°C, and the experiment was stopped when the rectal temperature reached 35.15°C. There were no indications of exhaustion, or a significant reduction in shivering.

The subject was then taken to the tent, and immersed in the warm water bath. Rectal temperature was 34.8°C on entry, dropping to a minimum of 34.65°C after 10 minutes. Recovery was rapid, and the subject stated shortly after his entry into the tub: "That wasn't as bad as I thought it would be – when can I do it again?"

S_{W2}. This subject was feeling very tired at the completion of the walk ("more tired than cold"); after only four hours of walking, he had described himself as feeling "really burnt out." Subject S_{W2} showed a decrease in rectal temperature of 1°C during the sitting period, dropping to a rectal temperature of 35.1°C after 70 min (Fig. 3.14). Some shivering was apparent early in the sitting period, but was absent by the time rectal temperature approached 35°C (no shivering interference was apparent on the ECG oscilloscope). Metabolic rate was maintained at a level near 2.5 W•kg^{-1}, slightly lower than the MR of some other subjects in the S_{W1-5} group, and did not change over the course of the 90-min sitting period.

Fig. 3.14. Rectal temperature (°C) of S_{W2} during sitting phase at completion of walking in rain and wind (R_1W_1).


End Walk
Start Sit
37.0
36.0
35.0
Rectal Temperature (°C)
Sw2
270
300
S0
S90
Time (min)

3.4. Results: Motor Performance

3.4.1. Performance After 2 Hours of Wet-Cold

Grip Strength. There was a significant ($p < 0.001$) decrease in grip strength between the initial, pre-walk test and the contraction recorded after two hours of wet-cold exposure (Table 3.9). On average, the mean grip strength at t_{180} was 69 ± 14% of the t_0 contraction. At t_{90}, the mean contraction (42.7 ± 7.5 kg) was intermediate to the other tests, about 87 ± 11% of the initial value. Contractions exhibted wide variation. At t_{180}, relative contractions ranged from 42 to 91% of the initial value; 10 of 14 subjects had contractions less than 80% of the initial value.

Threading Test. The relative increase in time required to complete the threading test was significantly ($p < 0.002$) greater at t_{180}, in comparison to the initial, pre-walk test (Table 3.9). The average increase (113 ± 84%) was more than double the initial test time. There was considerable variation in the threading test, similar to grip strength. Most subjects (8 of 14) required more than double the initial time, and 11 of 14 subjects required more than 80% of the inital test time. One subject showed an increase of only 10% (this subject also had a decrement of only 10% in grip strength). Performance on the t_{90} threading test was intermediate to the t_0 and t_{180} tests (increase of 43 ± 43% above the t_0 test).

Relationship to Thermal Variables. A comparison of rectal and skin temperatures to grip strength and threading test performance (Table 3.10) shows that significant decreases in skin temperatures are associated with significant decrements in the two manual performance tests. However, although there was a significant decrease in rectal temperature from t_{60}, the rectal temperature was similar at t_0 and t_{180}.

Table 3.9. Comparison of changes in motor performance tests between t_0 and t_{180} (mean ± SD, n=14)

Test	t_0	t_{180}
Grip Strength (n = 14)		
Contraction (kg)	48.9 ± 6.4	33.9 ± 9.1
Difference (kg)		−15.0 ± 7.5[1]
% of t_0 grip strength		69.2 ± 14.3
Threading Test (n = 14)		
Time (sec)	52.2 ± 11.7	109.1 ± 43.5
Difference (sec)		+57.0 ± 41.7[2]
% Increase		113.6 ± 83.5

[1] $p < 0.0001$

[2] $p < 0.0002$

Table 3.10. Relationship between core and skin temperatures, and motor performance before and after 2 hours of wet-cold exposure (mean ± SD, n=14)

Test	t_0	t_{180}
T_{Re} (°C)	37.1 ± 0.3	37.0 ± 0.5
T_{MS} (°C)	30.6 ± 1.3	23.5 ± 1.5
T_H (°C)	23.2 ± 0.4	8.5 ± 8.9
Grip Strength (kg)	48.9 ± 6.4	33.9 ± 9.1
Threading Test (sec)	52.2 ± 11.7	109.1 ± 43.9

3.4.2. Motor Performance During 4 Hours of Wet-Cold

Performance measures were compared for subjects completing both wet and dry walks (n = 5). Subject S_{W2} did not complete a dry sitting period; data for this time are compared for subjects $S_{W1,3-5}$.

Grip Strength. Changes in grip strength over the first two hours parallel changes already discussed with respect to the larger group (Fig. 3.15). The t_{180} mean grip strength was 71 ± 20% of the initial test (t_0), a significant ($p < 0.0326$) decrease of −14.9 ± 10.4 kg. There was a considerable range of responses (42–91%). The weakest mean contraction occurred at t_{270} (Fig. 3.15), after 3.5 hours of wet-cold exposure; the relative grip strength at this time was 58 ± 14% of the initial value. Following the sitting period, there was some recovery of contraction strength (Fig. 3.15). Based on overlap of standard deviations, there were no significant differences between the test contractions, except between the t_{90} and t_{270} tests; all contractions were significantly below the initial grip strength. No grip strength decrements were observed in the dry condition. There were no significant differences between wet and dry contractions at t_{90} and after the sitting period. Lack of significance is associated with large variation.

Threading Test. After the t_{90} threading test, percentage increase in time to complete the threading test increased significantly with wetting (Fig. 3.16). The difference in time required to complete the test at t_{180} (33.8 ± 25.5 sec) was significant. As with grip strength, the poorest mean performance occurred at t_{270} (+114 ± 21%) At the end of the sitting phase, performance was significantly better than the t_{270}. The differences between wet and dry performances were not significantly different for any test; again, variation in responses was large.

Fig. 3.15. Comparison of change in grip strength (% initial contraction) between wet (R_1W_1) and dry (R_0W_1) walks (mean ± SD, n = 5).

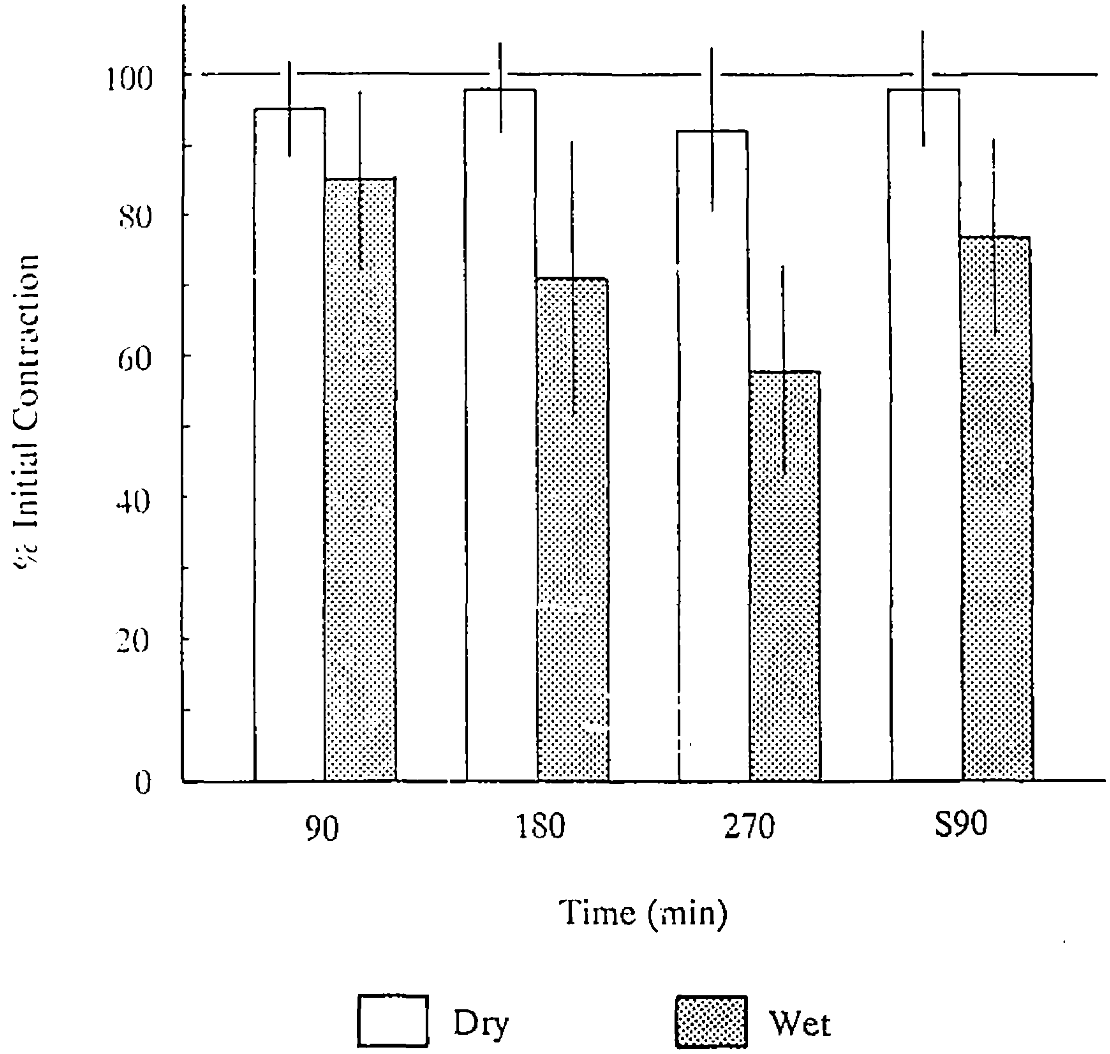
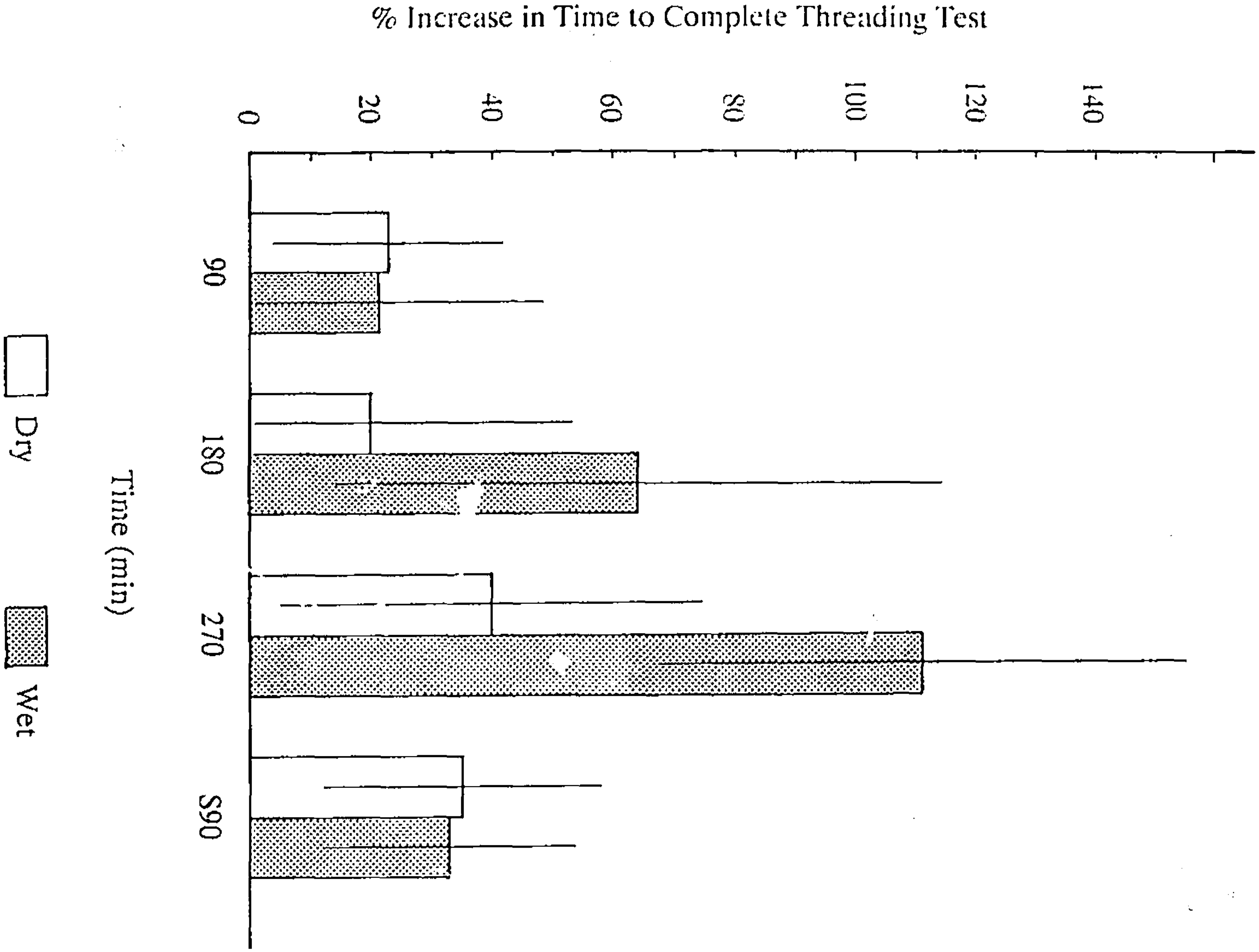

% Initial Contraction
100
80
60
40
20
0
90
180
270
S90
Time (min)
Dry
Wet

Fig. 3.16. Comparison of change in relative threading test performance (% increase above initial test time) between wet (R_1W_1) and dry (R_0W_1) walks (mean ± SD, *n* = 5).


% Increase in Time to Complete Threading Test
0
20
40
60
80
100
120
140
90
180
270
S90
Time (min)
Dry
Wet

Relationship to Physiological Variables. As previously discussed, performance decrements were associated with decreased skin temperatures; mean rectal temperature at t_{180} was similar to the initial, resting rectal temperature. In the 90-minute period after t_{180}, prior to the next performance test series (t_{270}, t_{280}), there were no meaningful changes in mean skin temperature (Fig. 3.5) or hand temperature, and only a slight drop (0.3°C) in rectal temperature (Fig. 3.4). During the sitting period, rectal temperature continued to fall (Fig. 3.7), and skin temperature increased (Fig. 3.8). Mean hand temperature at the end of the sitting phase was 15.2 ± 2.7°C in R_1W_1 and 19.7 ± 4.7°C in R_0W_1.

3.5. Results: Sensory Evaluation Scales

3.5.1. Sensation Ratings Over 2 Hours of Wet-Cold ($n = 15$)

Rating of Perceived Exertion (RPE). Prior to the onset of rain and wind, work was rated between "very light" and "fairly light" (10.0 ± 1.8). Rating increased over time with wetting (Table 3.11), and at t_{180}, the mean rating was 14.1 ± 1.8, between "somewhat hard and "hard", individual ratings ranging from 11 ("fairly light") to 17 ("very hard"). The increase in rating (3.9 ± 0.6) between t_{60} and t_{180} was significant ($p < 0.001$).

Rating of Thermal Sensation (RTS). At t_{60}, subjects reported, on average, that they felt "warm" (1.9 ± 1.0). After 30 minutes of rain and wind, the mean rating had decreased to below "cool" (-2.5 ± 1.5), and reached "cold" at t_{180}. The mean rating decrease between t_{60} and t_{180} (-6.0 ± 0.6) was significant ($p < 0.0001$). Individual ratings ranged from a high of 0 ($n = 1$) to a low of -7 (towards "unbearably cold").

Rating of Thermal Comfort (RTC). At t_{60}, subjects were "comfortable" (1.8 ± 0.9). After 30 minutes of wet and wind, the mean rating had moved towards

Table 3.11. Comparison of changes in sensory evaluation ratings for 2-hour exposures (n = 15) and 4-hour exposures (n = 5) (mean ± SD)

Test	n = 15	n = 5
Rating of Perceived Exertion (RPE)		
t_{20}	9.0 ± 2.2	9.0 ± 2.1
t_{60}	10.0 ± 1.8	9.8 ± 2.3
t_{90}	11.5 ± 1.6	10.8 ± 2.4
t_{120}	12.7 ± 1.9	12.0 ± 2.5
t_{180}	14.1 ± 1.8	13.2 ± 1.5
t_{240}		13.6 ± 1.7
t_{300}		14.8 ± 2.1[1]
Rating of Thermal Sensation (RTS)		
t_0	1.3 ± 1.2	1.0 ± 1.4
t_{60}	1.9 ± 1.0	1.8 ± 1.3
t_{90}	−2.5 ± 1.5	−2.6 ± 0.6
t_{120}	−3.6 ± 1.8	−3.2 ± 1.1
t_{180}	−4.1 ± 1.9	−3.4 ± 1.7
t_{240}		−3.2 ± 1.9
t_{300}		−4.0 ± 1.6[1]
Rating of Thermal Comfort (RTC)		
t_0	1.5 ± 1.2	1.2 ± 0.8
t_{60}	1.8 ± 0.9	1.4 ± 0.9
t_{90}	−0.9 ± 1.0	−1.2 ± 0.8
t_{120}	−1.6 ± 1.0	−2.0 ± 0.7
t_{180}	−1.9 ± 0.9	−2.0 ± 0.7
t_{240}		−2.0 ± 1.4
t_{300}		−2.5 ± 1.0[1]

[1] n = 4

"uncomfortable" (−0.9 ± 1.0), and reached "uncomfortable" at t_{180} (1.9 ± 0.9). The mean rating decrease between t_{60} and t_{180} (−3.6 ± 0.3) was significant ($p < 0.0001$). Individual ratings ranged from a 0 to −3; there were no "very uncomfortable" ratings.

3.5.2. Sensation Ratings Over 4 Hours of Wet-Cold (n = 5)

Only data for wet walks is presented; S_{W2} is absent in the sitting phase, as previously mentioned, and S_{W4} ratings were made on a protoypte scale in the dry condition.

RPE. The average RPE rating at t_{60} was "very light" and "fairly light" (9.8 ± 2.3). The rating increased over time with rain and wind exposure (Table 3.11), and at t_{180}, the mean rating was 13.2 ± 1.7, equivalent to "somewhat hard", subject ratings ranging from 11 ("fairly light") to 15 ("hard"). The increase in rating (3.4 ± 1.5) between t_{60} and t_{180} was significant ($p < 0.0074$). Over the next 2.5 hours of rain and wind, RPE increased slightly, to 14.8 ± 2.1 ("hard"); this difference was interpreted as insignificant. Individual values ranged from 12 to 17.

RTS. At t_{60}, subjects reported feeling "warm" (1.8 ± 1.3). After 30 minutes of rain and wind, the mean rating had decreased to below "cool" (−2.6 ± 1.6), and approached "cold" at t_{180} (Table 3.11). The mean rating decrease between t_{60} and t_{180} (−5.2 ± 1.2) was significant ($p < 0.0001$). Ratings ranged from a high of −2 to a low of −6. Over the 2-hour, $t_{120\text{-}240}$ period, there was no shift in RTS (Table 3.11). There was a small but insignficant drop at t_{300}, the final mean rating of −4.0 ± 1.6 equivalent to "cold"; the range of values was similar to that observed at t_{180}.

RTC. At t_{60}, subjects were moderately "comfortable" (1.4 ± 0.9). After 30 minutes of rain and wind, the mean rating had moved towards "uncomfortable" (−1.2 ± 0.8), and reached "uncomfortable" at t_{180} (−2.0 ± 0.7). The mean rating decrease between t_{60} and t_{180} (−3.4 ± 1.3) was significant ($p < 0.0048$). Individual ratings ranged from a −1 to −3. Similar to RTS ratings, there was no significant shift in rating between t_{120} and t_{240}, with a small drop at t_{300}. The final rating was −2.5 ± 1.0, on the cool side of "uncomfortable".

3.6. Results: Rectal Temperature Cooling and Cold Tolerance

The relationships between rectal temperature, fitness and anthropometeric characteristics were analyzyed over the 2-hour period between the beginning of rain and wind (t_{60}) and t_{180}. As shown in Fig. 3.4, rectal temperature stabilized after t_{180}; as well, this time period provided a relatively large sample size ($n = 16$). No significant correlations were found between rectal temperature and VO_{2max} ($r = 0.12$) or the change of rectal temperature and VO_{2max} ($r = -0.02$). A significant correlation was found between rectal temperature and mean skinfold ($r = 0.50$, $p < 0.04$), but not between change in rectal temperature and mean skinfold ($r = 0.46$, $p < 0.06$). The value of this correlation is somwewhat enhanced by the fact that the analysis does not include the data of S_{W18}, the subject who became hypothermic at t_{180}. However, it should also be noted that the range of rectal temperatures at t_{180} was narrow (10 of 18 subjects within a 0.4°C range), as was the range of subject skinfold measurements.

Given that hypothermia was a rare event, and that cooling rates stabilized after t_{180}, the more significant issue appeared to be the relationship between these factors and "tolerance time", the length of time that a subject was able to continue walking. As previously discussed, 13 of the 18 subjects did not complete the protocol; 11 of these 13 stopped for reasons not associated with core hypothermia.

Seven subjects had a rectal temperature less than 37.2°C at t_{120}; none of this group walked beyond t_{210}. This group also included five of the six subjects who stopped prematurely due to leg pain. Only one of these subjects (S_{W18}) stopped because of hypothermia.

Conversely, nine of the eleven subjects with a rectal temperature above 37.4°C at t_{120} were able to continue walking until at least t_{240}.

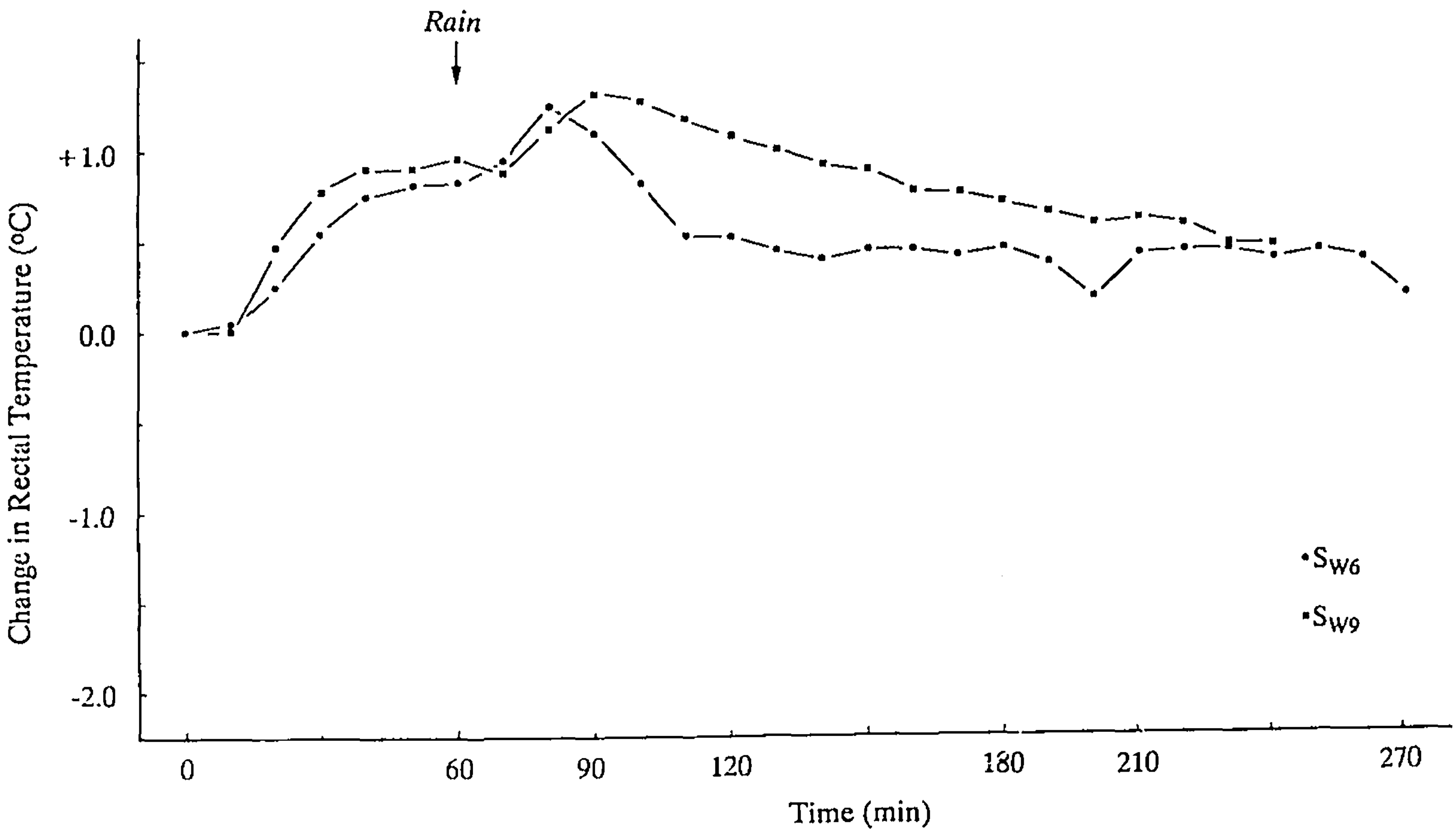
In order to study the possible effects of fitness and fatness on *Wet Walk* cold tolerance, a classification rating-system was developed for these variables, based on the upper- and lower-thirds of the fitness (VO_2max) and fatness (mean skinfold) distributions. Factors having a predicted, positive influence on cold tolerance (high VO_2max, high mean skinfold) were given an H (high) value, while those predicted to have a negative influence (low fitness, low mean skinfold) were given an L rating. Finally, the distribution of these ratings was compared among subjects whose walks were terminated at or before t_{190} (low tolerance) to those who continued walking at least to t_{270} (high tolerance) (Table 3.12). It is evident from Table 3.12 that, in general, higher fitness and greater skinfolds were associated with high *Wet Walk* cold-exposure tolerance, while low fitness and leaner skinfolds tend to be associated with low tolerance. However, it should be noted that ambient temperatures in the latter group were slightly cooler (1–2°C).

In contrast, five subjects (two examples shown in Fig. 3.17) maintained relatively high rectal temperatures. S_{W6}, for example, had an initial rectal temperature of 37.0°C; at t_{180}, rectal temperature was 37.4°C, and remained unchanged until t_{260}. Despite maintaining high levels of rectal temperature, none of the five subjects with a rectal temperature more than 0.3°C above the initial temperature was able to tolerate more than 3.5 hours of wet-cold exposure. Metabolic rates in several of these subjects were above average, but not extreme.

Table 3.12. Comparison of fitness and fatness ratings for high- and low-tolerance groups

Tolerance Group	Lower Risk Ratings		Higher Risk Ratings	
	High Fit	High Fat	Low Fit	Low Fat
HIGH (≥ 4.5 hrs) (n = 7)	4	4	1	1
LOW (≤ 3.0 hrs) (n = 6)	0	1	4	3

Fig. 3.17. Changes in rectal temperature (°C) in two subjects (S_{W6}, S_{W9}) during prolonged wet-cold (R_1W_1) exposure, showing maintenance of high rectal temperature.


Rain
Change in Rectal Temperature (°C)
+1.0
0.0
-1.0
-2.0
0
60
90
120
180
210
270
Time (min)
•S_{W6}
▪S_{W9}

A review of rectal temperature data at t_{180} suggests that individuals with rectal temperatures in the middle range of the distribution were able to continue walking for the duration of the experiment.

3.4. Discussion

The results of this experiment support the concepts that: (a) wet-cold exposure hypothermia is associated with exhaustion, and (b) cold-induced impairment in motor function under these conditions is primarily associated with the effects of peripheral cooling, a stage defined by Vanggaard (1975) as the "wet-cold syndrome". The data are particularly significant in providing experimental evidence for the predicted relationship between the signs of hypothermia (stumbling, reduced shivering), exhaustion (reduced oxygen consumption) and progression into hypothermia.

The staggering gait, nausea and dizziness experienced by subject S_{W7} in conjunction with descent into hypothermia are consistent with anecdotal reports of the behaviour of hypothermia victims prior to collapse (Pugh 1966a; Strang 1969; Freeman and Pugh 1969). The acceleration in cooling rate observed in this incident, concomitant with reduced heat production, also demonstrates that progression into hypothermia in terrestial, wet-cold environments results from failure of thermoregulatory endurance. This is a contrasting scenario to cold-water immersion hypothermia, associated with inadequacy of thermoregulatory power. There was also a noticeable absence of shivering. Fatigue-associated hypothermia was observed in S_{W2} in the latter stages of the sitting phase; however, it should be noted that although rectal temperature reached 35.1°C, it did not continue to decrease but was maintained at this level for nearly 30 min. Haight and Keatinge (1973) induced hypothermia in lightly-clothed subjects at 15°C, after exhaustive exercise and intake of alcohol (alcohol or exercise alone did not induce hypothermia). The development of hypothermia was attributed to failure of thermoregulation, due to exercise- and ethanol-induced hypoglycemia. Felig et al. (1982) related hypothermia to hypoglycemia in marathon runners: the descriptions of mountaineering hypothermia, and observations of S_{W7}, suggest that hypothermia during exercise in wet-cold may be the mountaineer's equivalent of "hitting the wall."

A second case of hypothermia during walking was observed (S_{W18}), but was apparently independent of exhaustion, based on an observed lack of related symptoms during exposure, and shortly afterwards in the rewarming bath. This ectothermic subject's relaxed behaviour once he was out of the cold stress and into the bath ("That wasn't as bad as I thought it would be...") contrasted dramatically to the behaviour of S_{W7}.

Correlations between somatotype, fitness rating and physiological wet-cold tolerance demonstrated a general relationship, suggesting that less fit, more ectomorphic individuals were less tolerant of the *Wet Walk* exposure conditions. Subjects S_{W18} and S_{W15}, the two fastest coolers during the t_{60-180} time period, had the highest observed ectomorphy ratings (Heath and Carter 1967). However, the relationship postulated by Pugh, that fit individuals would be less likely to become hypothermic was not supported by these data. Subject S_{W7} was, in fact, one of the most fit subjects in the study; however, he was able to *tolerate* the exposure experience for a longer period of time than less-fit subjects. It is possible that significantly less-fit subjects would become hypothermic sooner, as Pugh surmised, but they must be exposed for longer periods of time than occurred on the *Wet Walk* in order to demonstrate this prediction. It is possible that more aerobically-fit individuals are able to continue exercising for a longer duration during wet-cold exposure, on average, for reasons indirectly related to the relative levels of metabolic rate.

Decrements in manual performance tests, in combination with general observations, indicate that significant changes in overt behaviour can occur without the development of hypothermia. This is particularly evident at t_{180}, after two hours of exposure: although rectal temperature is approximately 1°C below exercise-elevated rectal temperature seen in dry conditions, it is almost identical to the initial, resting level, near 37°C. These observations are congruent with the descriptions of the wet-cold exposure syndrome advanced by Vanggaard (1975), that "invalidation" or collapse occurs too early in a wet-cold exposure incident for the development of a general hypothermia. Hypothermia was a direct factor in only two of thirteen prematurely-terminated exposures in this research.

Regulation of core temperature at steady levels after t_{210}, indicated by insignificant changes in rectal temperature, skin temperatures, and metabolic rate, demonstrates re-establishment of a condition of thermal balance, following an adjustment period (t_{60-180}) of significant heat loss. Pugh (1963) noticed a tendency among mountaineers to maintain steady, but low, oral temperatures during cold exposure. Stabilization of core temperature at lower levels during prolonged, moderate cold-water exposure has also been observed in divers (Vaughan and Mavor 1972) and in cold water immersees wearing survival suits (Hayward 1984). The linear cooling rate observed in cold water can be used to generate survival time equations (Hayward et al. 1975b). However, cooling curves observed in this study of terrestrial, wet-cold conditions, suggest that similar predictive equations would not be easily attained.

The results of this experiment showed that a wet-cold exposure scenario is characterized by two, progressive stages:

(a) An initial, prolonged phase characterized by strong shivering (HP increased 35%) and motor impairment associated with cooling of peripheral tissues, but without significant core hypothermia. Rectal temperature was maintained at near-constant levels as long as metabolic rate remained at the elevated level.

(b) Descent into core hypothermia, associated with decreased heat production (reduced shivering) due to exhaustion. In the one case observed, a sudden decline in rectal temperature began after 3 hours of exposure, concomitant with decreased oxygen consumption, despite a constant pace; core temperature dropped 1.4°C to 35.3°C in less than 30 minutes. Signs of exhaustion (staggering, faintness, nausea) were evident at the cessation of the experiment.

Chapter 4. VIGILANCE PERFORMANCE DURING PROLONGED EXERCISE IN A WET, COLD ENVIRONMENT (EXP_3)

4.1. Introduction

During EXP_1 (and again in EXP_2), many subjects appeared to withdraw during a wet-cold exposure, evidenced in part by reduced attention to the external environment. Typically, there was a marked reduction in subject-observer verbal interaction, subjects initiating little conversation except to ask direct questions regarding the experiment (i.e., "How much time is left?"). It was not unusual for subjects to ignore observer queries. Many subjects reported that they spontaneously created mental distraction exercises (e.g., images of lying on a warm sunny beach, concentration on a mental problem, reviewing lecture material, counting laps) to divert their attention from the discomfort at hand. Subjects also said that verbal interventions by the observer – to check on their well-being or motivate them – were irritating, breaking their concentration, and reminding them of their current status.

Concomitant with this internalization process was a characteristic walking style exhibited by subjects during a wet-cold exposure. Subjects typically walked with a straight-legged, shuffling gait, arms held stiffly at the sides, fists clenched, shoulders tensed and hunched up, with the head bent downwards and eyes groundward. (This behaviour appeared similar to a generalized response to walking outside on a cold, windy day.) Although this behaviour may offer some thermal protection from rain and wind exposure (particularly in the facial area), and reduce thermal discomfort, it may prove detrimental in a wilderness environment where visual and/or other clues may be important to survival.

The effects of cold-related distraction and reduced attention to performance have already been discussed (Teichner 1958; Vaughan 1977). Although these generalized effects of cold distraction are relevant, the primary interest in this investigation was the possible reduction in vigilance to visual cues, based on the observed eyes-downward behaviour during wet-cold exposures.

Mackworth (1957) defines vigilance as "a state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment." If increased vigilance means an increased ability to make discriminative responses (Davies and Tune 1970), then a reduction in vigilance represents a decreased ability to make such responses. Mackworth (1950) and Pepler (1958) both observed vigilance-performance decrements in heat-acclimatized individuals "stripped to the waist" in ambient tenperatures of 21°C and 19°C, respectively.

Kissen et al. (1964) studied the effects of hypnosis on thermoregulatory responses of non-acclimatized, lightly-clad (1 clo insulation) men exposed to 4°C air. A vigilance task requiring constant attention was included, in part, to monitor subject alertness during the hypnotic state. They found that hypnotic subjects shivered less and had lower rectal temperatures (36.6°C) than during non-hypnotic control sessions, although no significant differences in skin temperatures were observed between the sessions. Vigilance performance during the hypnotic sessions showed significant improvements, with significantly more correct responses and fewer errors of omission. Interestingly, subjects described the hypnotic cold exposures as less stressful, suggesting that improved performance may be associated with reduced distraction (despite having lower rectal temperatures) and general cold habituation. However, the authors allow that some of the improvement in performance may be associated with increased mechanical efficiency (reduced interference from shivering).

Poulton et al. (1965) investigated the effects of cold and rain on the vigilance of naval ratings during lookout duties at sea. Subjects were required to report the occurrence of a randomly-occurring light signal. The number of long response times (> 2 sec) was significantly greater during rain and cold (6°C) than during dry cold conditions (−1°C). No explanations for the increased response time were offered, however. In the dry cold condition, subjects were described as "cold but not shivering" and a slight drop in oral temperature (−0.6°C) was noted, leading the authors to suggest that "the efficiency of watchkeeping in the cold may be correlated with body temperature." They concluded that watchkeeping performance is likely to be impaired in rain, and that lookouts should be protected from rain.

Angus et al. (1979) investigated the effects of sleep quality on performance of a 40-minute visual vigilance task under "Arctic" conditions (0 - 5°C). During cold-exposure tasks, subjects were dressed in cold-protective clothing. The initial results in the cold room were significantly below baseline, but improved with time, returning to baseline levels after six task days. Results suggest an interaction between cold and sleep effects. The authors suggest that improvement in performance is related to cold adaptation.

A test of vigilance was designed and incorporated into the experimental design. The test required that a subject detect randomly-occurring light signals as he walked along the *Wet Walk*. Based on previous observations, a decline in vigilance efficiency was expected. To study the effects of enhanced fatigue on cooling rate, the pre-rain exercise period was increased from 1 to 4 hr.

4.2. Methods

Pilot studies were carried out in the year preceding EXP_3 to complete the design of a test of vigilance. Development of the vigilance test is discussed in Appendix H1.

4.2.1. The *Wet Walk*

No significant changes were made in the *Wet Walk* for EXP_3. Minor adjustments were made in the observation areas to accommodate the vigilance test. Refer to Fig. 1.2 for a layout of the *Wet Walk*.

4.2.2. Subjects

Experimental procedures were approved by the Committee for Research on Human Subjects at the University of Victoria. Each subject was informed of his right to withdraw from the experiment at any time; subjects were reminded of this right prior to the beginning of an experimental session. An experiment was normally terminated if *(a)* rectal temperature reached 35°C, or *(b)* a subject requested to withdraw from the experiment. The experimenter also reserved the right to terminate an experiment if he felt that its continuation would not be in the best interests of the subject's health and/or well-being.

Subject selection. Eleven male subjects volunteered to participate in the experiment. Additional volunteers were recruited for use in pilot studies. Informed consent was obtained from each subject after he had been familiarized with the purpose and procedures of the study. Subjects also completed a medical history questionnaire and the *PARQ* questionnaire (B.C. Ministry of Health 1978) prior to testing.

Subject characteristics. Subject characteristics are summarized in Table 4.1. Fitness level was established using a submaximal bicycle ergometer test (PWC_{170})

Table 4.1. Subject characteristics (EXP_3), grouped by experiment condition[1] (mean ± SD)

Characteristic	R_1W_1	R_0W_1	Total
n	7	3	10
Age (yr)	21.7 ± 3.5	27.7 ± 6.4	23.5 ± 5.0
Height (cm)	176.7 ± 5.4	179.1 ± 6.4	177.4 ± 5.4
Weight (kg)	73.6 ± 6.2	74.0 ± 4.8	73.7 ± 5.5
Surface area (m^2)	1.90 ± 0.10	1.92 ± 0.10	1.90 ± 0.10
Area:mass ($cm^2 \cdot kg^{-1}$)	258.2 ± 9.1	259.6 ± 5.6	258.6 ± 7.9
Mean Skinfold (mm)	8.0 ± 1.2	9.7 ± 1.6	8.5 ± 1.5
% Body Fat	10.6 ± 1.0	11.4 ± 1.3	10.9 ± 1.1
Somatotype:[2,3]			
Endomorphy	2.2 ± 0.6	2.8 ± 1.1	2.3 ± 0.7
Mesomorphy	5.8 ± 0.7	4.3 ± 2.5	5.4 ± 1.3
Ectomorphy	2.1 ± 0.7	2.8 ± 1.1	2.3 ± 0.8
Index[4]	0.19 ± 0.1	0.28 ± 0.2	0.21 ± 0.1
$\dot{V}O_2max$ (ml $O_2 \cdot min^{-1} \cdot kg^{-1}$)	54.4 ± 6.8	54.7 ± 7.9	54.5 ± 6.7

[1] R_1W_1 = rain/wind (n = 7); R_0W_1 = no rain/wind (n = 3)

[2] Heath-Carter somatotype

[3] Somatotype: For R_1W_1, n = 6; for R_0W_1, n = 2

[4] Index = Ectomorphy/(Endomorphy • Mesomorphy)

and aerobic capacity (VO_{2max}) estimated from predictive tables based on cardiac frequency (Åstrand and Rodahl 1977: 351). Height, weight, and skinfold measures were recorded for each subject. Mean skinfold thickness was the average value of skinfold measurements taken at six standard sites: triceps, subscapular, suprailiac, abdominal, thigh and calf. Percentage body fat, surface area, relative surface area and surface area:mass ratio were calculated as described in chapter 2. Additionally, Heath-Carter somatotyping was also completed (Heath and Carter 1967) and a relative index calculated (Hayward et al. 1978).

4.2.3. Clothing

The clothing ensemble worn by subjects was similar to previous experiments, with two exceptions. To reduce the attrition of subjects associated with muscle pain in the thigh/hip region, lighter hiking boots (Kodiak *Grizzlies*: average weight per pair 0.95 kg) were worn, and jeans were discarded in favour of lighter, more loosely-fitting cotton pants (GWG *Nev'r-Press* green workpants). Clothing weight (including boots) averaged 2.3 kg (wet weight 4.5 kg).

4.2.4. Backpack

The EXP_2 backpack (Appendix E3) was used in this experiment. The digital thermometers were not carried in the backpack (see description of skin temperatures below), reducing the loaded pack weight to 7.2 kg.

4.2.5. Walking Pace

Subjects walked the track at a constant rate of 35 $sec \cdot lap^{-1}$ (50 m), equivalent to a walking pace of 5.15 $km \cdot hr^{-1}$ (3.2 mph), similar to EXP_2; the same lap pacer mechanism (Appendix B3) was used.

4.2.6. Protocol

The protocol for EXP_3 is summarized in Table 4.2. An experiment was divided into two phases: (a) a preliminary 3-hr period of walking (phase A); and after a rest break, (b) another walking phase of 3 – 3.5 hr duration (phase B). Subjects were randomly assigned to one of two conditions: wet with wind (R_1W_1) or a dry with wind (R_0W_1), the latter a control condition. Seven subjects completed the R_1W_1 condition; four completed the R_0W_1 condition, but one of these subjects was not included in analysis due to unique responses (see Results).

Following equilibration, subjects walked for three 50-minute walking periods separated by 10-minute rest breaks, during which time they sat on a stool adjacent to the observation area (phase A). This was followed by a 30-minute rest period; in the last 10 minutes of this period, subjects were introduced to the vigilance test. The second phase of the experiment (phase B) began at the completion of vigilance learning trials. Subjects walked for 60 minutes in dry conditions; after the 60-minute reading, the rain and wind "storm" was initiated and continued until the end of the experiment. At the end of the walking phase, subjects were rewarmed in a therapeutic warm-water bath.

4.2.7. Physiological Variables

As in previous experiments, portable and telemetric monitoring systems were used to measure physiological responses. Some of the devices were carried by the subject in the insulated, waterproof backpack described in chapter 3.

Rectal temperature (T_{Re}). Rectal temperature was measured with a YSI series 400 rectal thermistor (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio); a small disposable surgical tube plug prevented slippage during exercise. The thermistor was permanently connected to a tele-thermometer (Yellow Springs

Table 4.2. Protocol (EXP$_3$)

t_{CUM} (mins)	t_{ACT} (mins)	Activity	Description
−30 – −15	15	SITTING	Equilibration; *POMS*$_1$ (tent)
Phase A			
0 – 170	170	**WALKING** ***(DRY)***	Walking (5.2 km/hr)
	50	Walking	*SENSORY* (0, 50)
	10	Resting	*RPE* (10, 50)
	50	Walking	*SENSORY, RPE* (110)
	10	Resting	
	50	Walking	*SENSORY, RPE* (170)
170 – 200	30	SITTING	Resting; POMS$_2$
Phase B			
200– 260	60	WALKING *(DRY)*	*VIGILANCE* (200 – 410) *SENSORY* (200) *RPE* (210)
260 – 410	150	WALKING *(WET)*[1]	*SENSORY, RPE* (260, 320, 380, 410)
415		SITTING	*POMS*$_3$
	60	SITTING	Rewarming in hot bath
		SITTING	*POMS*$_4$

[1] In dry condition, subjects continue walking without rain.

t_{CUM} = cumulative experiment time
t_{ACT} = activity time

Instruments) via an umbilicus (Tygon tubing, with skin thermistors) firmly attached to the pack (any pull on the system was absorbed by the pack and not the probe). The umbilicus dragged on the ground behind the subject; the length was set so that a subject would not cross over the umbilicus going through the turnabouts. Drag resistance was not measured, but did not appear to have any significant effect (based on subjective experience).

Skin temperatures. Mean skin temperature (T_{MS}) was calculated from surface temperatures recorded at four sites (arm, chest, calf, thigh), using the weighted formula of Lund and Gisolfi (1974). Forehead skin temperature (T_H) was also recorded, as a potential index of perceived thermal stress. Skin temperatures were measured using YSI banjo-type surface thermistors connected to a YSI telethermometer via the umbilicus system described above. The thermistors were held in place on the skin with a 2.5-cm-square piece of Elastoplast waterproof adhesive tape.

Oxygen consumption/ventilation rate. Oxygen consumption and ventilation rate were measured with a portable Oxylog oxygen consumption meter (P.K. Morgan Ltd., Chatham, Kent, England) mounted in the backpack. The subject wore an oronasal mask connected to the Oxylog. Minute oxygen consumption (VO_2) was read directly from the Oxylog at the scheduled data recording stops, and metabolic rate (MR) calculated in watts using the conversion factor of $20.2\ kJ \cdot l\ O_2^{-1}$ consumed. Minute ventilation (V_E) was estimated from the change in total inspired volume over the ten-minute period.

Heart rate (HR). Cardiac activity was monitored by radio telemetry (Conestoga Medical Electronics, Model SCT-1; Tektronix Physiological Monitor

Type 414) and heart rate read directly from the Tektronix monitor. Three heart rate samples were taken every ten minutes.

4.2.8. Vigilance Test

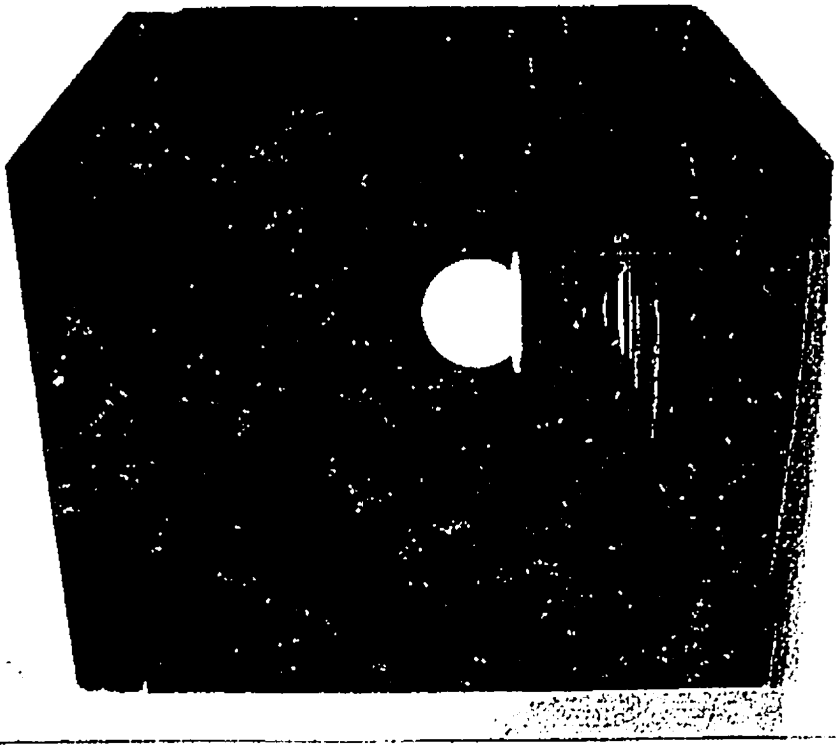
The test of vigilance required subjects to detect laterally-placed, randomly-occurring light signals (3-mm diameter) while walking along the *Wet Walk* circuit. These signals occurred at a frequency of 10 per hour, or 10 per 90 laps. Eight such signal lights were placed around the west end of the track.

Light Signal. The light signal was generated with a 7.5W Sylvania bulb (110V) placed in a small light box (Fig. 4.1a), the light passing through three layers of thin green acetate sheeting and two thicknesses of sanded 3-mm plexiglass. The 3-mm, green light-circle (Fig. 4.1b) was created by placing a third layer of plexiglass (painted black), with a 3-mm-diameter hole drilled in the centre, on the outer surface of the laminated structure. The outer surface of the light signal box (except the light hole) was painted flat black. All light sources were identical. (Construction details are described in Appendix H2.)

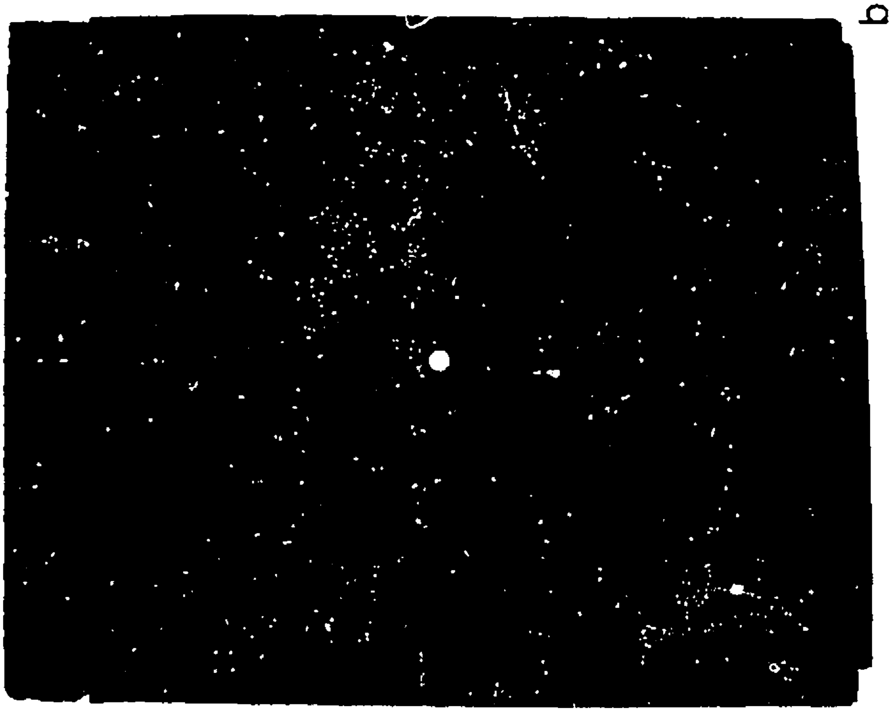
The light sources were placed at the back of long plywood "tunnels" to restrict the angle of view (Fig. 4.2; Appendix H2), therefore reducing the time the signal was visible to the subject. These tunnels were also painted flat black to reduce visibility of the systems at night.

The distribution of the eight signal systems is shown in Fig. 4.3. The light signal sequence was first visible just after the observation area heading west, continuing around the west turnabout, and ending by A_{10} on the eastern return, covering approximately 20.5 m. Details of light position are given in Appendix H3. The lights were angled in such a way that a subject only had to turn his head slightly to the left or right to see a signal; minimal head movement was necessary in order

Fig. 4.1. The vigilance signal light. (a) Front plate removed. (b) Front plate in place, showing light signal (the actual light colour was green).



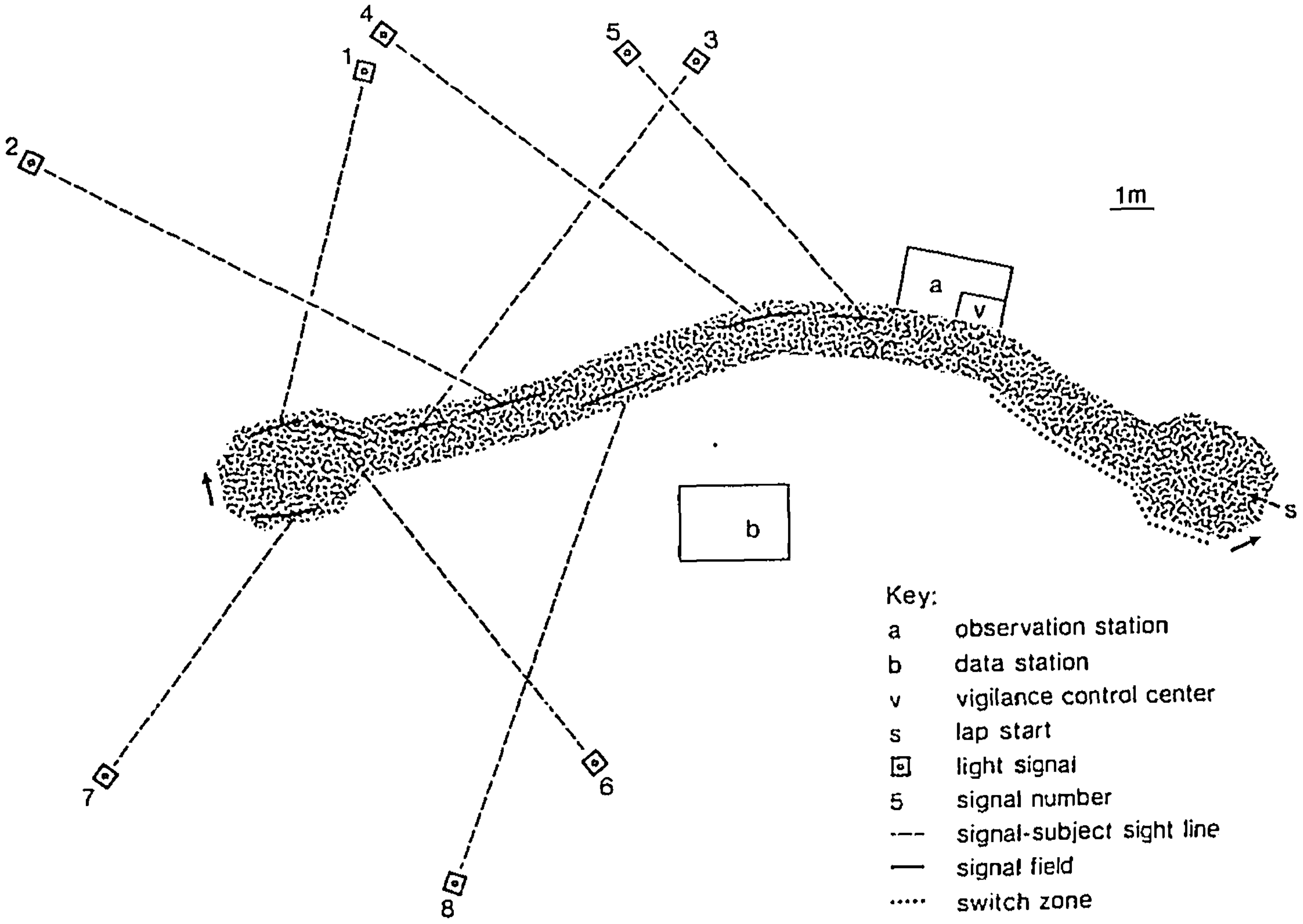
a



b

Fig. 4.2. A vigilance light "tunnel" (#4).

Fig. 4.3. Layout of the eight vigilance test signal lights. Subjects walked through the west and east turnabouts in the same direction each time (arrow). The signal lights were turned on or off as subject walked through the "switch zone" (facing away from the observation area).


4
1
5
3
2
1m
a
v
s
b
7
6
8
Key:
a observation station
b data station
v vigilance control center
s lap start
⊡ light signal
5 signal number
---- signal-subject sight line
—— signal field
······ switch zone

for a subject to continue walking safely at pace. Viewing distance averaged 9.4 ± 1.7 m, and a signal was visible for an average of 1.2 seconds (range 1.1 - 1.4 sec: Appendix H4). Five light signals could be seen by a subject as he walked uphill (west), and three on the downhill route (east); four of the signals were on the subjects' left, and four on the right.

The lights were connected to a multiple switch box in the observation station. Lights were manually operated by a technician according to the schedule outlined in the data sheet (described below). The switch box was placed behind a protective screen, and could not be seen by subjects (Appendix H2). All switching was done while a subject walked away from the observation area towards the east end (Fig. 4.3).

Software. The number of events (an event being one complete circuit of track) was set at 90 per hour, with some flexibility to accommodate differences in scheduled data stops (Appendix H4). The frequency of signal events (a light signal on) was 10 per hour, or 10 per 90 laps. The laps on which a signal event occurred were randomly selected, based on choosing 5 laps per 30 minutes period (Appendix H4). The probability of a signal event was 1/9 and a non-event 8/9. The frequency of a particular event (a specific light signal) was also randomly selected, after lap selection (Appendix H4). The probability of a specific event was therefore $1/8 \times 1/9 = 1/72$. Details of signal generation are provided in Appendix H4.

Vigilance Test Procedures. At the end of the mid-experiment rest break (Table 4.2), a subject was informed that he would be participating in a test of vigilance when walking resumed, requiring him to detect randomly-occurring light signals placed around the *Wet Walk*. He was told that he could expect the possibility of a signal on any lap (he was not given any information regarding the frequency of signals), but that only one signal could occur on a given lap. He was also informed that he would receive no feedback on his performance. All eight lights were turned on, and the experimenter led the subject along the track, pointing out the signals. When the subject had seen all the light signals, he walked slowly along the course on his own, calling and pointing out lights. Finally, the subject walked two laps at pace to confirm the signal location. Confirmation was accomplished by the subject calling out "1!... 2!... ...8!) in signal sequence.

During the test, a subject was asked to call out "light" as they passed the observation station when they wished to report a signal; the observed would acknowledge that the information had been received with a "thank you".

The vigilance test began after the first lap in phase B, and continued for each lap until the end of the walking phase of the experiment.

Scoring. The following scoring criteria were applied: CR (correct response) = light on/light reported or no light/no light reported; EO (error of omission) = light on/not reported; and EC (error of commission = no light/light reported (Appendix H4).

4.2.9. Psychological Testing

Self-rating Scales. Three rating scales were completed by subjects at regular intervals during the cold exposure (Table 4.2). The scales were (1) the rating of perceived exertion (RPE) (Borg 1973); (2) the rating of thermal comfort (RTC) (Hardy 1970); and (3) the rating of thermal sensation (RTS) (Marcus et al. 1978; Hardy 1970). These scales are described in chapter 3.

4.2.10. Other Variables

The following data were collected but are not presented for review in the dissertation.

Urine volume/temperature. Urine temperature and volume were recorded using the *TeePee* system (Appendix C5).

POMS. The *Profile of Mood States* (POMS) (Educational and Industrial Testing Service 1971) was completed by some subjects at times listed in Table 4.2. The test measures changes in mood and is described in chapter 3.

Personality tests. Two personality inventories were completed by subjects in the laboratory at the University of Victoria. These were the *Motivational Analysis Test* (Cattell et al. 1964) and *Test of Attention and Interpersonal Style* (Nideffer 1977). Analysis of these tests was not completed, as interpretation was beyond the scope of the author's skills.

4.2.11. Procedures

Subjects were requested to maintain a normal diet, avoid alcohol consumption and refrain from exercise during the 24 hours preceding the experiment. Subjects reported to the *Wet Walk* at approximately 1200 hours, and were familiarized with the walking pace and experimental routine. They changed into the standard clothing after the temperature sensors and ECG electrodes were applied. The preparation period was about 1 hour. Subjects then sat quietly in the heated tent (18°C), and resting values of rectal temperature, skin temperatures, metabolic rate, ventilation rate and heart rate were recorded. After the equilibration period, final instructions were given, and the first walking phase began at approximately 1330 hours. Subjects walked for about three hours, with two 10-minute rest breaks (Table 4.2), stopping briefly (17.5 sec) at 10-minute intervals for metabolic data readings. During the 30-minute break, the vigilance test was explained to subjects, as described earlier. The second period of walking began after the mid-experiment break. Following the 60-minute reading, rain and wind (R_1W_1) or wind alone (R_0W_1) conditions were initiated, and continued until the end of the walking phase of the experiment. At the end of the experiment, or if a subject stopped prematurely, he was rewarmed in a therapeutic warm-water bath. Subjects were given fluids (water) at regular intervals over the course of the experiment; total fluid intake was 500 ml over a complete 7.5 hour experiment.

4.2.12. Ambient Conditions

Mean ambient temperature (± standard deviation) at the beginning of the rain phase of the experiment was 4.5 ± 0.9°C in the wet condition ($n = 7$) and 5.4 ± 1.8°C in the dry condition ($n = 3$). The ambient temperature ranged by more than 1°C over the final 3 hours of the experiment in only two experimental sessions (Table 4.3). Air temperature was recorded with a mercury thermometer placed in a Stevenson weather screen adjacent to the Wet Walk (Fig. 1.2). Ambient relative humidity averaged 90% (Bacharach Model SAC sling psychrometer). Although limits on ambient wind were also established ($8\ \mathrm{km \cdot hr^{-1}}$), observed wind movement was not a significant factor. Wind speed was measured with an air meter (WEATHERtronics Model 2410) held at chest level.

4.2.13. Analysis of Results

Data are presented as the mean ± standard deviation, unless otherwise indicated. In figures, significance was assumed when standard deviations did not overlap, as previously described.

4.3. Results

4.3.1. Subject Performance

R_1W_1. Four (S_{W1-4}) of the seven subjects in this condition were able to complete the experimental protocol (two hours of wet-cold exposure); S_{W1} walked for an additional 30 minutes (2.5 hours of cold exposure) (Table 4.3). The mean ambient temperature at the beginning of wet-wind exposure for this group was 4.2 ± 0.7°C. All four of these subjects reported feeling very tired at the end of the experiment. It was my perception that they were at, or very near, their limits of voluntary cold tolerance. S_{W1} stated he felt "wobbly" and slightly nauseous at the end of his walk (although he had stated 30 minutes earlier that he was "feeling better"). S_{W2} reported "really sore" feet, ankles, and hips, and complained of back cramps towards the end of the experiment. S_{W4} felt that this experience would be "tough on someone who lived half their life in Hawaii."

Three subjects were unable to complete the protocol. S_{W5} proceeded for almost 3 hours of wet-cold exposure, but suffered from the hip-groin pain described previously, and walked at a slower pace during the final stages of the experiment. S_{W6} was forced to stop after approximately 2.5 hours due to nausea and bowel upset (this apparently was an exercise-induced problem associated with running). S_{W7} was very tired, and exhibited a significantly higher heart rate (> 150 bpm) in comparison to other R_1W_1 subjects; the experiment was terminated after 1 hour of wet-cold exposure. The fitness levels of the latter two subjects were "average" (around 48 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$), although these fitness ratings were among the lowest in the group (n = 7). These two subjects were also the smallest in the R_1W_1 group, but were no different in respect to skinfold or other anthropometric measures. No meaningful

Table 4.3. Summary of subject performance (EXP_3)

S	t_{EXP} (hrs)	T_{Re} (°C)	T_{Amb} (°C)		Description
			T_{rw}	T_{end}	
R_1W_1					
S_{W1}	3.5	36.8	4.5	4.0	Complete
S_{W2}	3.0	36.8	3.2	2.9	Fatigue; cramps
S_{W3}	3.0	37.0	4.0	4.0	Fatigue
S_{W4}	3.0	36.7	4.9	3.8	Fatigue
S_{W5}	2.8	36.5	4.5	4.5	Fatigue; nausea
S_{W6}	2.5	36.4	4.1	3.6	Intestinal cramps
S_{W7}	2.3	37.1	6.7	5.4	Fatigue; high HR
R_0W_1					
S_{D1}	3.5	37.3	4.0	4.5	Complete
S_{D2}	3.5	37.3	4.8	5.9	Complete
S_{D3}	3.5	37.9	7.5	6.6	Complete
S_{D4}	2.3	38.0	4.5	4.5	High HR, ventilation

t_{EXP} = walking time (Phase B)
T_{Re} = rectal temperature at end of walking period
T_{Amb} = ambient temperature
T_{rw} = ambient temperature at 260 min (rain/wind on)
T_{end} = ambient temperature at end of walking period

differences were observed between these subjects during the dry phases of the experiment.

R_0W_1. Three subjects completed non-rain walks without incident, although all three were fatigued by the experience. Subject S_{D4}, however, exhibited distinct physiological and behavioural responses, in some ways suggestive of wet-cold exposure. The performance of this particular subject is discussed later.

4.3.2. Preliminary 3-hour Walk

Mean physiological responses to exercise stress were similar in both groups during the initial 3-h exercise period, and remained stable over this time (Table 4.4). The mean increase in rectal temperature was slightly (but not signficantly) greater in R_0W_1 (0.85 ± 0.26°C) than in R_1W_1 (0.61 ± 0.23°C) at t_{170}. These similarities were also seen in subjective responses: no significant differences were found in RPE, RTS or RTC at the conclusion of the 3-hr exercise period (Table 4.5). Perceived exertion was rated between "fairly light" and "somewhat hard" by both groups at t_{170}. With the exception of one subject, ratings of thermal sensation (RTS) were on the "warm" side of neutral and "comfortable" side of thermal comfort (RTC).

4.3.3. Rectal Temperature (T_{Re}) (phase B).

During the 60 min of exercise prior to the onset of rain and wind ($t_{200-260}$), the increase in core temperature was similar in both groups (R_1W_1, +0.65 ± 0.12; R_0W_1, +0.77 ± 0.03) (Fig. 4.4); the mean rectal temperature was identical at t_{260} (R_1W_1, 37.63 ± 0.26; R_0W_1, 37.63 ± 0.28). Wetting produced the characteristic rise in rectal temperature in R_1W_1, mean T_{Re} reaching a maximum after 20 minutes of wetting (+0.26 ± 0.12°C). Significant cooling of rectal temperature began after t_{290} (Fig. 4.4). Over the next 90 minutes, rectal temperature decreased by 0.77 ± 0.15°C,

Table 4.4. Comparison of physiological responses during the preliminary walking phase between wet (R_1W_1) and dry (R_0W_1) groups (mean ± SD)

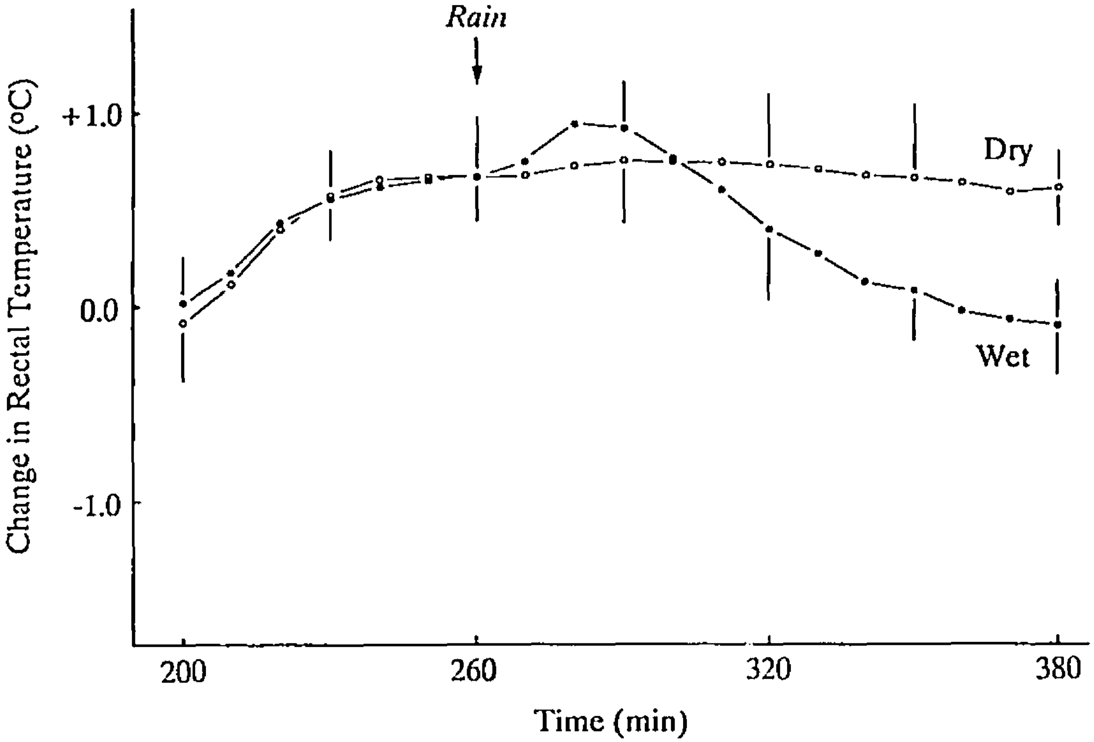
Variable	R_1W_1 (n = 4)	R_0W_1 (n = 3)
Rectal Temperature (°C)		
T_{Re0}	36.95 ± 0.35	36.95 ± 0.28
T_{Re50}	+0.67 ± 0.17	+0.78 ± 0.08
T_{Re170}	+0.61 ± 0.23	+0.85 ± 0.26
Mean Skin Temperature (°C)		
T_{MS0}	30.0 ± 0.9	30.0 ± 0.7
T_{MS50}	29.1 ± 0.8	28.6 ± 0.5
T_{MS170}	28.0 ± 1.6	27.5 ± 0.6
Metabolic Rate ($W \cdot kg^{-1}$)		
MR_0	1.4 ± 0.1	1.2 ± 0.1
MR_{50}	5.9 ± 0.5	5.5 ± 0.6
MR_{170}[1]	5.6 ± 0.4	5.5 ± 0.6
Ventilation Rate ($l \cdot min^{-1}$)		
V_{E0}	10.5 ± 1.0	9.5 ± 0.6
V_{E50}	31.6 ± 1.7	29.3 ± 1.4
V_{E170}	30.6 ± 2.8	27.6 ± 2.6
Heart Rate (bpm)		
HR_0	60.8 ± 8.6	61.7 ± 6.3
HR_{50}	101.3 ± 12.5	96.0 ± 4.1
HR_{170}	104.8 ± 9.1	100.7 ± 7.6

[1] For R_1W_1, n = 3

Table 4.5. Comparison of subjective evaluations of exercise and thermal stress during the preliminary walking phase, between wet (R_1W_1) and dry (R_0W_1) groups (mean ± SD)

Variable	R_1W_1 (n = 4)	R_0W_1 (n = 3)
Rating of Perceived Exertion (RPE)		
RPE_{10}	8.8 ± 1.3	9.7 ± 0.6
RPE_{50}	9.8 ± 1.3	11.3 ± 0.6
RPE_{110}	10.8 ± 0.5	12.0 ± 1.0
RPE_{170}	12.3 ± 0.5	12.0 ± 1.0
Rating of Thermal Sensation (RTS)		
RTS_0	0.5 ± 1.3	-0.7 ± 2.3
RTS_{50}	2.5 ± 1.7	2.0 ± 1.0
RTS_{110}	2.3 ± 1.5	0.3 ± 2.1
RTS_{170}	1.0 ± 0.8	0.3 ± 2.9
Rating of Thermal Comfort (RTC)		
RTC_0	1.0 ± 1.2	0.7 ± 1.5
RTC_{50}	1.5 ± 1.0	1.3 ± 1.2
RTC_{110}	1.0 ± 0.8	0.7 ± 0.5
RTC_{170}	0.5 ± 0.6	0.7 ± 1.5

Fig. 4.4. Change in rectal temperature (°C) during wet-cold exposure phase ($t_{200-380}$): R_1W_1 (n = 4), R_0W_1 (n = 3), (mean ± SD).


Rain
+1.0
0.0
-1.0
Change in Rectal Temperature (°C)
Dry
Wet
200
260
320
380
Time (min)

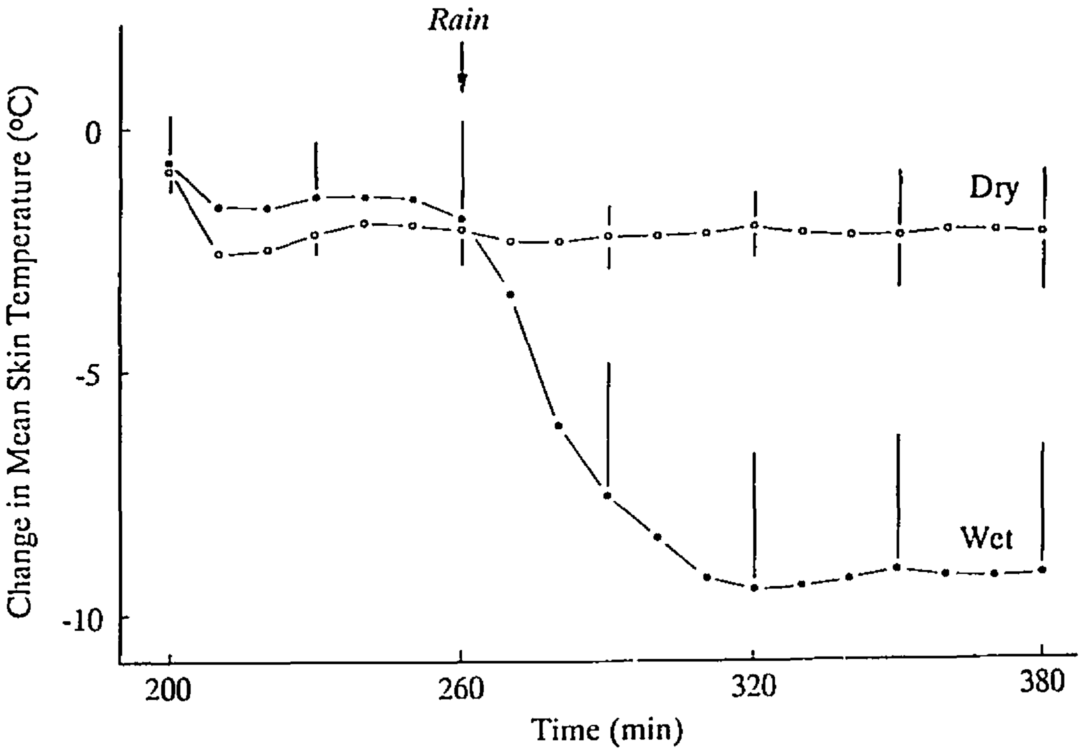
to a mean value of 36.86 ± 0.14°C at t_{380}, significantly below the pre-rain rectal temperature. No subject developed clinically-defined hypothermia; the lowest recorded rectal temperature in R_1W_1 was 36.7°C. There was no significant change in R_0W_1 rectal temperature over this same period (Fig. 4.4), and the final temperature of 37.58 ± 0.28°C was significantly greater than the mean R_1W_1 rectal temperature at t_{380}.

4.3.4. Skin Temperatures

Mean Skin Temperature (T_{MS}). There was no significant difference in mean skin temperature responses during the pre-rain exercise period. At the initiation of wetting (t_{260}), mean skin temperatures were similar in R_1W_1 (28.2 ± 1.5°C) and R_0W_1 (28.0 ± 0.3°C) (Fig. 4.5). Wetting produced significant peripheral cooling in R_1W_1 subjects, the mean skin temperature decreasing by 7.7 ± 0.6°C in the first hour of wet-cold exposure, resulting in a mean skin temperature of 20.5 ± 2.3°C at t_{320}. This level of skin temperature was maintained over the final hour of exposure (change between t_{320} and t_{380} = +0.3 ± 1.1°C); the final mean skin temperature of 20.8 ± 2.3° was significantly below the pre-rain temperature. R_0W_1 mean skin temperature remained stable throughout the final two hours of exercise, showing a mean change of −0.1 ± 0.8°C from the pre-wind value, and was significantly higher than the R_1W_1 mean skin temperature at t_{380} (Fig. 4.5).

Forehead Temperature (T_H). Mean forehead skin temperature was similar in R_1W_1 and R_0W_1 at the begining of the second exercise phase (t_{200}: R_1W_1, 29.0 ± 1.1°C; R_0W_1, 29.1 ± 1.7°C), and prior to the initiation of rain and wind (t_{260}: R_1W_1, 23.4 ± 1.4°C; R_0W_1, 23.6 ± 4.2°C). Forehead temperature cooled rapidly with wetting in R_1W_1, falling an average of 8.3 ± 2.1°C within 30 minutes, 13.9 ± 1.8°C below the t_{200} (resting) forehead temperature. Forehead temperature stabilized at

Fig. 4.5. Change in mean skin temperature (°C) during wet-cold exposure phase ($t_{200-380}$): R_1W_1 (n = 4), R_0W_1 (n = 3), (mean ± SD).


Rain
Change in Mean Skin Temperature (°C)
0
-5
-10
Dry
Wet
200
260
320
380
Time (min)

approximately 14°C during the final hour of wet-cold exposure, significantly below the pre-rain temperature. R_0W_1 forehead temperature showed no effective change (−0.5 ± 0.4°C) during the final two hours of walking.

4.3.5. Metabolic Rate (MR)

Pre-rain metabolic rates were similar to values observed during the 3-hr preliminary walk (Table 4.4). No significant differences in MR were apparent between R_1W_1 and R_0W_1 subjects (Fig. 4.6); MR was estimated to be 6.1 ± 0.3 $W \cdot kg^{-1}$ ($n = 2$) and 5.7 ± 0.5 $W \cdot kg^{-1}$, respectively, at t_{260}. Oxygen consumption was equivalent to approximately 30% of $\dot{V}O_{2max}$ (range 26 – 38%). R_1W_1 metabolic rate steadily increased after wetting was initiated, reaching levels about 10 $W \cdot kg^{-1}$ after approximately 1 hour; this represented an increase of 50% above the pre-rain MR. During the last hour of exposure, MR continued to increase at a slower rate, reaching a peak value of 10.7 ± 1.5 $W \cdot kg^{-1}$ (175% pre-rain MR) towards the end of the walk (Fig. 4.6). End-walk MR was significantly elevated above pre-rain MR values (Fig. 4.6). By this stage, relative oxygen consumption had increased to 50–60% of $\dot{V}O_{2max}$. Shivering was apparent towards the latter half of the first hour of wet walking, reaching maximum visible levels in the second hour. R_0W_1 metabolic rate stabilized around pre-rain values; at t_{380}, mean MR was 5.6 ± 0.8 $W \cdot kg^{-1}$ (relative O_2 consumption 31 ± 5% $\dot{V}O_{2max}$), significantly below the mean R_1W_1 metabolic rate (Fig.4.6).

4.3.6. Ventilation Rate (V_E)

Prior to the onset of rain and wind (t_{260}), mean estimated V_Es were insignificantly different (R_1W_1, 29.5 ± 2.4 $l \cdot min^{-1}$; R_0W_1, 27.1 ± 2.0 $l \cdot min^{-1}$) (Table 4.6), and similar to values observed during phase A (Table 4.4). Mean R_1W_1 V_E increased steadily in the first hour of wetting to 44.2 ± 4.3 $l \cdot min^{-1}$. In the final hour,

Fig. 4.6. Metabolic rate ($W \cdot kg^{-1}$) during wet-cold exposure phase ($t_{200-380}$): R_1W_1 (n = 2), R_0W_1 (n = 3), (mean ± SD).

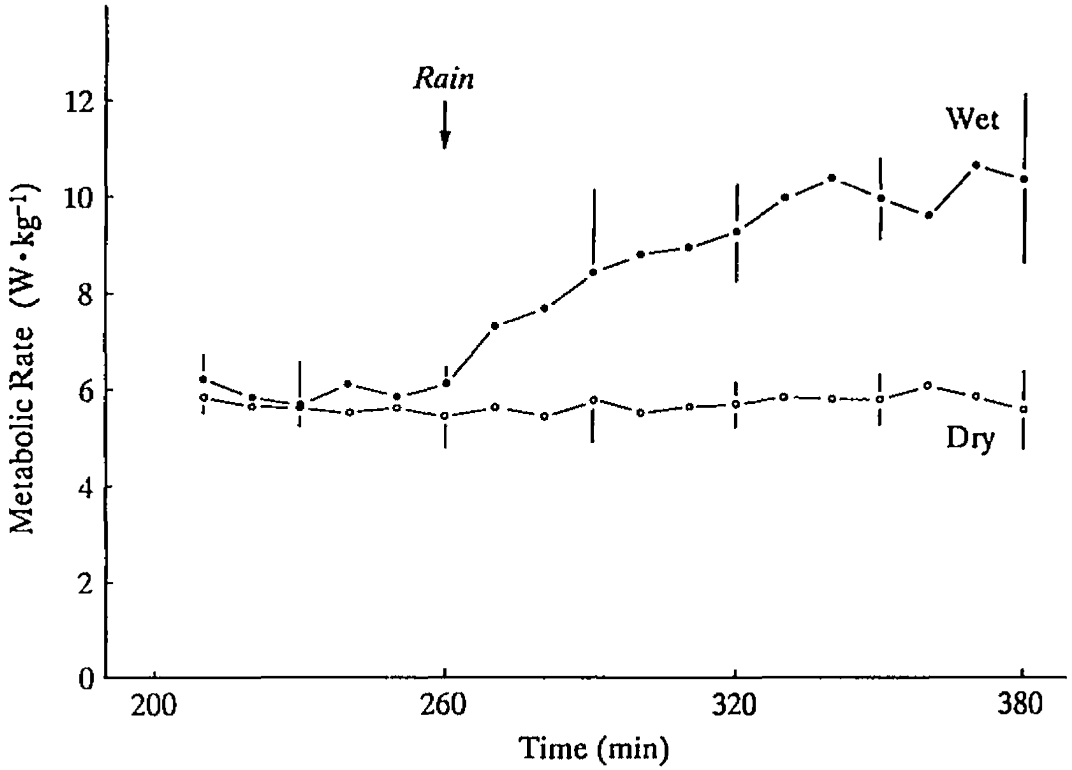

Rain
Wet
Dry
Metabolic Rate (W•kg^{-1})
0
2
4
6
8
10
12
200
260
320
380
Time (min)

Table 4.6. Comparison of V_E ($l \cdot min^{-1}$) and heart rate (bpm) responses during second exercise period (B) between wet (R_1W_1) and dry (R_0W_1) groups (mean ± SD)

Variable	R_1W_1 (n = 4)	R_0W_1 (n = 3)
Ventilation Rate ($l \cdot min^{-1}$)[1]		
V_{E260}	29.5 ± 2.4	27.1 ± 2.0
V_{E320}	44.2 ± 4.3	29.4 ± 2.2
V_{E380}[2]	56.5 ± 2.8	29.6 ± 3.3
Heart Rate (bpm)		
HR_{260}	109.0 ± 8.8	104.7 ± 8.7
HR_{320}	119.8 ± 10.6	109.7 ± 4.1
HR_{380}	125.4 ± 13.1	111.3 ± 9.6

[1] For R_1W_1, n = 3 (S_{W1-3})

[2] n = 2 (typical value between 48–53 $l \cdot min^{-1}$)

V_E increased slightly, stabilizing around 50 l•min^{-1}, average 10-minute V_E values ranging between 48.2 ± 1.6 l•min^{-1} and 53.0 ± 3.4 l•min^{-1}. R_0W_1 ventilation rates remained stable throughout this period; during the final 1.5 hours of the walk, average V_E values ranged between 28.5 ± 1.8 l•min^{-1} and 29.9 ± 2.2 l•min^{-1}. This value range is significantly less than R_1W_1 V_E estimates, based on non-overlap of standard deviations.

4.3.7. Heart Rate

Mean heart rates were insignificantly different at t_{260} (R_1W_1, 109.0 ± 8.8 bpm; R_0W_1, 104.7 ± 8.7 bpm) (Table 4.6), slightly elevated above values observed at the completion of phase A (Table 4.4). After 2 hours of wet-wind exposure (t_{380}), mean heart rate had steadily increased to 125.4 ± 13.1 bpm in R_1W_1, compared to a mean rate of 111.3 ± 9.6 bpm in R_0W_1 (Table 4.6). The 16.4 ± 5.3 bpm mean increase in R_1W_1 heart rate over the 2-hr exposure period ($t_{260-380}$) was significantly greater than the increase recorded for R_0W_1 (6.7 ± 1.7 bpm).

4.3.8. Sensory Evaluation Scales

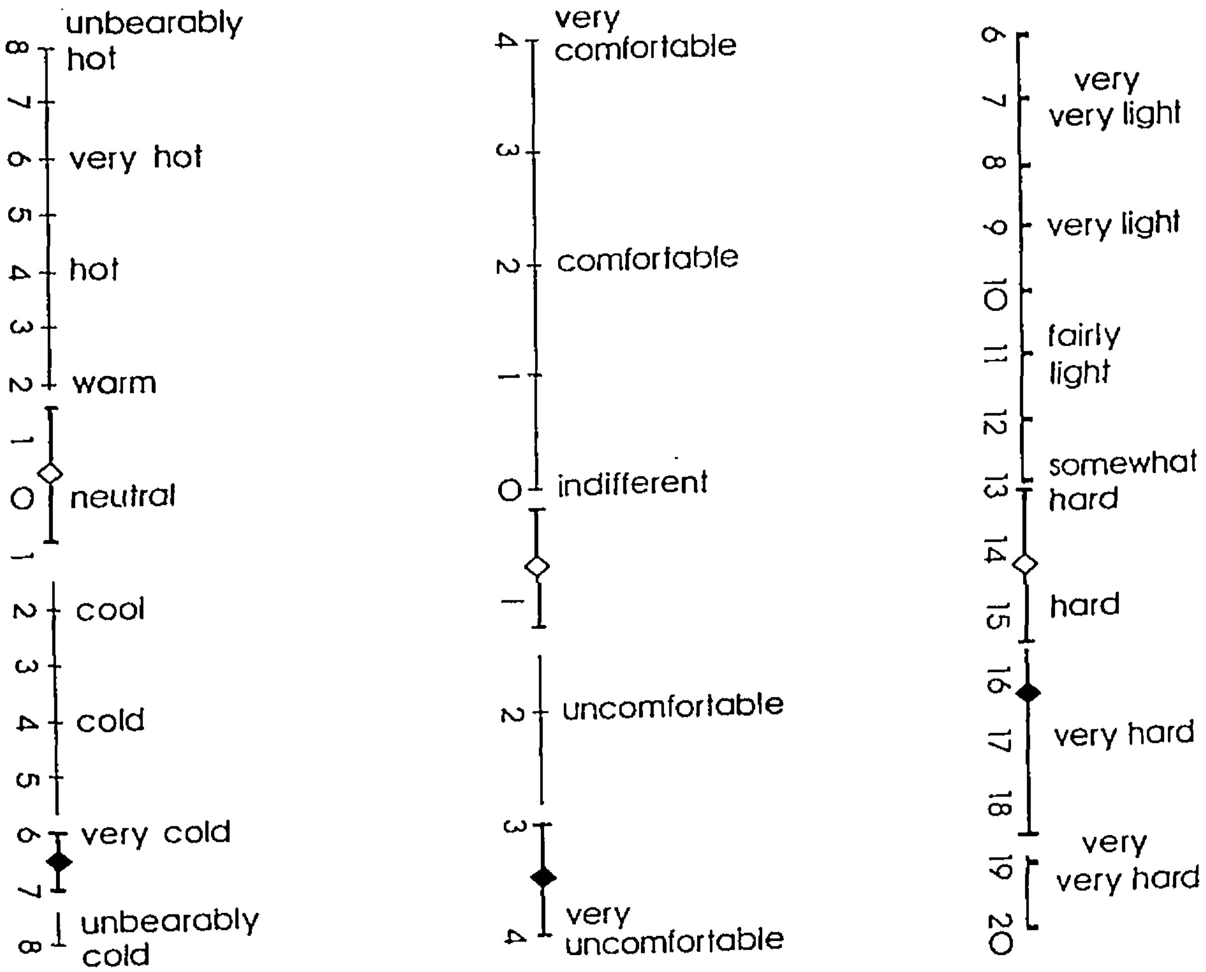
Changes in subject perception of events reflect physiological observations. While mean R_0W_1 ratings of thermal sensation and comfort are similar and stable in both phases A and B (Tables 4.5, 4.7), significant changes were recorded in R_1W_1 (Table 4.7). The wet-cold exposure group's rating of thermal sensation (RTS) at t_{380} averaged −6.5 ± 0.5, equivalent to a rating between "very cold" and "unbearably cold" (Fig 4.7); the mean thermal comfort rating dropped to −3.5 ± 0.5, close to the extreme negative end of the scale. The changes in perception of thermal status in R_1W_1 are significant for both scales.

No significant differences were observed between mean RPE ratings at t_{260}, or during the wet exposure (Table 4.7), based on overlap of standard deviations.

Table 4.7. Comparison of sensory scale responses between wet (R_1W_1) and dry (R_0W_1) groups (mean ± SD)

Scale	R_1W_1 (n = 4)	R_0W_1 (n = 3)
Rating of Perceived Exertion RPE		
RPE_{210}	11.0 ± 1.0	10.7 ± 1.7
RPE_{260}	12.8 ± 0.4	13.7 ± 0.9
RPE_{320}	14.5 ± 1.1	14.7 ± 1.7
RPE_{380}	16.3 ± 2.3	14.3 ± 1.2
Rating of Thermal Sensation (RTS)		
RTS_{200}	-2.0 ± 1.0	-3.0 ± 1.4
RTS_{260}	0.5 ± 1.1	2.0 ± 0.0
RTS_{320}	-4.5 ± 1.7	1.3 ± 0.9
RTS_{380}	-6.5 ± 0.5	0.3 ± 1.2
Rating of Thermal Comfort (RTC)		
RTC_{200}	-0.5 ± 0.5	-0.7 ± 0.9
RTC_{260}	0.5 ± 1.1	0.3 ± 1.2
RTC_{320}	-2.3 ± 0.4	0.3 ± 1.2
RTC_{380}	-3.5 ± 0.5	-0.7 ± 0.5

Fig. 4.7. Comparison of subject responses on sensory scales at t_{380} between wet (R_1W_1, closed diamond, n = 4) and dry (R_0W_1, open diamond, n = 3) groups (mean ± SD).


unbearably hot
very hot
hot
warm
neutral
cool
cold
very cold
unbearably cold
very comfortable
comfortable
indifferent
uncomfortable
very uncomfortable
very very light
very light
fairly light
somewhat hard
hard
very hard
very very hard

However, relative change in RPE over the 2-hour exposure period suggests a difference in perception may be hidden in the variance of R_1W_1 responses. In R_0W_1, 2 of the 3 subjects indicated a RPE rating increase of +1, with no change recorded in the third subject (RPE_{260} vs. RPE_{380}). In contrast, two of four R_1W_1 subjects indicated a rating change of at least +5 (13 to 18; 13 to 19); the other two subjects reported only a minor change (+1, +2). (S_{W5} gave an RPE rating of 20 at the end of his walk (t_{370}), an increase of +8.)

4.3.9. Vigilance Test

No significant performance differences were observed between groups during the first, pre-rain hour of the vigilance test (Table 4.8); subjects correctly reported 8 of 10 signal lights on average. Errors of commission were recorded for only two subjects [S_{W4} (7); S_{D1} (3)]. During the first hour of wetting, R_1W_1 subjects recorded significantly more errors of omission (less than 7 of 10 lights reported) than the R_0W_1 controls; again, errors of commission were unusual events [S_{W2} (1); S_{W4} (2); S_{D1} (1)]. The percentage of correct responses (95.8 ± 2.3%) decreased in R_1W_1, primarily due to the increased frequency of errors of omission. In contrast, the CR increased to 99.0 ± 1.0% in R_0W_1. [This CR difference is technically insignificant. The R_1W_1 standard deviation (± 2.3%) reflects a considerable EO range – only 1 EO was recorded for S_{W1}, and 6 for S_{W3}, for example. Inclusion of S_{W5-7} data for this time period reduces the mean CR to 95.4 ± 2.0% (n = 7).] In the third hour, a significant increase in the R_1W_1 error rate was observed (Fig. 4.8), concomitant with a significant reduction in the percentage of correct responses (Table 4.8). Error of commission frequency increased slightly in R_1W_1 subjects [S_{W1} (1); S_{W2} (1); S_{W2} (2)].

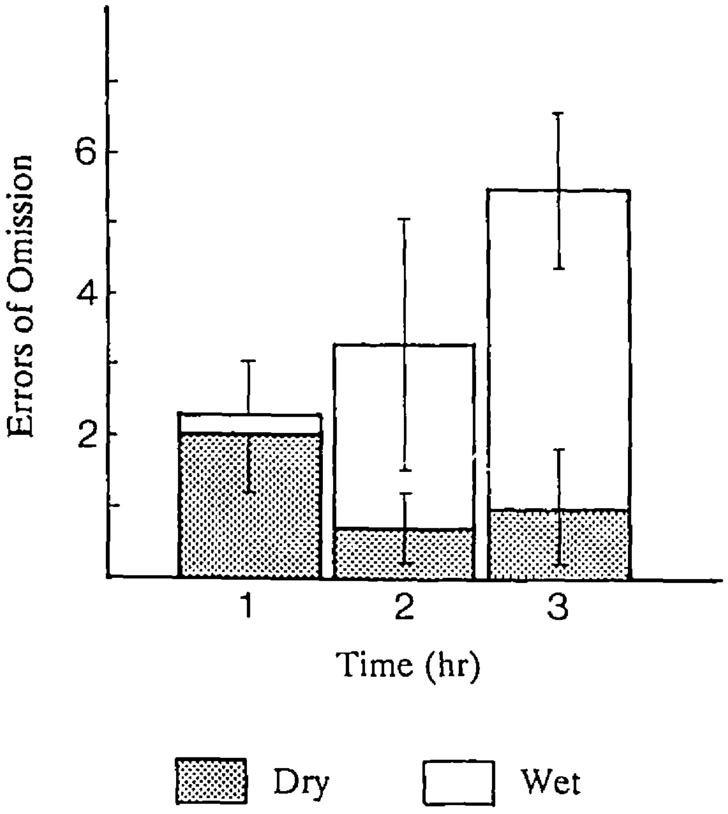
Table 4.8. Comparison of vigilance performance between wet (R_1W_1) and dry (R_0W_1) groups (mean ± SD)

Variable	R_1W_1 (n = 4)	R_0W_1 (n = 3)
Pre-rain hour ($t_{200-260}$)		
EO	2.3 ± 1.0	2.0 ± 1.0
EC	1.8 ± 3.5	1.0 ± 1.7
CR (%)	95.8 ± 4.4	96.8 ± 1.1
First Hour of Wet-Cold Stress ($t_{260-320}$)		
EO	3.3 ± 2.1	0.7 ± 0.6
EC	0.8 ± 1.0	0.3 ± 0.6
CR (%)	95.8 ± 2.3	99.0 ± 1.0
Second Hour of Wet-Cold Stress ($t_{320-380}$)		
EO	5.5 ± 1.3	1.0 ± 1.0
EC	1.3 ± 1.3	0.0 ± 0.0
CR (%)	93.0 ± 0.6	99.0 ± 1.0

EO = error of omission
EC = error of commission

CR = [# laps walked − Σ(EO + EC)]/(# laps walked) × 100

Fig. 4.8. Vigilance test errors of omission committed by wet (R_1W_1, n = 4, open area) and dry (R_0W_1, n = 3, shaded area) groups (mean ± SD).


Errors of Omission
2
4
6
1
2
3
Time (hr)
Dry
Wet

The three R_1W_1 subjects (S_{W5-7}) not included in the main analysis had vigilance performance scores similar to S_{W1-4} during their wet exposures, with the exception of S_{W7} in the pre-rain hour (5 EOs). S_{D4} (R_0W_1) was also not included in the primary analysis, as previously noted. The vigilance perfomance scores of this subject were unusually low – ten errors in the first hour (7 EO, 3 EC) and ten (6 EO, 4 EC) in the second and final hour of his walk. At the completion of his walk (t_{320}), this fit subject (54 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$) reported an RPE of 18 (beyond "very hard"), an RTS of −6 ("very cold") and RTC of −3 (towards "very uncomfortable"). The RPE was greater than any RPE reported by an R_1W_1 subject at t_{320}, and no subject in the latter condition reported thermal conditions any colder than S_{D4}.

4.3.10. Vigilance, Physiological Responses and Subjective Experience: Integrated Overview of Results.

The first hour of wet-cold exposure was characterized by rapid decreases in body surface temperatures, accompanied by significant increases in metabolic rate and ventilation rate (Table 4.9). As previously described, a significant rate of rectal temperature cooling began after 30 min of wetting (Fig. 4.4); during the first 30 min of wet exposure, T_{MS} decreased 5.8 ± 1.5°C as rectal temperature increased by 0.24 ± 0.19°C ($n = 4$). No significant vigilance performance decrements were observed in this initial period of exposure (only 2 of 7 R_1W_1 subjects had three or more EOs). Significant vigilance decrements (within R_1W_1) did not occur until the second hour of exposure, when surface temperatures had stabilized, and the rate of rectal temperature cooling had declined (Table 4.10). V_{O_2} and V_E reached their maximum towards the end of this period.

Changes in subjective rating of the wet-cold experience mirror changes in surface temperature. The most significant changes in this rating appear to occur

Table 4.9. Comparison of R_1W_1 physiological responses and subjective interpretations during the first ($t_{260-320}$) and second ($t_{320-380}$) hours of rain and wind exposure (n = 4, unless otherwise indicated)

Variable	t_{260}	$t_{260-320}$	$t_{320-380}$
Physiological Responses			
ΔT_{Re} (°C)		-0.3 ± 0.2	-0.5 ± 0.1
ΔT_{MS} (°C)		-7.7 ± 1.0	+0.3 ± 1.1
ΔT_H (°C)		-8.9 ± 1.8	-0.6 ± 0.5
MR ($W \cdot kg^{-1}$)[1]	6.1 ± 0.3	9.3 ± 1.0	10.5 ± 1.8
V_E ($l \cdot min^{-1}$)[2]	29.5 ± 2.4	44.4 ± 4.3	56.5 ± 0.8
Subjective Interpretation[3]			
RPE	12.8 ± 0.4	14.5 ± 1.3	16.3 ± 2.6
RTS	0.5 ± 1.1	-4.5 ± 1.9	-6.5 ± 0.6
RTC	0.5 ± 1.1	-2.3 ± 0.5	-3.5 ± 0.6

[1] Mean values at end of period (t_{320}; t_{380}); (n = 2)
[2] $t_{260-320}$ value at t_{330} (n = 3); t_{380} (n = 2)
[3] Recorded at end of period (t_{320}, t_{380})

Table 4.10. Errors of omission committed by R_1W_1 subjects during 30 min intervals (5 signals/30 min)

Time Interval	Subject				
	S_{W1}	S_{W2}	S_{W3}	S_{W4}	Mean ± SD
$t_{200-230}$	1	1	2	2	1.5 ± 0.5
$t_{231-260}$	1	0	1	1	0.8 ± 0.4
$t_{261-290}$	0	1	4	2	1.8 ± 1.5
$t_{291-320}$	1	2	2	1	1.5 ± 0.5
$t_{321-350}$	2	3	4	1	2.1 ± 1.1
$t_{351-380}$	3	3	3	3	3.0

during the initial hour of cooling; the lowest absolute mean thermal ratings are given at the end of the second hour of exposure (Table 4.9).

4.4 Discussion

The observed increase in vigilance error-rate over time with prolonged wet-cold exposure was consistent with generalized predictions, that attention to environmental cues would be reduced in subjects exercising in rain and wind. It was postulated that vigilance reduction was associated with generalized cold distraction (Teichner 1958; Vaughan 1977), and *Wet Walk*-specific behaviours, including spontaneous, active mental distraction processes, and inattentiveness to the surrounding environment: subjects typically looked down towards the ground as the walked along the track.

Significant increases in error rate were not immediate, however. Despite rapid cooling of the skin surface, no significant increases in error rate occurred in the first 30 minutes of wetting. Consistently higher error rates did not occur until the second hour of exposure, when skin temperature had stabilized at low levels and core temperature continued to decrease, although at a reduced rate.

If reduced vigilance is primarily associated with cold distraction, then a rapidly-cooling skin surface would be expected to cause accelerated error-rates. However, it should also be noted that high error rates were associated with steady but low levels of skin temperature (near 20°C).

Cold distraction is possibly only one aspect of the problem, since there was no significant cold effect on a simple vigilance tasks over a short-term exposure. Fatigue and boredom are other possible factors, since the increase in error-rate occurred with time. Boredom or monotony may be ruled out on the grounds that subjects in dry walks showed no decrease in performance, although a general vigilance decrement is common over time. Vigilance decrement, a progressive decline in vigilance performance over time (Warm 1984), is a common finding in vigilance research; no such decline was observed in dry walks. This would suggest that moderate levels of fatigue were not a contributing factor. However, the level of fatigue experienced by subjects in wet conditions, based on subjective evaluation, was significantly greater than that observed in the dry subjects.

The low error of commission rate suggests that signal discrimination was not a contributing factor in decreased performance. Only one subject (S_{W4}) showed any significant "guessing"; significant differences in error rate between dry and wet conditions were solely attributable to errors of omission.

One interesting aspect of this study was the change in behaviour initiated by the introduction of a vigilance test. The test was initially included to measure a specific behaviour (reduced vigilance). However, the non-vigilant behaviour was replaced by active attention to the environment in the presence of a vigilance task. [The eventual test was modified to reflect the original behaviour, by increasing the difficulty of identifying a signal, and by reducing the frequency of events, factors that tend to reduce vigilance scores (Davies and Tune 1970)]. Therefore, the question arises: were subjects vigilant when attention was required, but assume a non-vigilant state when no attention-demanding activity was present? This might be true for relatively high-frequency, low-difficulty tasks, as was the case for the initial test structure, and during the early stages of wet-cold exposure. However, an increase in significance of error-rate over time suggests that cold and/or other factors override this possibility. Nonetheless, the definition of "reduced vigilance" in this experiment must be carefully defined, since vigilance was apparently enhanced under the original circumstances.

Changes in rectal temperature in response to wet-cold were similar in EXP_2 (Fig. 3.4) and EXP_3 (Fig. 4.4). However, although no immediate effects of fatigue were noted, it was my impression that the EXP_3 subjects were significantly more fatigued than EXP_2 subjects after 2 hours of wet-cold exposure, as previously stated. RPE ratings are not significantly different, although the tendency was for higher ratings in the EXP_3 group (EXP_3 subjects were more fit individuals on average). This demonstrates the general effectiveness of additional exercise time on the *potential* for progression into hypothermia in this experiment, but unfortunately offers no direct evidence. However, it supports the notion that progression into hypothermia with exhaustion may occur relatively rapidly, as in S_{W7} in EXP_2, without significant, discernible, pre-hypothermic differences in regulation of core temperature. As long as a constant exercise rate is maintained, and fatigue is not sufficient to interfere with shivering, then similar stabilization curves should be observed. It might be that R_1W_1, EXP_3 subjects would have shown S_{W7}-like thermal behaviour with increased exposure and exercise time (although there is no evidence for this).

Furthermore, it is interesting to note that concomitant with a greater indication of fatigue, was an apparent elevation in the rating of cold distress by EXP_3 subjects (−6.5 ± 0.5) over that of EXP_2 R_1W_1 subjects (−3.4 ± 1.7, n = 5) after 2 hours of wet-cold; ambient temperatures were not significantly different between these groups. If perception of cold is moderated by fatigue, then this observation might lend indirect support to the idea that hypothermia symptoms are *not* symptoms of a cold core temperature *per se*, but symptoms of exhaustion. Are the symptoms of exhaustion confused with those of hypothermia because they occur conjointly in a cold environment? In a thermally comfortable environment, some of these responses (dizziness, nausea) are indicative of exhaustion, with no reference to hypothermia.

In summary, subjects exercising in rain and wind at ambient temperatures near 5°C, without protection from waterproof clothing, demonstrated a significant decrement in vigilance performance. The decrement in attention was associated with reduced mean skin temperature (about 20°C) and increased metabolic rate (+45%), concomitant with shivering. However, rectal temperature was close to normal, resting levels (37°C), although a significant decline had occurred from an elevated, exercise-induced rectal temperature of about 37.6°C. Reduced attention to the environment may have significant, and fatal, consequences for individuals exposed to these conditions during participation in outdoor activites. This situation may be even more pronounced in miltary conflicts in wet-cold conditions (McCaig and Gooderson 1986).

Chapter 5. SUMMARY

These three experiments were conducted in order to investigate hypothermia in humans, caused by prolonged exposure to rain, wind, and cold. Current interpretations of wet-cold exposure hypothermia (Maclean and Emslie-Smith 1977; Kaufman 1983; Lloyd 1986) are largely based on the results of a single study (Pugh 1967), part of a series of papers on exposure hypothermia (Pugh 1964, 1966a, 1966b, 1967, 1969) stimulated by the tragic deaths of three youths during the Four Inns walking competition (Pugh 1964). This limited experimental database is supplemented by anecdotal descriptions of exposure accidents (Pugh 1964, 1966a; Kreider 1967; Strang 1969; Hunter 1968; Ogilvie 1977).

The primary objective was to induce hypothermia ($T_{CORE} \leq 35°C$) in subjects exercising in these conditions, and to determine if hypothermia was a consequence of exhaustion. Secondarily, measures of motor and psychological performance were included to study the relationship between prolonged wet, cold exposure and changes in behaviour. Lightly-clothed male subjects walked along a simulated hiking trail (*Wet Walk*) at a constant pace, exposed to continuous "rain" and, later "wind", for up to 4 hours at air temperatures near 5°C. Thermal and metabolic responses were monitored continuously during a trial exposure, as well as respiratory rate and heart rate. Tests of motor and behavioural performance were completed at specific intervals.

The first experiment (EXP_1) was designed to compare thermal and metabolic adjustments to wet-cold exposure at different exercise levels (walking paces), ranging from 0 (sitting) to 6 $km \cdot hr^{-1}$. Before, during, and after exposure, a set of four cognitive tests (*PETER*) was administered to subjects as a means of evaluating changes in cognitive performance with progressive body cooling.

During 2.5 hours of walking in rain, and a further hour of sitting in wet clothing in the cold, not one case of clinically-defined hypothermia was observed in 27 wet-cold exposures. Only one subject had a rectal temperature below 36°C at the end of the walking phase of the experiment (35.6°C). Only 4 of 23 subjects ended this phase of the experiment with rectal temperatures below 36.5°C. Four other subjects sat in rain for the same period of time, with similar non-hypothermic results: only 1 of these four subjects ended the rain phase of the experiment with a rectal temperature below 36°C (35.9°C).

Prior to rain exposure, rectal temperatures were significantly different between the P_0 (sitting), intermediate-pace (P_L, P_M) and the high pace (P_H) groups after 45 minutes of exercise. However, after approximately 2.5 hours of rain, differences in rectal temperature between the pace groups were not significant, suggesting no thermal advantage to exercise, relative to the duration and severity of experimental conditions. Significant relative increases in metabolic rate were observed in the exercising groups during wet-cold exposure, concomitant with visible shivering. An undefined amount of the metabolic rate increase was also attributed to increased work associated the increased weight of wet clothing and boots.

The absence of hypothermia under these conditions was unexpected, particularly given behavioural indications suggestive of hypothermia - including intense shivering, reduction in motor abilities and mood depression - according to descriptions of hypothermia symptoms found in popular outdoor-recreation magazines (Del Guercio 1989) and medically-related texts (Maclean and Emslie-Smith 1977).

Decrements in cognitive performance were reported on three of four cognitive tests. The observed decrements, however, were restricted to the number of attempted respsonses: there were no changes in accuracy score. The decline in performance was largely attributed to cold distraction effects (Teichner 1958; Vaughan 1977). However, most subjects suffered significant dexterity impairment, to the point where some subjects required the use of both hands to manipulate the pencil. In conjunction with a reduction in mechanical efficiency due to interference from shivering (Kissen et al. 1964), performance decrements may also be explained as a result of slower writing capabilities.

In the following experiment (EXP$_2$), the duration of wet-cold exposure was increased (4 hours), and wind was included as a factor, in order to increase the probability of inducing hypothermia. More attention was given to behavioural responses: tests of motor performance, such as grip strength and manual dexterity, and additional objective measures of psychological response, were included in the design.

Only 5 of 18 subjects were able to complete the established protocol. However, only 2 of the 13 incomplete walks were terminated due to the direct effects to hypothermia. Three subjects exhibited rectal temperatures near the clinical level of hypothermia, two in association with exhaustion. In the primary case, a sudden decline in rectal temperature began after 3 hours of wet, cold exposure, concomitant with decreased oxygen consumption despite a constant walking pace: rectal temperature dropped 1.4°C to 35.3°C in less than 30 minutes. Signs of exhaustion (staggering, faintness, nausea) were evident. A second exhaustion-related case occurred in a subject during the sitting phase of the experiment, about 1 hour after he had completed 4 hours of walking in wind and rain. In both cases, subjects reported that they felt more tired than cold, significantly before hypothermia occurred. The results also suggested that cold tolerance, the ability to maintain prolonged activity in wet-cold, was related to aerobic fitness and somatotype. For example, a low-fitness, ectomorphic subject, whose relative heat production decreased as his walking pace slowed, developed hypothermia (rectal temperature 35.2°C) while walking.

Decrements were observed in the two reported performance tests: grip strength was reduced to less than 70% normal, and manual dexterity, to less than 50% normal. These decrements were associated with with significant decreases in surface body temperatures (mean skin and hand temperature). However, performance decrements were also observed in association with near-normal rectal temperatures (near 37°C), although a significant decline had occurred from an elevated, exercise-induced rectal temperature (38°C). As in EXP_1, shivering was visible in subjects with core temperatures above or near 37°C, suggesting, along with other observed changes in behavior, that there are discrepancies between popular conceptions of "hypothermia" signs and symptons, and the reality of physiological potential.

The results of this experiment, therefore, supported the concepts that: (a) wet-cold exposure hypothermia is associated with exhaustion, and (b) cold-induced impairment in motor function under these conditions is primarily associated with the effects of peripheral cooling, a stage defined by Vanggaard (1975) as the "wet-cold syndrome". The data were particularly significant in providing experimental evidence for the predicted relationship between the signs of hypothermia (stumbling, reduced shivering), exhaustion (reduced oxygen consumption) and progression into hypothermia.

In the final experiment (EXP$_3$), a test of vigilance was designed and incorporated into the experimental design. The test required that a subject detect randomly-occurring light signals as he walked along the *Wet Walk*. Based on previous observations, a decline in vigilance efficiency was expected. The pre-rain exercise period was increased from 1 to 4 hr, in order to study the effects of enhanced fatigue on cooling rate.

Subjects exercising in rain and wind at ambient temperatures near 5°C demonstrated a significant decrement in vigilance performance. The decrement in attention was associated with reduced mean skin temperature (about 20°C) and increased metabolic rate (+45%), concomitant with shivering. However, rectal temperatures were close to normal, resting levels (37°C), although a significant decline had occurred from an elevated, exercise-induced rectal temperature, as in EXP$_2$. It was suggested that reduced attention to the environment may have significant, and fatal, consequences for individuals exposed to these conditions, if reduced vigilance affects hazard perception or other attention-dependent survival behaviour.

No cases of clinical hypothermia were observed during the two hours of wet-cold exposure in this experiment. Subjects appeared more fatigued and colder than in EXP$_2$ after a similar wet-cold exposure period, based on subject evaluation scales. However, no significant differences were observed in respect to the major physiological measurements.

The results show that wet, cold exposure is characterized by two stages:

(1) An initial, prolonged phase, referred to as the wet-cold exposure syndrome (Vanggaard 1975), is characterized by intense shivering (30-50% increase in oxygen consumption) and behavioural responses associated with the effects of peripheral

cooling. *Wet Walk* subjects often exhibited signs and symptoms of "hypothermia" within 2 hours of wet, cold exposure, but rectal temperature was typically maintained above 36°C. Nonetheless, individuals may be incapacitated at core temperatures near, or in fact above, normal core body temperature, due to cold-related injuries, or other distress, which may in turn lead to hypothermia through reduced heat production.

(2) Rapid descent towards clinical hypothermia is associated with decreased heat production due to exhaustion. The symptoms of exhaustion, however, may not occur until thermal balance has been lost, and the individual is near a state of collapse. Hypothermia may also occur in individuals independent of exhaustion, if they exhibit traditional, cold-susceptible factors, such as low body fat or low fitness, in concert with extreme behavioural responses. However, these cases are considered unusual.

The overall conclusion from this study is that prolonged wet, cold exposure of humans produces significant cold stress as evidenced by thermoregulatory, psychological and motor responses, but does not produce significant hypothermia in the absence of exhaustion. Moreover, it would appear that analysis and interpretation of "man in wet-cold" should not be restricted or isolated strictly within the bounds of the hypothermia paradigm. Recently, Golden stated that there has been an over-emphasis on hypothermia during cold water immersion, and now recognizes hypothermia as one aspect of an overall problem (Allaway 1987). Therefore, it would be appropriate for future research on human performance in wet-cold to consider an integrated approach, interpreting behavioural responses in relation to the physiological potential for survival in the wet-cold environment.

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APPENDIX A. THE *WET WALK*

A1. Construction Details

A2. Layout of the *Wet Walk*

A3. Elevation Data

A4. Rainfall

A5. Windspeed

Appendix A1. Construction Details

A photograph of the *Wet Walk* under construction (Fig. A1.1) shows the general features of the arch framework. The framework was constructed of 18-mm EMT conduit (commonly used for carrying electrical cables in buildings); conduit was considered the most economical building material for this project. The dimensions of the *Wet Walk* framework were influenced in part by the fact that the conduit came in 10-ft (3.05 m) lengths (1980). The arches were connected in series by lengths of 1 × 2-in fir strapping at the arch apices, and by straight lengths of 18-mm conduit at the level of the lower arch angle. These components were bolted together using 3 × 25-mm steel strapping brackets. The system was made of two types of arch structure: straightaway or standard arches in the narrow central pathway, and the arches of the expanded turnabout areas. The height of the arch components was increased by adding 150-cm lengths of conduit.

Lengths of 1 × 1-in fir were bolted to the outside edges of the upper framework, providing a stapling surface for the plasticized nylon tarp. The tarp was supplied in 1.8-m widths; it was folded and stapled together along the apex stringers, continuing in a single piece from the west to east turnabout. The covering was stapled down as far as the lateral conduit supports, the remainder remaining free for additional protection from ambient rain or wind when required.

To fix the arches in position, 60-cm lengths of reinforcing rod were driven into the ground at the arch position. The hollow conduit slid over the rod, preventing any lateral movement.

Fig. A1.1. The *Wet Walk* framework under construction (photograph taken from the position of the canvas tent).

Figs. A1.2 – A1.5. The straightaway arch framework.

Fig. A1.2. Standard arch unit. The basic straightaway arch unit was made from a single 3-m length of 18-mm EMT conduit, using a pipe bender and a reference jig. The design was based on a 120-cm-wide arch, with a 60-cm rise at the center.

Fig. A1.3. Standard arch with 150-cm riser. An arch unit was completed with the addition of 150-cm lengths of conduit, joined to the standard arch unit with straight couplers. During *Wet Walk* construction, the arch units were completely laid out before the 150-cm risers were added (see Fig. A1.1). Note the position of the sprinkler (s). Also shown: (a) arch-connecting conduit in cross section; (b) 3-mm steel strapping bracket; (c) conduit straight connector.

Fig. A1.4. Straightaway arch framework (top view). The arches were linked by a length of 1 × 2-in fir strapping at the peak, and by lengths of 18-mm conduit at the level of the 135° angle. These were connected to the arches and adjacent connections with pieces of 3-mm steel strapping; the strapping could be bent to accomodate turns and slope changes in the *Wet Walk*. Note that the lengths of the connecting pieces were variable, depending on arch position.

Fig. A1.5. Straightaway arch framework (side view). Lengths of 1 × 1-in fir (approx. 60 cm) were bolted to the outside edges of the arch framework as a base for stapling the orange polyweave plastic tarp (wood grain pattern).

KEY: 1 × 2-in fir strapping = stippled areas
1 × 1-in fir stapling strips = woodgrain pattern
steel brackets = dark screen (flat) or line (on edge)

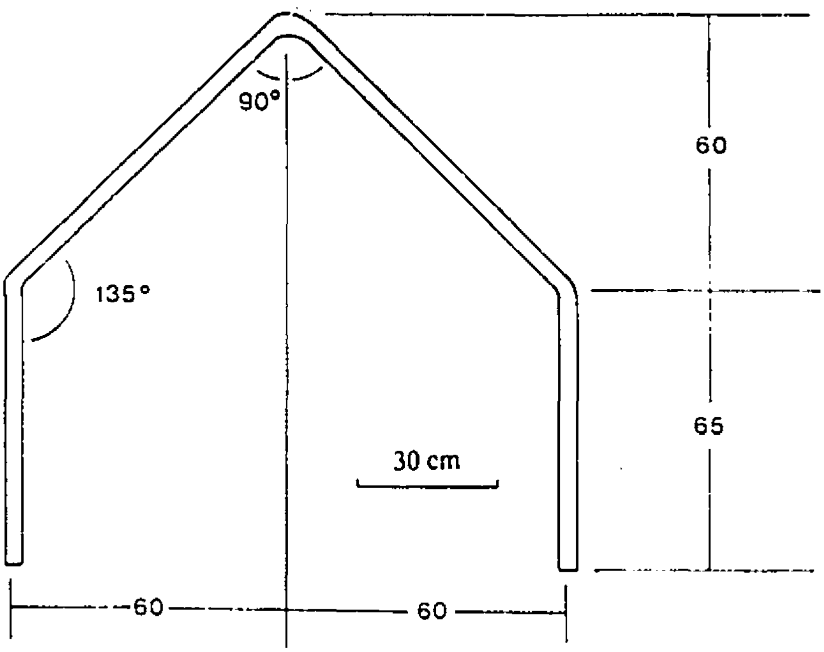


Fig. A1.2. Standard arch unit.

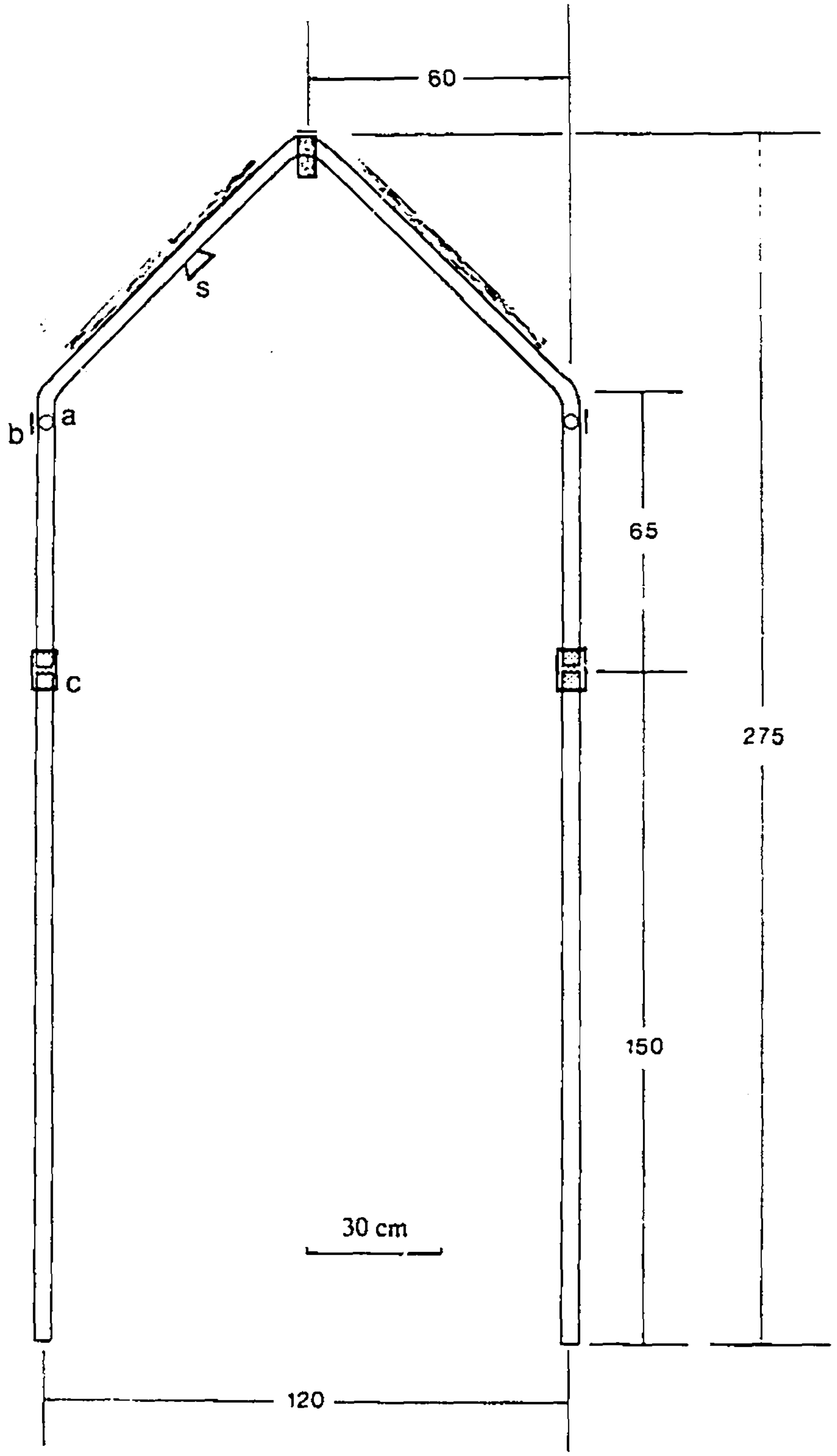


Fig. A1.3. Standard arch with 5' riser.

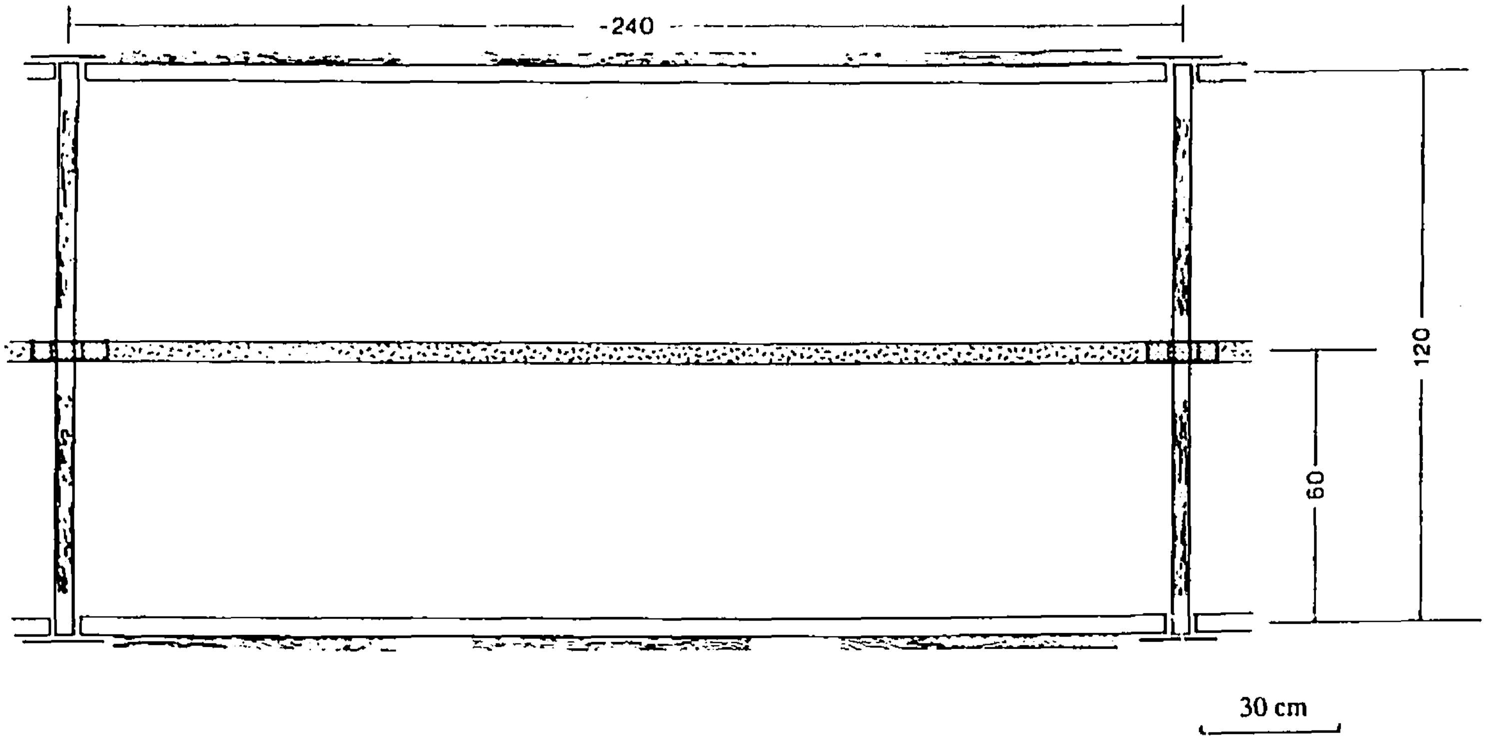


Fig. A1.4. Straightaway arch framework (top view).

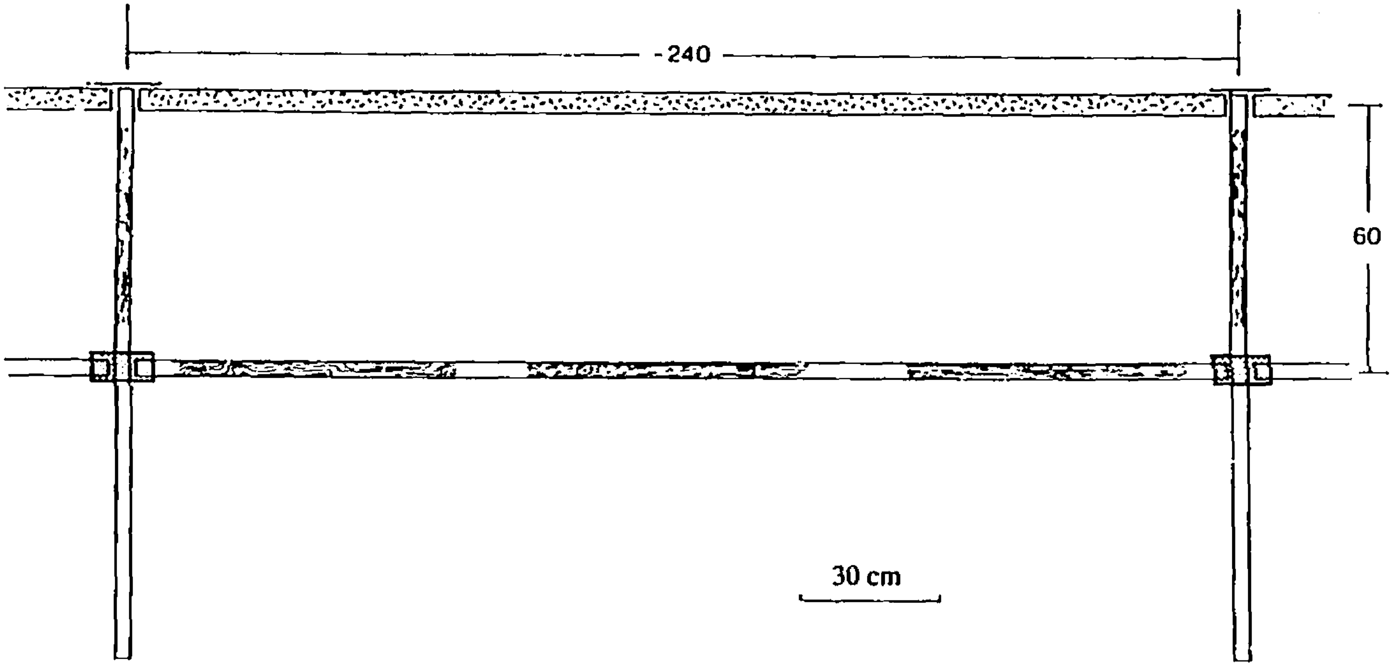


Fig. A1.5. Straightaway arch framework (side view).

Figs. A1.6 – A1.9. The turnabout arch framework.

Fig. A1.6. Turnabout arch unit. The basic turnabout arch unit was constructed from a 3-m length of 18-mm EMT conduit bent at two locations. A jig similar to that used for the straightaway arch was built to help bend the archway. A complete arch required two pieces, connected at the peak of the turnabout with a 3-mm steel bracket (Fig. A1.9). The lower angle of 135° corresponds to a similar angle in the straightaway arch. A second angle of 150° was added to increase the slope of the roof, increasing water and snow sloughing.

Fig. A1.7. Turnabout arch framework (top view). The width of the turnabout area expanded to 240 cm from the 120-cm-wide straightaway track, by adding 60 cm to each side; the turnabout was approximately 300 cm long. Each (2) turnabout arch was made of two basic turnabout arch units joined at the peak by 3-mm steel strapping (see Fig. A1.9). These were linked by a 180-cm lengths of 1 × 2-in fir strapping, similar to the straightaway arches. Lengths of fir strapping were also added at the 150° bends. The outside end of the turnabout was formed by a standard arch, and linked to the peak of the expanded portion by a short length of fir strapping; the straightaway arch was connected to the turnabout peak in a similar fashion.

Fig. A1.8. Turnabout arch framework (side view). Note the 16-cm elevation of the turnabout roof.

Fig. A1.9. Turnabout arch framework (end view). The standard arch on the outside end has a brace added at the level of the 135° bend. Note the position of the fir strapping in the turnabout roof at the 150° angles.

KEY: 1 × 2-in fir strapping = stippled areas
1 × 1-in fir stapling strips = woodgrain pattern
steel brackets = dark screen (flat) or line (on edge)

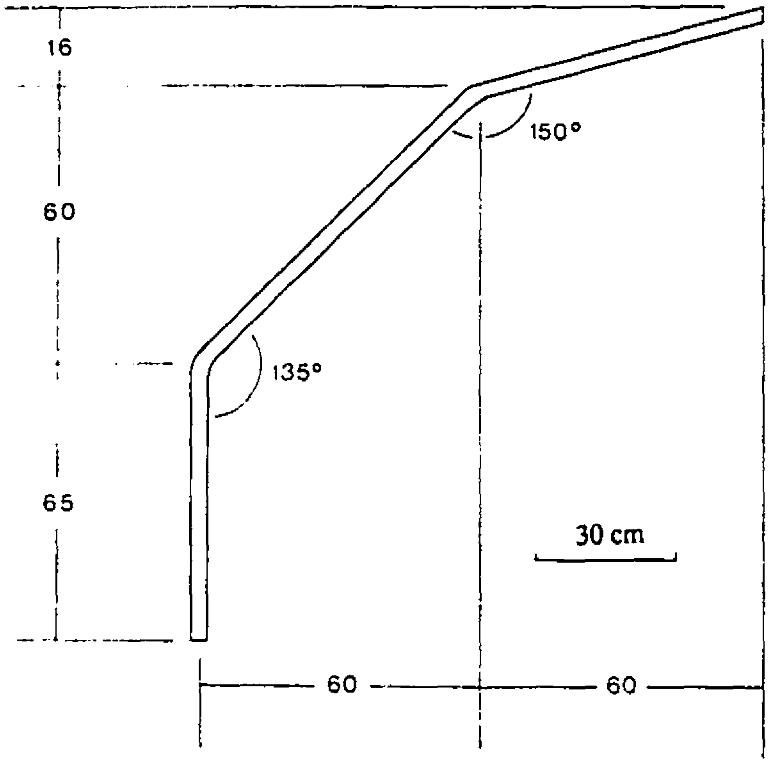


Fig. A1.6. Turnabout arch unit.

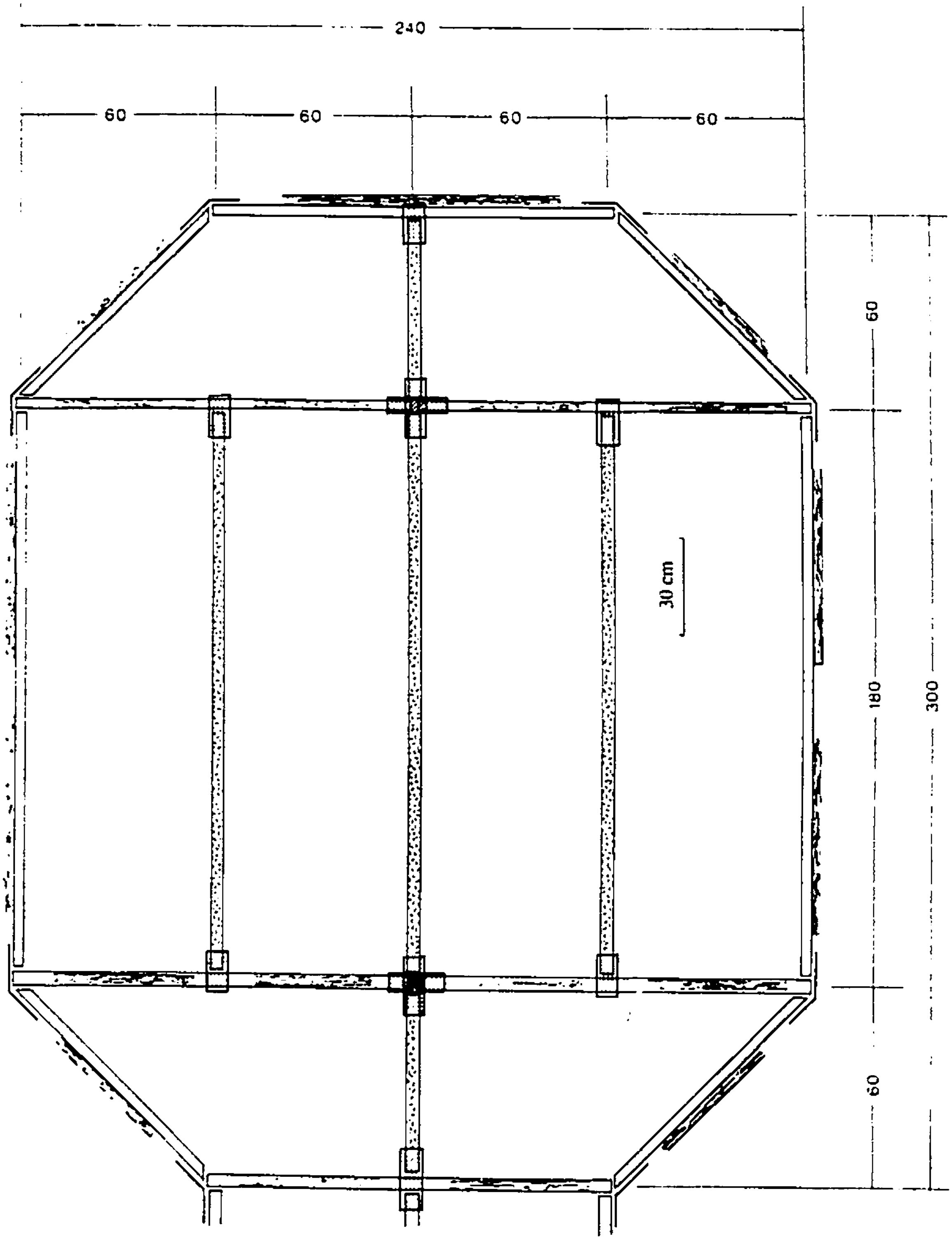


Fig. A1.7. Turnabout arch framework (top view).

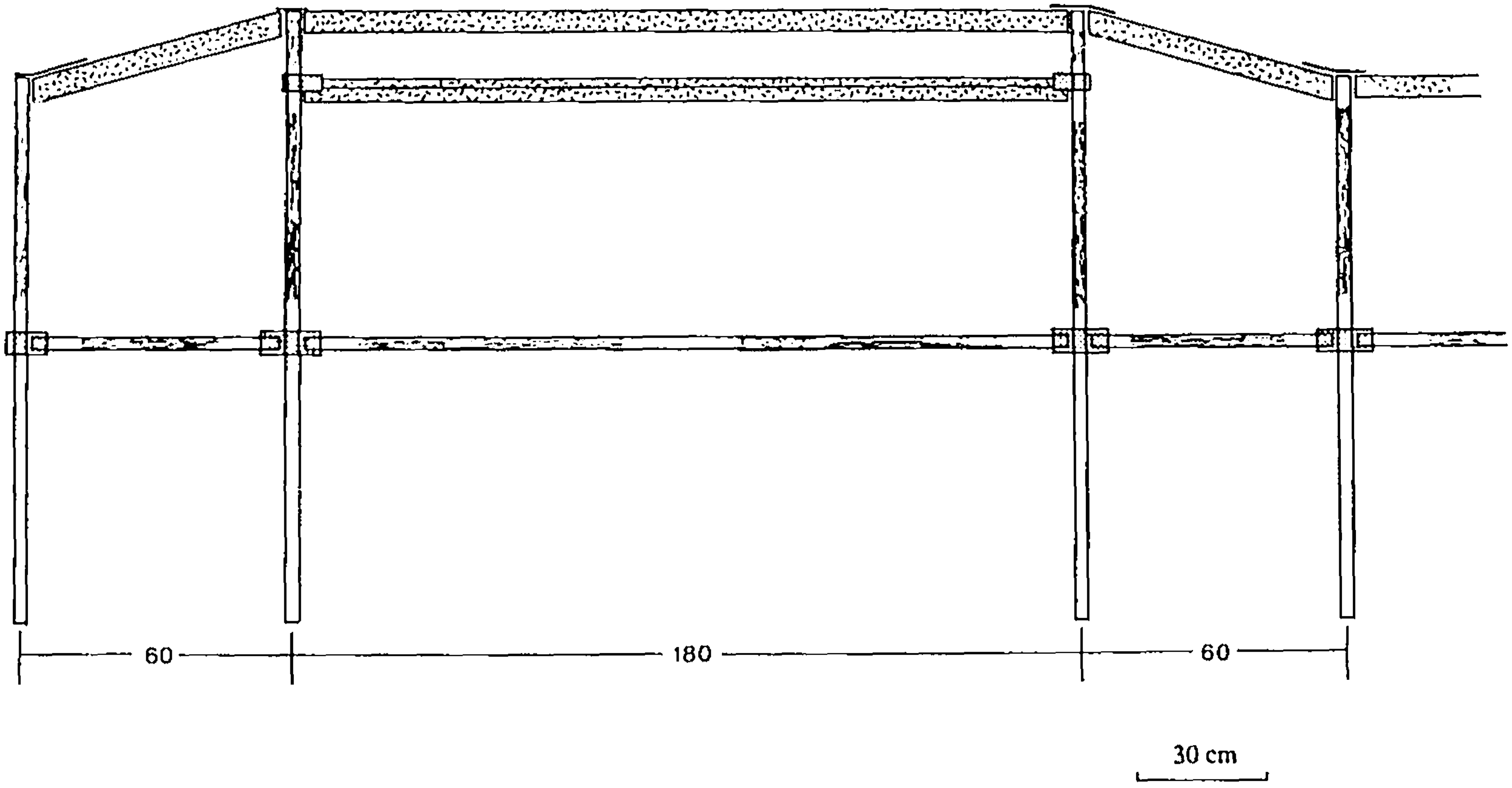


Fig. A1.8. Turnabout arch framework (side view).

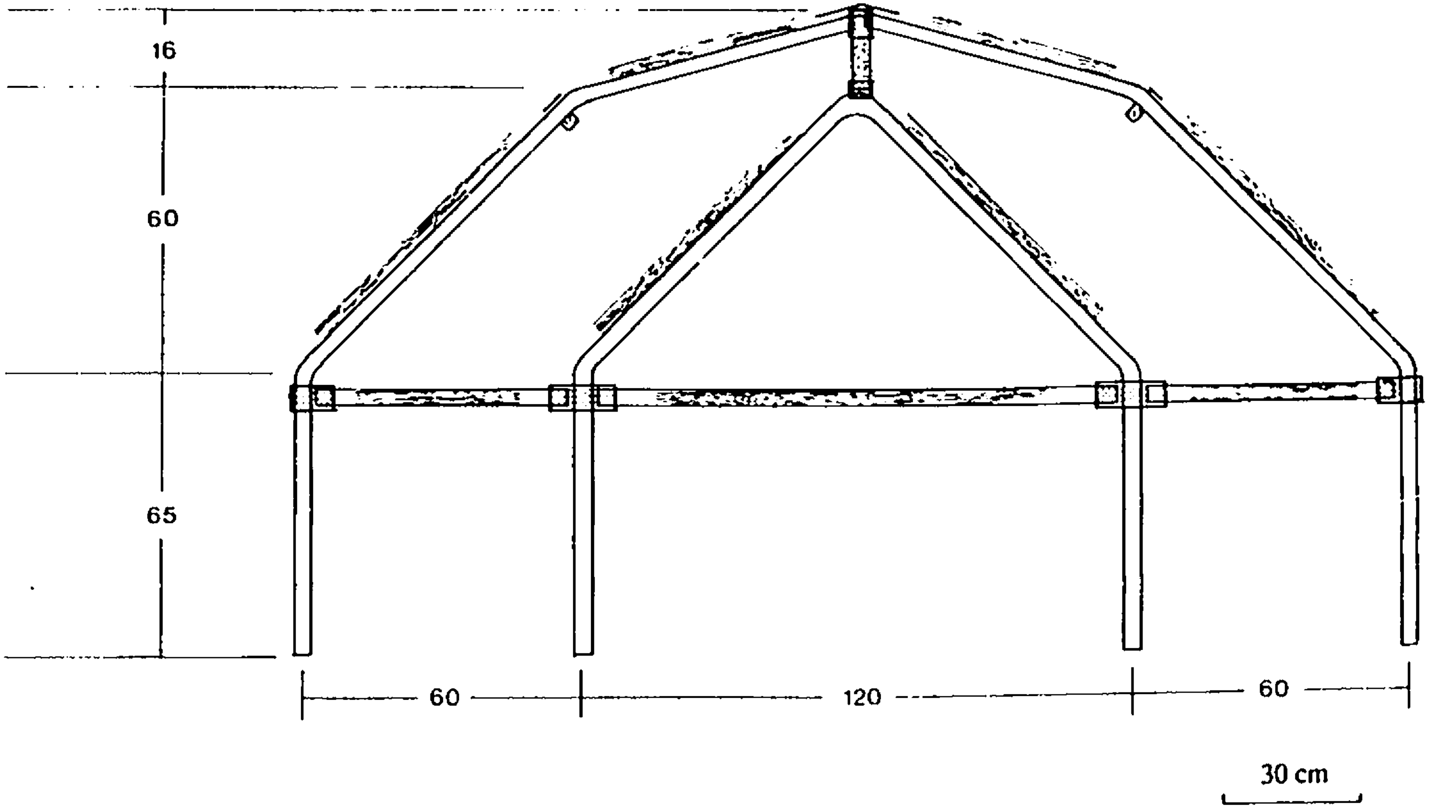


Fig. A1.9. Turnabout arch framework (end view).

Appendix A2. Layout of the *Wet Walk*

Fig. A2.1. Plan of the *Wet Walk*. Layout of the arches on a 1-m grid. The position of the arches was determined by triangulation to fixed points, and translated to the grid. The layout of the *Wet Walk* in Fig. 1.3 is based on this figure. The arches were numbered consecutively from A_1 (east end) to A_{15} (west end); the track midpoint is at A_8. (a) East end of the *Wet Walk*; (b) west end of the track. Arch A_9 is a common reference point in both figures.

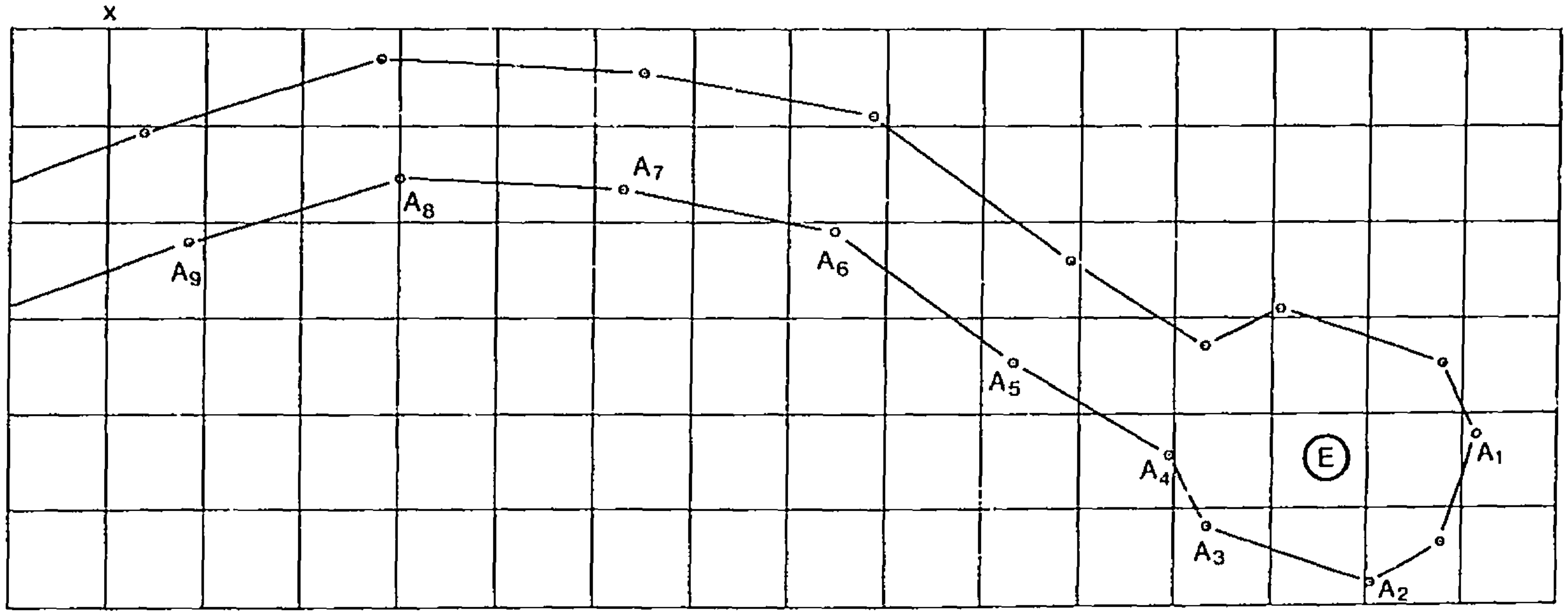


Fig. A2.1a. Plan of the *Wet Walk* (east end).

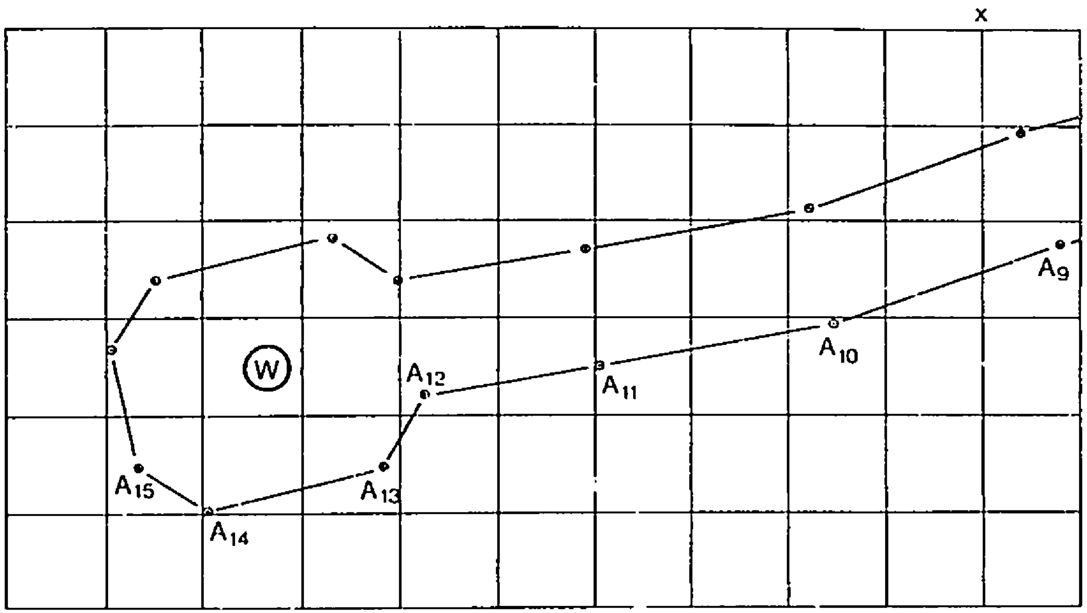


Fig. A2.1b. Plan of the *Wet Walk* (west end).

Appendix A3. Elevation Data

Elevation was calculated by fixing a level line between two successive arches on the south side, and measuring difference in height from the point on each arch to ground level at that arch. These values were adjusted relative to the elevation of A_1, arbitrarily set at 0 m. The distances between arches were measured and slopes calculated for progressive arches, moving from the east to west end of the *Wet Walk* (Table A3.1).

Table A3.1. Elevation data for *Wet Walk*

Arch	Height (cm)	Change (cm)	Distance (m)	Slope (cm/m)
A_1	0			
A_4	-3	-3	3.05	-1.0
A_5	-2	+1	1.96	+0.5
A_6	9	+11	2.29	+4.8
A_7	13	+4	2.26	+1.8
A_8	22	+9	2.39	+3.8
A_9	20	-2	2.33	-0.9
A_{10}	30	+10	2.46	+4.1
A_{11}	54	+24	2.52	+9.5
A_{12}	73	+19	1.76	+10.8
A_{13}	104	+31	3.05	+10.2

Arch: Refer to Fig. A2.1
Height: Elevation relative to A_1 (0 m)
Change: Change in elevation between arches (i.e., $A_8 - A_7$)
Distance: Horizontal distance between arches (i.e., $A_8 - A_7$)
Slope: Rate of change of elevation between successive arches (Change/Distance)

Note: Track midpoint = A_8

Appendix A4. Rainfall

Table A4.1. Sample ambulatory rainfall measurements along center of *Wet Walk* (mean ± SD, n = 5)

Sample	Rain (in)	Time (min)	Rate (in/hr)	(cm/hr)
1	1.13	30.25	2.23	5.67
2	1.60	30.28	3.17	8.05
3	1.50	30.35	2.97	7.53
4	1.53	30.15	3.03	7.71
5	1.58	29.95	3.16	8.01
Mean ± SD				7.39 ± 0.99

Appendix A5. Windspeed

Elevation of Fans (mean ± SD, n = 4): 58.5 ± 1.9 cm

Table A5.1. Sample windspeeds along *Wet Walk* measured at a height of 1.5 m (mean ± SD, n = 3)

Arch	m/sec	km/hr
A_1	3.85 ± 0.21	13.87 ± 0.77
A_2	4.33 ± 0.35	15.60 ± 1.28
A_3	3.16 ± 0.08	11.36 ± 0.29
A_4	2.94 ± 0.22	10.57 ± 0.78
A_5	2.08 ± 0.10	7.48 ± 0.36
A_6	2.38 ± 0.18	8.58 ± 0.66
A_7	1.66 ± 0.07	5.98 ± 0.26
A_8	2.00 ± 0.17	7.22 ± 0.61
A_9	2.79 ± 0.22	10.04 ± 0.79
A_{10}	1.63 ± 0.04	5.86 ± 0.16
A_{11}	1.71 ± 0.02	6.14 ± 0.06
A_{12}	2.75 ± 0.06	9.89 ± 0.23
A_{13}	3.10 ± 0.30	11.18 ± 1.06
A_{14}	3.93 ± 0.15	14.15 ± 0.53
A_{15}	3.91 ± 0.18	14.09 ± 0.65

APPENDIX B. WALKING DISTANCE AND RELATED FACTORS

B1. Walking Distance EXP_1

B2. Walking Pace Pilot Study

B3. Lap Pacer

B4. Walking Distance EXP_2

B5. Walking Distance EXP_3

Appendix B1. Walking Distance EXP_1

The distance walked by subjects during the exercise phase of this experiment can be estimated by application of a simple equation:

(1) calculation of the number of laps walked within a 5-minute data-recording period, based on time required for completion of a lap (50 m) at a given pace;
(2) summation of laps walked during a given time period; and (3) multiplication of the number of laps walked by .05 km.

This net value represents a predicted maximum walking distance, and does not take into account unpredicted or prolonged stops during individual experimental sessions. It therefore represents a comparative walking distance value.

The number of laps (Table B1.1) and cumulative distances walked (Table B1.2) were calculated tor each pace.

Table B1.1. Estimated number of laps walked per time period during exercise phase of EXP_1 as a function of pace

	Walking Pace (km/hr)			
Time (min)	0	3.0	4.5	6.0
0 - 45	0	42	63	84
45 - 90	0	42	63	84
100 - 150	0	47	70	94
160 - 210	0	47	70	94
Total	0	178	266	356

Table B1.2. Cumulative distance (km) walked during a 3.5-hour exposure as a function of pace (EXP_1)

	Walking Pace (km/hr)			
Time (min)	0	3.0	4.5	6.0
0 - 45	0	2.10	3.15	4.20
45 - 90	0	4.20	6.30	8.40
100 - 150	0	6.55	9.80	13.10
160 - 210	0	8.90	13.30	17.80
Wet*	0	6.80	10.15	13.60

* Distance walked after rain turned on (45 min).

Appendix B2. Walking Pace Pilot Study

The results of EXP_1 suggested an appropriate walking pace would be between 4.5 km/hr (too slow for many subjects) and 6 km/hr (high attrition rate, associated with subject and equipment malfunctions). A pace around 5 km/hr was considered to be an average, comfortable walking pace.

In the autumn preceding EXP_2, five subjects (including the author) took part in a short experiment designed to illustrate a "comfortable" walking pace that an individual felt he could maintain for many hours. Subjects walked the *Wet Walk* for approximately 30 minutes, or 54 consecutive 50-metre circuits, at this self-regulated pace. The time for each 1/2 lap (25 m from midpoint to west end and return; 25 m from midpoint to east end and return) was recorded and the overall mean calculated for each subject. Equivalent walking speed was calculated by dividing the total walking distance (Σlaps × 0.05 km) by the total walking time (Σlap time). Results are shown in Table B2.1.

All subjects demonstrated an ability to maintain a consistent walking pace, as indicated by the small standard deviation, without the assistance of regulatory feedback. One subject's (MD) "comfortable" pace was considered excessive (6.6 km/hr). The mean equivalent walking speed of the remaining four subjects was 5.1 ± 0.3 km/hr.

This result supported an intermediate pace between 4.5 and 6.0 km/hr. A half-circuit (25 m) time of 17.5 seconds was therefore selected; this value lies precisely between the half-circuit time for 4.5 km/hr (20 sec) and 6.0 km/hr (15 sec). It is equivalent to walking 5.14 km/hr.

Table B2.1. Walking pace pilot study summary. A lap represents one half-circuit (25 m) of the *Wet Walk* (either west or east of midpoint)

Subject	Laps	Lap Time (sec) (mean ± SD)	Pace (km/hr)	Pace (km/hr) (mean ± SD)
RT	106	19.2 ± 0.8	4.7	
KW	108	17.9 ± 0.5	5.0	
LR	108	15.8 ± 0.6	5.7	
BD	108	18.1 ± 0.5	5.0	5.1 ± 0.3 (n=4)
MD	108	13.6 ± 0.6	6.6	5.4 ± 0.6 (n=5)

Appendix B3. Lap Pacer

In order to help subjects maintain a constant walking speed, a pacing device was designed to provide them with a simple feedback system. This device was supported on the midpoint arch (A_{8S}; Fig. B3.1), and was clearly visible over the length of the track, as well as from the observation area. The pacer contained two 7.5W light bulbs – a lower yellow bulb and an upper red bulb – controlled by an automatic timing device (Fig. B3.2).

The subject-facing surfaces of the pacer were made of sanded plexiglass. These covers (facing west and east) were painted flat black (as the rest of the external surface) except for an inverted triangle opposite the upper red bulb and a square opposite the lower yellow bulb. Therefore, when the red bulb was on, the subject saw a red inverted triangle; when the yellow bulb was on, he saw a yellow square (Fig. B3.1).

The timing device was set to cycle within a 17.5-second period, consisting of a 15.5-second phase (yellow on; red off) and a 2.0-second phase (red on; yellow off), the time required to walk a half-circuit of the *Wet Walk*. A subject always started any timed period from the observation station arch (A_{7N}) heading west; he began walking at the red-on signal.

A subject was walking at the correct pace if the red light turned on (yellow off) as he passed through A_7 heading west (uphill) or A_9 heading east (downhill), as he approached the track midpoint (A_8). The phase would switch (red off/yellow on) as he passed through A_8.

If the red triangle was lit before a subject passed through the pre-midpoint arch, then he was walking too slowly, and therefore increased his pace. If the red triangle was not lit before a subject passed through the pre-midpoint arch, then he was walking too quickly, and therefore he would decrease his pace.

Construction details are illustrated in Fig. B3.2. The sides and top/bottom of the pacer were made of 13-mm plywood; the inner edges were inset 6 mm to receive the 3-mm plexiglass plates. Standard 110V plastic light sockets were mounted on risers, and connected to the timing device set on a divider in the middle of the pacer; this was connected to an external starter switch and a 110V supply. The pacer was bolted to the arch with a D-clamp.

Fig. B3.1. The *Wet Walk* lap pacer, showing the (a) yellow on/red off, and (b) red on/yellow off phases.

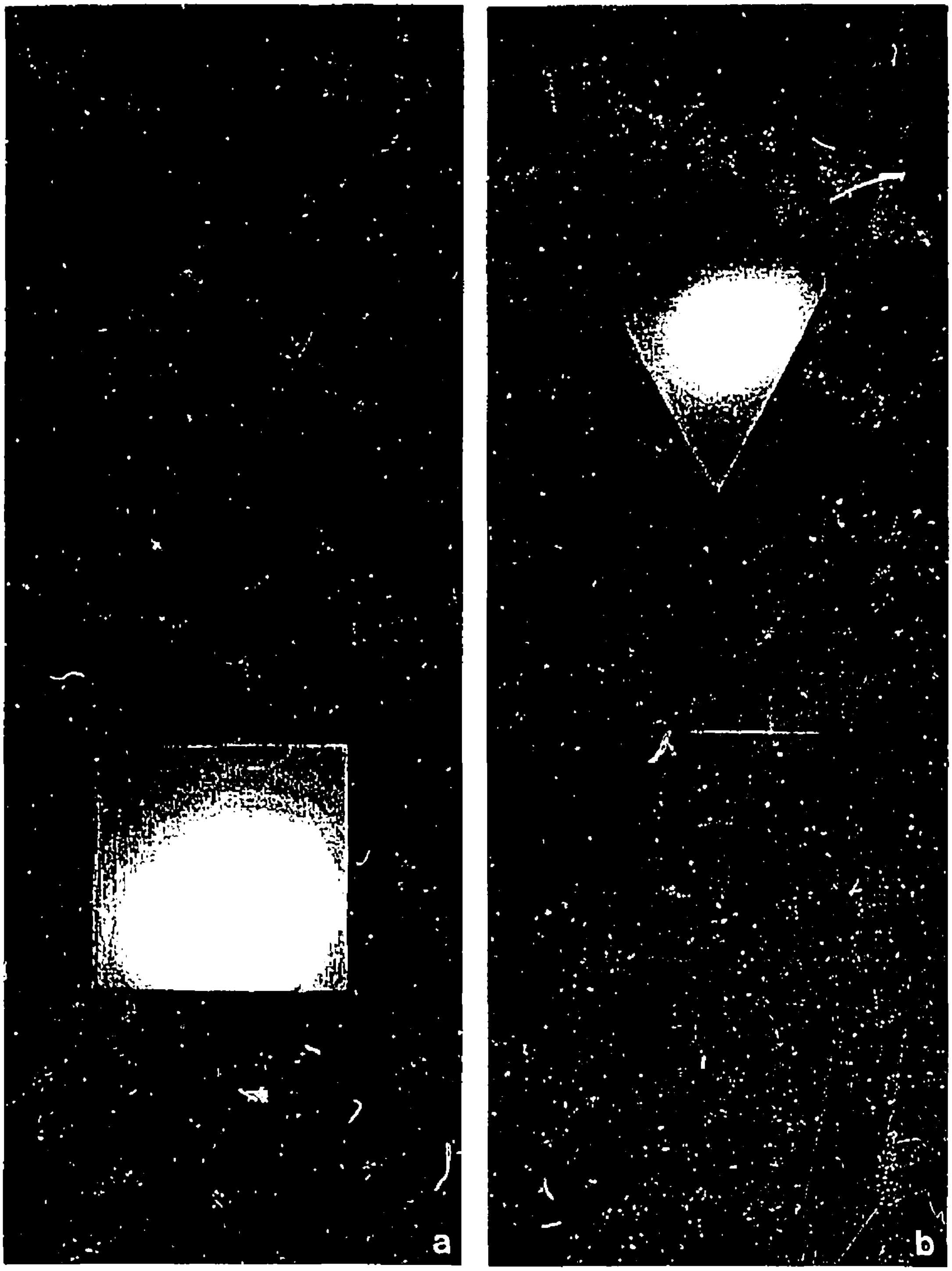

a
b

Fig. B3.2. Construction details of *Wet Walk* lap pacer. The pacer was 147 mm in depth. (T), timing device; (SW), switch; (B), 5-mm bolt.

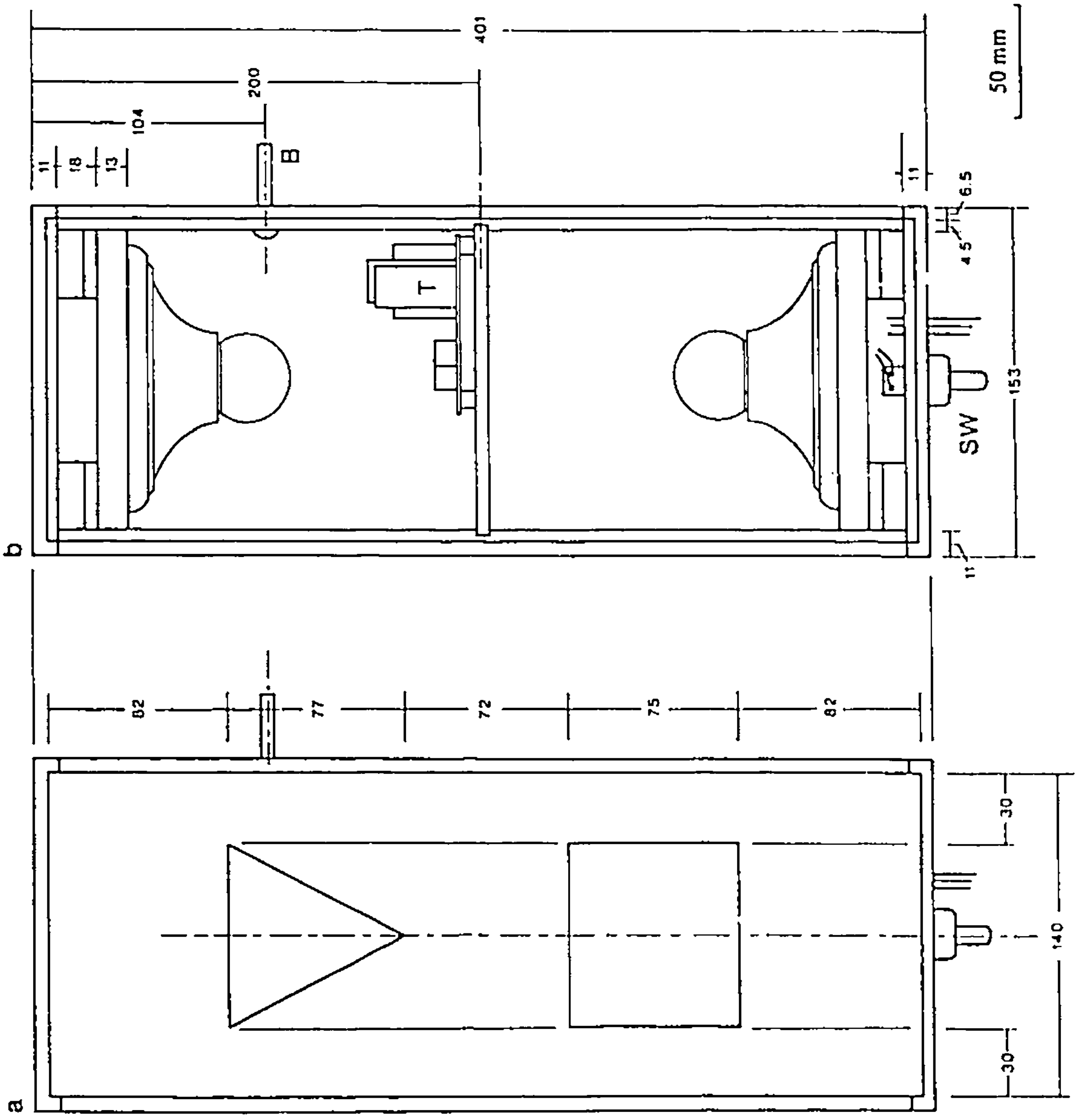


Fig. B3.2. Construction details of *Wet Walk* lap pacer.

Appendix B4. Walking Distance EXP$_2$

Walking pace in EXP$_2$ was 35 seconds/lap (50m), equivalent to a walking speed of 5.1 km/hr. Subjects were stopped every 10 minutes for 35 seconds (time for one lap) in order to complete data recording. Typically, 16 or 17 laps were completed in this period. At 90-minute intervals subjects stopped to complete behaviour tests. This required a break of approximately 3.5 minutes at the 90-, 180- and 270-minute readings, and 6 minutes at the 100-, 190, and 280-minute readings. As in EXP$_1$, walking distance was calculated as a function of the number of laps completed, and converted to km.

Summary data is provided on an hourly basis (Table B4.1), and in relation to analytical phases described in chapter 3 (Table B4.2). A detailed description is given in Table B4.3.

Table B4.1. Walking distance calculated per hour (EXP_2)

Hour	Laps		Km	
	/Hour	Total	/Hour	Total
1	98	98	4.90	4.90
2	82	180	4.10	9.00
3	97	277	4.85	13.85
4	83	360	4.15	18.00
5	83	443	4.15	22.15

Distance walked in rain (t_{2-5}) = 17.25 km (345 laps)

Table B4.2. Walking distance per analysis phase (EXP_2)

Hour (range)		Laps		Km	
		/Phase	Total	/Phase	Total
0.0	1.0	98	98	4.90	4.90
1.0	1.5	48	146	2.40	7.30
1.5	2.0	34	180	1.70	9.00
2.0	3.0	97	277	4.85	13.85
3.0	3.5	34	311	1.70	15.55
3.5	4.5	98	409	4.90	20.45
4.5	5.0	34	443	1.70	22.15

Table B4.3. Detailed calculation of walking distance (EXP_2); all times given in minutes:seconds

Time Period					Cumulative Totals	
Start	End	Time	Laps	M	Laps	Km
0:00	9:55	9:55	17	850	17	0.85
10:30	19:50	9:20	16	800	33	1.65
20:25	29:45	9:20	16	800	49	2.45
30:20	39:40	9:20	16	800	65	3.25
40:15	49:35	9:20	16	800	81	4.05
50:10	60:05	9:55	17	850	98	4.90
60:40	70:00	9:20	16	800	114	5.70
70:35	79:55	9:20	16	800	130	6.50
80:30	89:50	9:20	16	800	146	7.30
93:35	100:00	6:25	11	550	157	7.85
105:55	110:00	4:05	7	350	164	8.20
110:35	119:55	9:20	16	800	180	9.00
120:30	129:50	9:20	16	800	196	9.80
130:25	139:45	9:20	16	800	212	10.60
140:20	149:40	9:20	16	800	228	11.40
150:15	159:35	9:20	16	800	244	12.20
160:10	169:30	9:20	16	800	260	13.00
170:05	180:00	9:55	17	850	277	13.85
183:35	190:00	6:25	11	550	288	14.40
195:55	200:00	4:05	7	350	295	14.75
200:35	209:55	9:20	16	800	311	15.55
210:30	219:50	9:20	16	800	327	16.35
220:25	229:45	9:20	16	800	343	17.15
230:20	239:40	9:55	17	850	360	18.00
240:15	249:35	9:20	16	800	376	18.80
250:10	259:30	9:20	16	800	392	19.60
260:05	270:00	9:55	17	850	409	20.45
273:35	280:00	6:25	11	550	420	21.00
285:55	290:00	4:05	7	350	427	21.35
290:35	299:55	9:20	16	800	443	22.15

Appendix B5. Walking Distance EXP_3

The walking pace in EXP_3 was identical to EXP_2 (35 sec/50m lap). Subjects were stopped every 10 minutes for 17.5 seconds (time for a half circuit) to record metabolic data. Improvements in data acquisition mechanisms allowed an abbreviated data stop. Again, about 17 laps were completed during the 10-minute period. The experiment was divided into two phases: *(1)* a preliminary exercise phase consisting of three 50-minute walks punctuated by 10-minute rest breaks (phase A); and after a 30-minute rest break, *(2)* a second exercise phase, including the vigilance test, with rain/wind initiated after the first hour (phase B). A summary of walking distances by period is presented in Table B5.1, and a more detailed description given in Table B5.2.

Table B5.1. Summary of distance walked (EXP_3). Phase A consisted of three similar 84-lap stages. Wet walks stopped after 3 hours (551 laps), dry walks continuing to 3.5 hours (601 laps)

Time	Laps Walked			Km Walked		
	Hour	Phase	Total	Hour	Phase	Total
Phase A						
	(3) 84	252		(3) 4.20	12.60	
Phase B						
1	100	100	352	5.00	5.00	17.60
2	99	199	451	4.95	9.95	22.55
3	100	299	551	5.00	14.95	27.55
3.5	50	349	601	2.50	17.45	30.05
4	50	399	651	2.50	19.95	32.55

Distance walked in rain (t_{2-3}) = 9.95 km (199 laps)

Table B5.2. Detailed calculation of walking distance (EXP_3); all times given in minutes:seconds

Time Period					Cumulative Totals	
Start	End	Time	Laps	M	Laps	Km
Phase A – 3 × 50 minutes						
0:00	9:55	9:55	17	850	17	0.85
10:13	19:33	9:20	16	800	33	1.65
19:50	29:45	9:55	17	850	50	2.50
30:03	39:58	9:55	17	850	67	3.35
40:15	50:10	9:20	17	850	84	4.20
Phase B						
0:00	9:55	9:55	17	850	17	0.85
10:13	19:33	9:20	16	800	33	1.65
19:50	29:45	9:55	17	850	50	2.50
30:03	39:23	9:20	16	800	66	3.30
39:40	49:35	9:55	17	850	83	4.15
49:53	59:48	9:55	17	850	100	5.00
60:40	70:00	9:20	16	800	116	5.80
70:13	79:38	9:20	16	800	132	6.60
79:55	89:50	9:55	17	850	149	7.45
90:08	100:03	9:55	17	850	166	8.30
100:20	109:40	9:20	16	800	182	9.10
109:58	119:52	9:55	17	850	199	9.95
120:10	129:30	9:20	16	800	215	10.75
129:47	139:42	9:55	17	850	232	11.60
140:00	149:55	9:55	17	850	249	12.45
150:13	159:33	9:20	16	800	265	13.25
159:50	169:45	9:55	17	850	282	14.10
170:03	179:58	9:55	17	850	299	14.95
180:15	189:35	9:20	16	800	315	15.75
189:53	199:48	9:55	17	850	332	16.60
200:05	210:00	9:55	17	850	349	17.45
210:18	219:38	9:20	16	800	365	18.25
219:55	229:50	9:55	17	850	382	19.10
230:08	240:03	9:55	17	850	399	19.95

APPENDIX C. THERMOMETERY

C1. EXP_1

C2. EXP_2

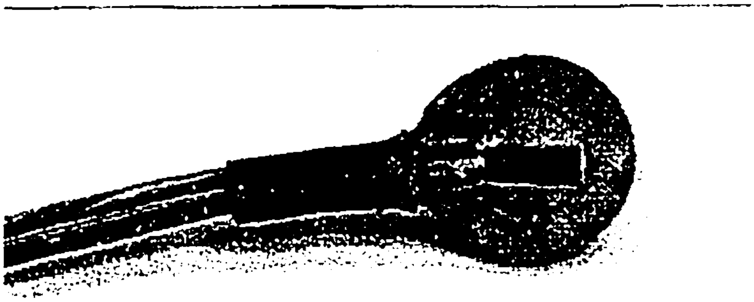
C3. EXP_3

C4. Thermometer Case

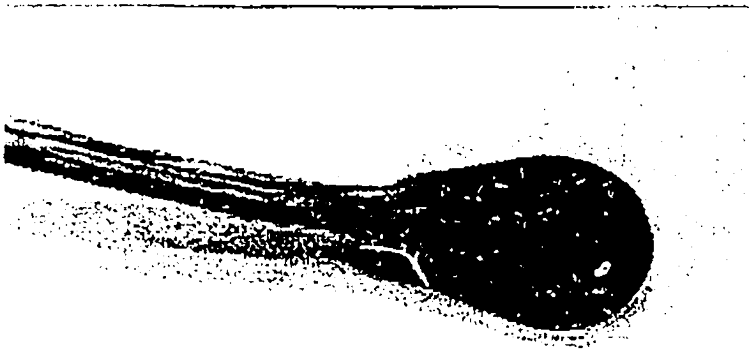
C5. *TeePee*

Fig. C1. Skin thermosensors used during *Wet Walk* research: (a) EXP_1, (b) EXP_2, and (c) EXP_3 pilot studies. Standard YSI skin thermistors were used during EXP_3.

a



b



c

Appendix C1. EXP$_1$

Fig. C1.1. Skin thermosensor used for EXP$_1$: (a) top, (b) side, and (c) bottom view. A type AD590JH temperature sensor (s) was surrounded by a small disc of neoprene (shaded area). Coaxial cable (3 mm) was soldered to the sensor, and the upper surface covered by a thin layer of insulating foam (i). The exposed connections were covered with heat shrink (h), and the assembly enclosed in a resin cap (IFC GLS1 cold-cure resin). An Amphenol 44 Series waterproof connector was soldered to the distal end of the coaxial cable, for connection to a sister-cable extending from RAEKIT 3200D digital thermometers contained in the backpack (Fig. E2.1).

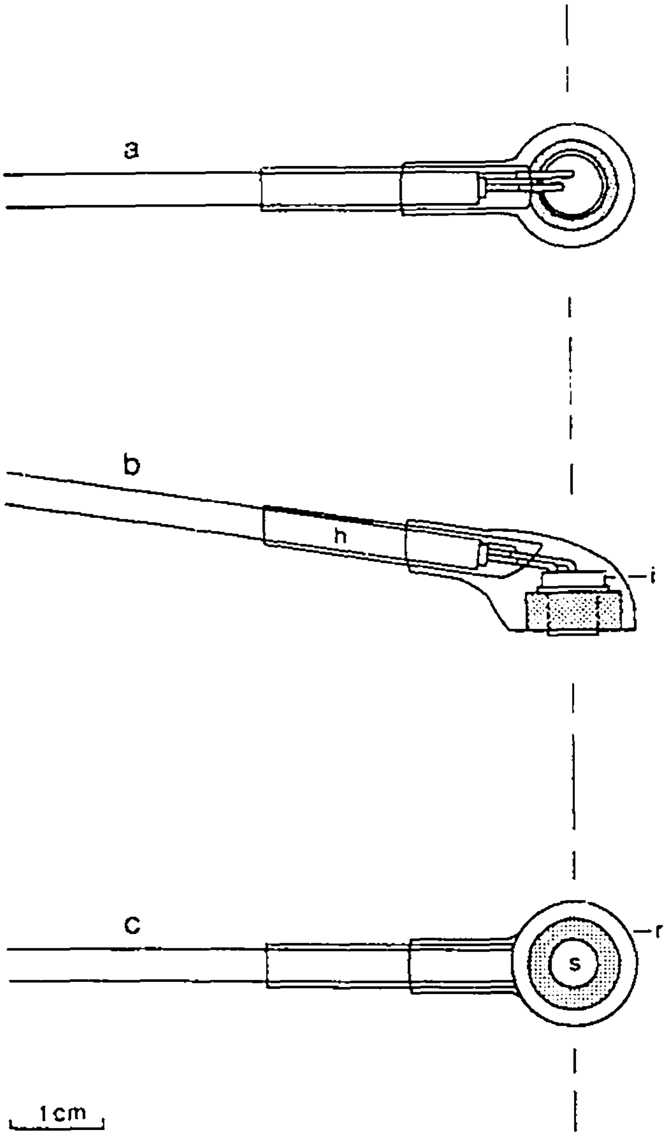


Fig. C1.1. Skin thermosensor used in EXP_1.

Appendix C2. EXP$_2$

Fig. C2.1. Skin thermosensor used for EXP$_2$: (a) side, and (b) bottom view. A type AD590KF thermosensor (s) soldered to speaker wire was inserted through a notch cut in a thin plastic washer (w). A resin cap (IFC GLS1 cold-cure resin) was applied over the assembly while applying pressure to both components in order to get a smooth lower surface. Heat shrink (shaded area) was used to protect the connection as much as possible. The wire was connected to telephone mini-plugs leading to RAEKIT 3200D digital thermometers mounted in the backpack (Fig. C4.1). Significant difficulties were encountered using this system. Although offering greater potential accuracy, the structure of the AD590KF sensor made construction of a water-tight connection very difficult. Higher-then-expected skin temperatures may be explained by moisture transfer through the thin resin layer.

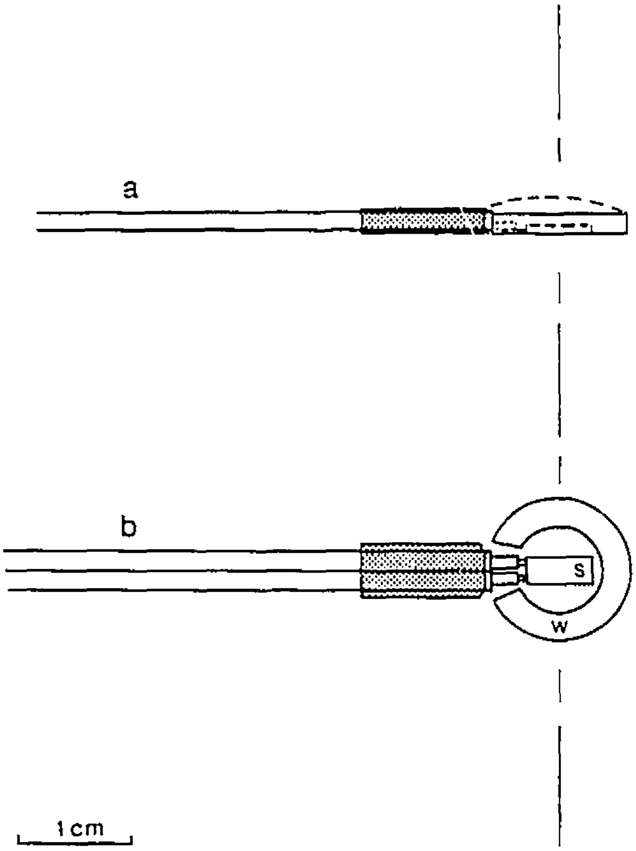


Fig. C2.1. Skin thermosensor used in EXP_2.

Appendix C3. EXP$_3$

Fig. C3.1. Skin thermosensor used for EXP$_3$ pilot studies: (a) top, (b) side, and (c) bottom view. A type AD590JH thermosensor (s) inserted through two base components: *(1)* a thin steel washer (w), and *(2)* an overlying section of 1.6-mm plexiglass support (p). The sensor was soldered to speaker wire, and the assembly covered in a protective resin cap (IFC GLS1 cold-cure resin). As in the previous experiment, the wire was connected to telephone mini-plugs leading to RAEKIT 3200D digital thermometers mounted in the backpack (Fig. C4.1). This system was replaced during the vigilance experiments with standard YSI skin thermistors.

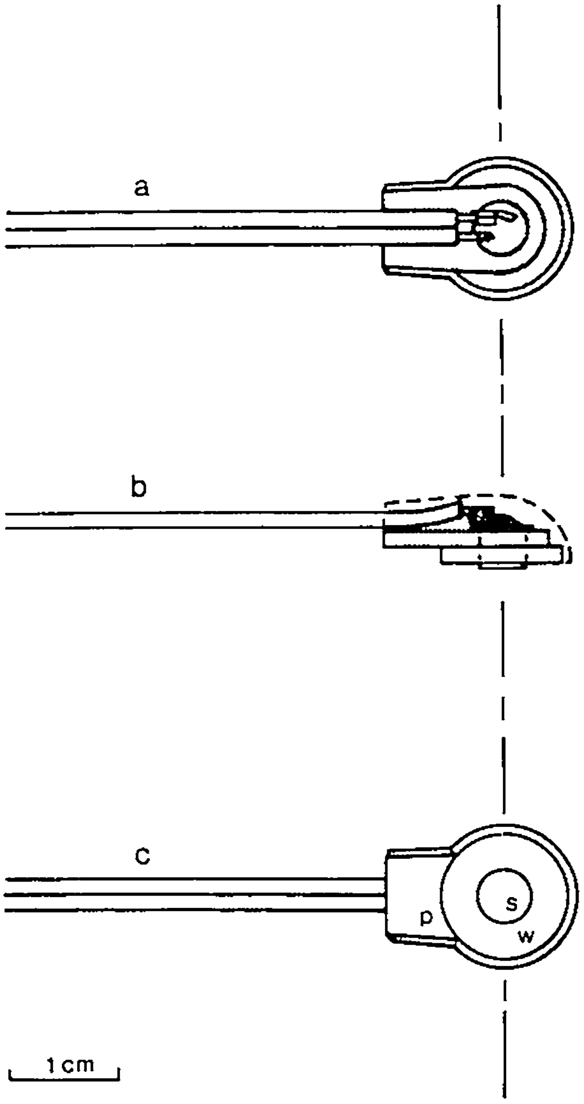
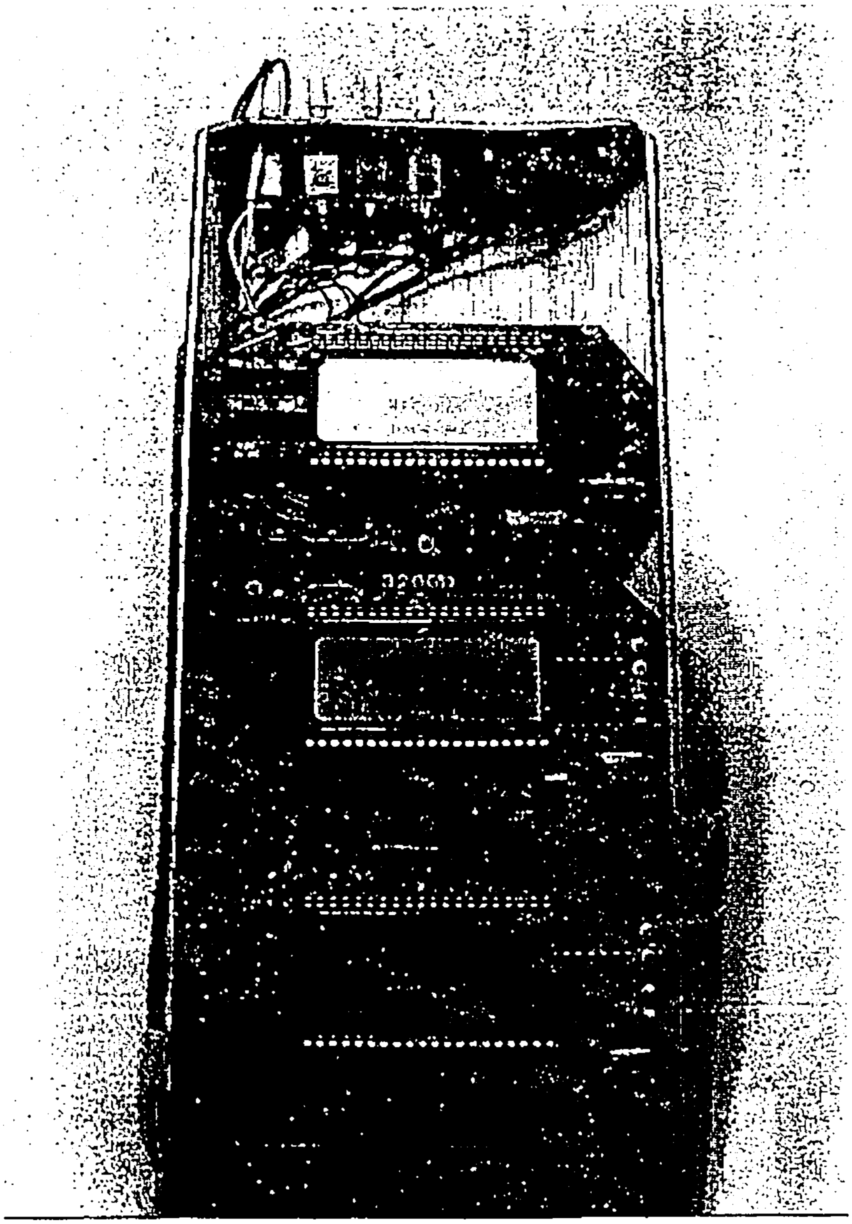


Fig. C3.1. Skin thermosensor used in EXP$_3$ pilot studies.

Appendix C4. Thermometer Case

Fig. C4.1. Photograph of thermometer case containing the RAEKIT 3200D thermometer displays. The cases were specifically designed to hold these thermometers. These were placed in the pack on opposite sides of the Oxylog in the backpack, the displays visible though viewing ports in the pack lid (Appendix E3). The body of the case was constructed of 1.6-mm balsa covered with a light fiberglass layer, and the cover of 1.6-mm plexiglass.

Fig. C4.2. Cross-section of thermometer case mold (length 23 cm). The hatched area represents the relative position of the Oxylog in the pack; the thermometer case was attached to the backpack base at a level below the inner pack surface (Appendix E). The case was designed to hold three RAEKIT 3200D digital thermometers at a viewing angle of 60°. Dimensions and angles were calculated using triangle geometry programs on an HP33E calculator. Angles: (a) 120°; (b) 150°. Lengths: (A) 14.65 mm; (B) 6.35 mm; (C) 12.7 mm; (D) 83.26 mm; (E) 7.34 mm; (F) 6.35 mm; (G) 25.4 mm; (H) 72.29 mm. The body of the case was formed by sides BAHGF, and the cover by CDE. Velcro was glued to case surfaces A and G for attachment of the case to the pack and Oxylog straps.



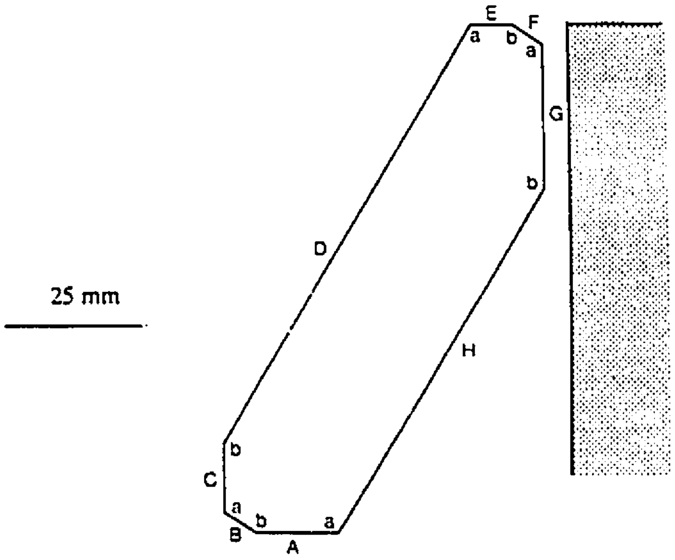


Fig. C4.2. Cross section of thermometer case mold (EXP_2).

Appendix C5. *TeePee*

Fig. C5.1. The *TeePee* – a system for collection of urine samples and measurement of urine temperature: (a) side, and (b) top view. A hole was cut in the lid of a 500-ml Nalgene bottle, slightly smaller than the diameter of the bottle opening; a small funnel, with overflow holes drilled in its sides (b), was held in place by the screwed-down lid. A hole was drilled in the side of the Nalgene bottle and through the funnel, for placement of a low-reading Zeal mercury thermometer (G.H. Zeal, London, England) in the funnel neck. A small length of surgical tubing was attached to the end of the funnel to reduce flow (c). When subjects urinated in the bottle, the urine stream flowed over the thermometer, and a small urine pool formed around the head of the thermometer. The constant supply of warm urine reduced the potential cooling effects of cold ambient temperatures.

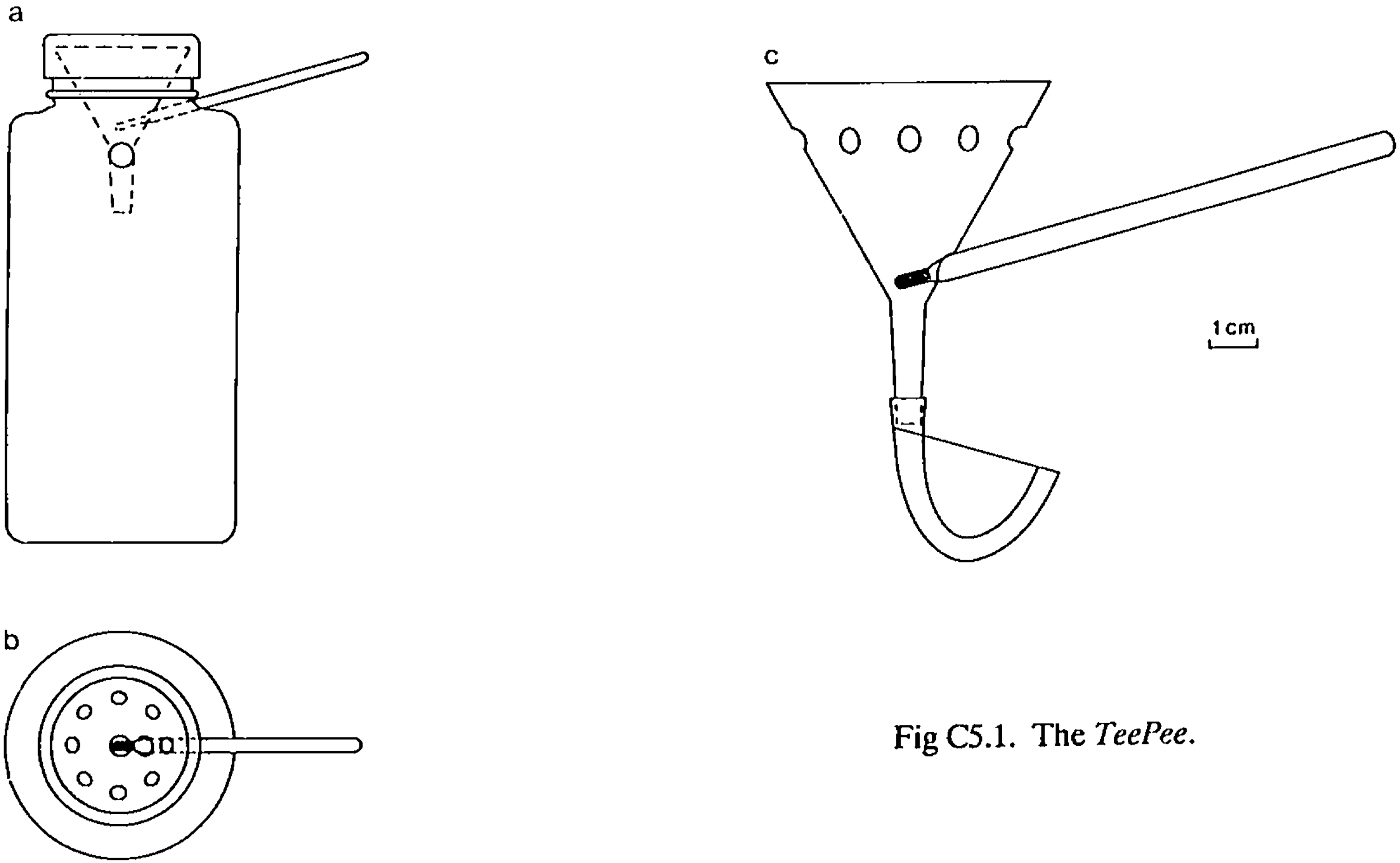


Fig C5.1. The *TeePee*.

APPENDIX D. OXYLOG MODIFICATIONS

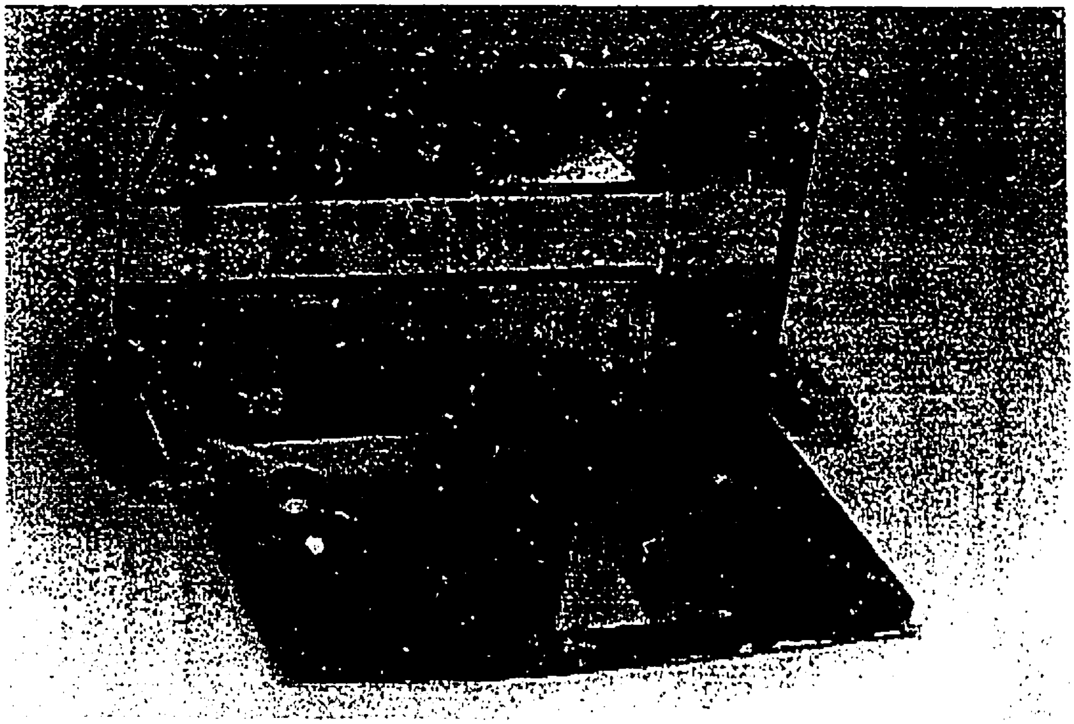
Appendix D. Oxylog Modifications

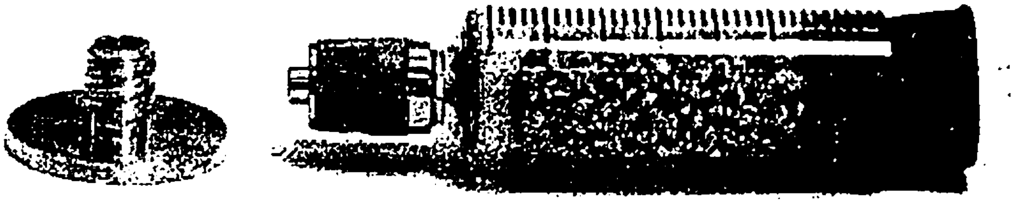
Several adjustments were required in order to adapt the Oxylog for use in a wet cold environent. Placement of the Oxylog in a vertical position in an insulated pack required: (a) use of a "periscope" to view the Oxylog LED output display through a viewing port in the pack lid (Fig. D1); (b) adapters for air sample input and output from the pack; and (c) development of an external V_E/VO_2 switch. An extended plexiglass nosepiece was placed on the oronasal mask inspiratory input valve to prevent water collecting on the flowmeter vanes.

Periodically, the Oxylog did not function properly; in some cases, the calculated VO_2 values were extremely low. This problem was partly alleviated by replacing the supplied drying tube mechanism with a replacement system illustrated in Fig. D2. It was believed that the rubber gasket on the original drying tube system may have been blocking the air sample tube.

Fig. D1. The plexiglass mirror "periscope" used to adapt the Oxylog for vertical placement in the pack.

Fig. D2. Replacement Drierite tube (made from a 10-cc syringe) and the threaded aluminum base. The tube was sealed with a small rubber stopper; a short piece of glass tube was used as an input hose connector.





APPENDIX E. BACKPACKS

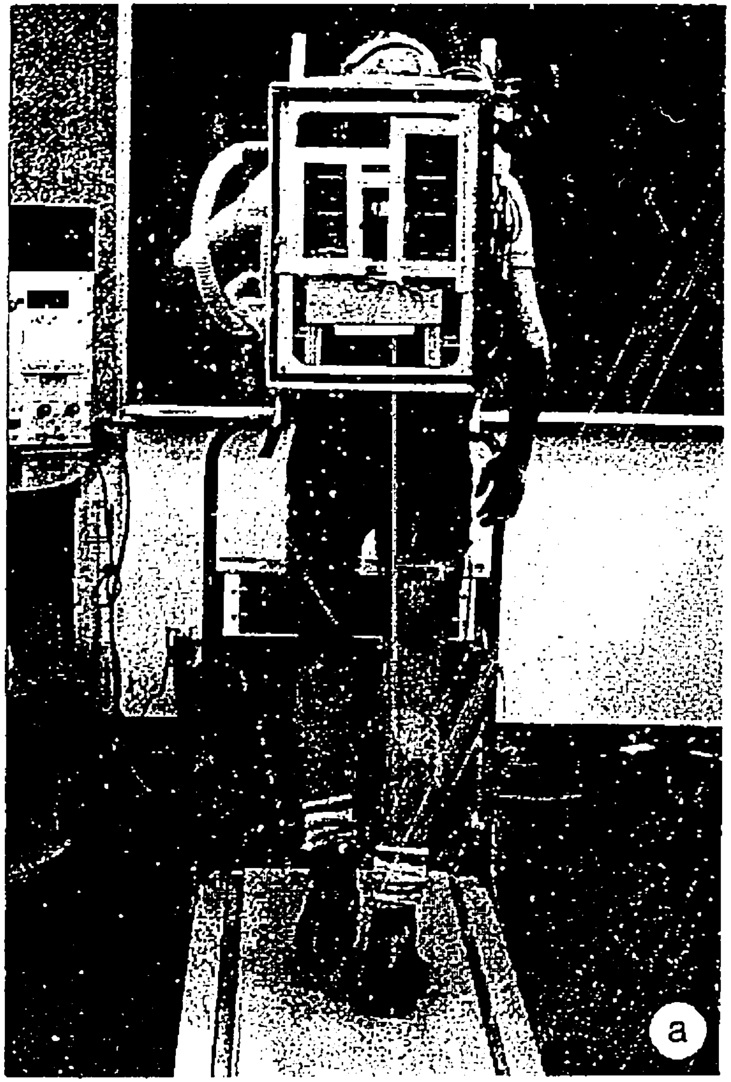
E1. Preliminary Backpack

E2. EXP_1 Backpack

E3. EXP_2 Backpack

Appendix E1. Preliminary Backpack

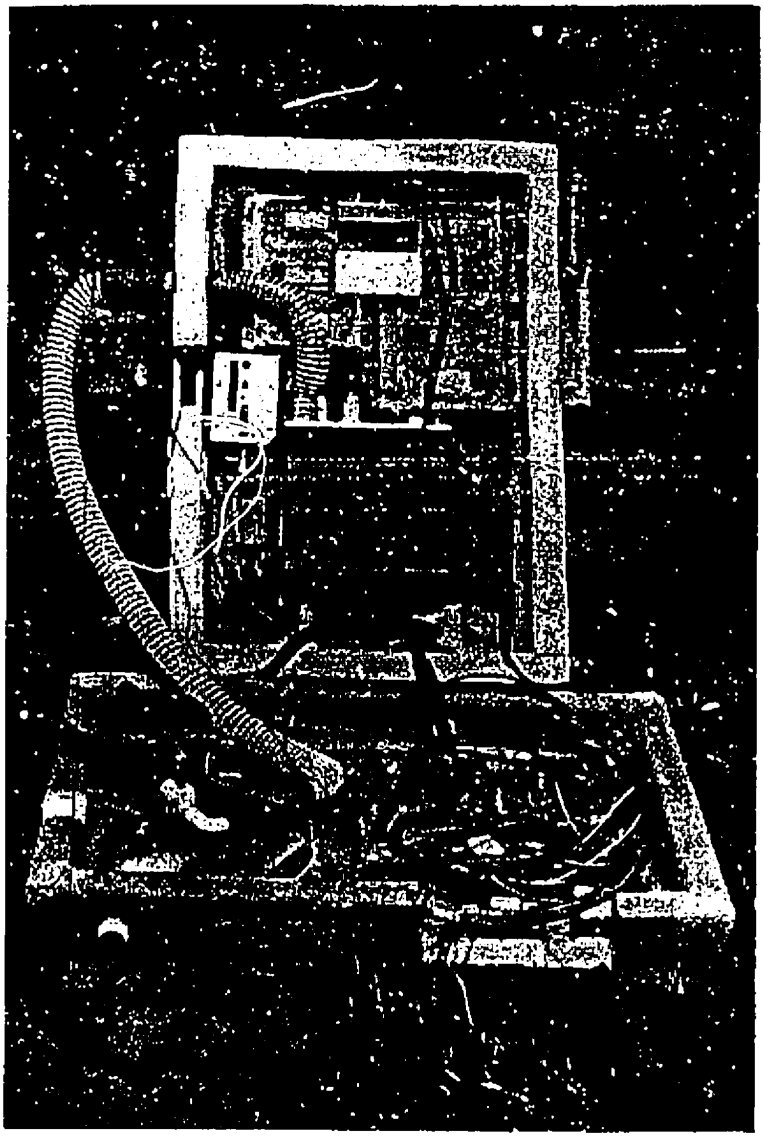
Fig. E1.1. The first backpack in use during a treadmill pilot study at the University of Victoria: (a) back, and (b) side views. It was constructed of 13-mm plywood, and was attached to a standard aluminum packframe with plastic fasteners. This is the second model of this pack. The Oxylog was initially placed horizontally in the pack, projecting several inches beyond the plexiglass cover. The Oxylog was moved to a vertical position to improve balance; this required making the small "periscope" (Appendix D). The digital thermometers were attached to the plexiglass cover, and malfunctioned when studies began in cold temperatures, as did other recording apparatus in the pack. The pack was therefore discarded and replaced by the insulated pack described in Appendix E2.


a


b

Appendix E2. EXP$_1$ Backpack

Fig. E2.1. Photograph of the EXP$_1$ backpack, showing the contents of the pack. Note the weatherproof ensolite gasket around the perimeter of the base. The backpack was made of 13-mm polyurethane foam coated with 2 layers of fiberglass; the unloaded pack weighed 5.8 kg.



Figs. E2.2 – E2.4. EXP$_1$ backpack base.

Fig. E2.2. Interior layout of the EXP$_1$ backpack base. The digital thermometers were contained in plexiglass cases (Fig. E2.1), screwed into dowels (d) in the pack base. The heart rate transmitter was attached on the left side of the pack with velcro (HR); a switch (SW) on the left of the pack was used to turn the transmitter on or off as required. The Oxylog was placed on a piece of ensolite between the bolts and firmly strapped in (Fig. E2.1). The Oxylog inlet was tightly connected with hair dryer hose to a plexiglass tube (In) connected on the outside the outflow hose from the oronasal mask. The outflow of the Oxylog was snugly attached to a plexiglass adapter (Out) attached to the end of the base (the lines indicate a thin layer of plexiglass over the adapter).

Fig. E2.3. EXP$_1$ backpack base (left side view), showing the inlet adapter (In) for the Oxylog. Note that the floor of the base is inset 25 mm. The base of the backpack was attached to the packframe (PF) with fiberglass filler and several wraps of fiberglass. Straps were riveted to the frame (st) for fastening the lid.

Fig. E2.4. EXP$_1$ backpack base (end view). The gap betwen the base and packframe (PF) was filled with fiberglass filler.

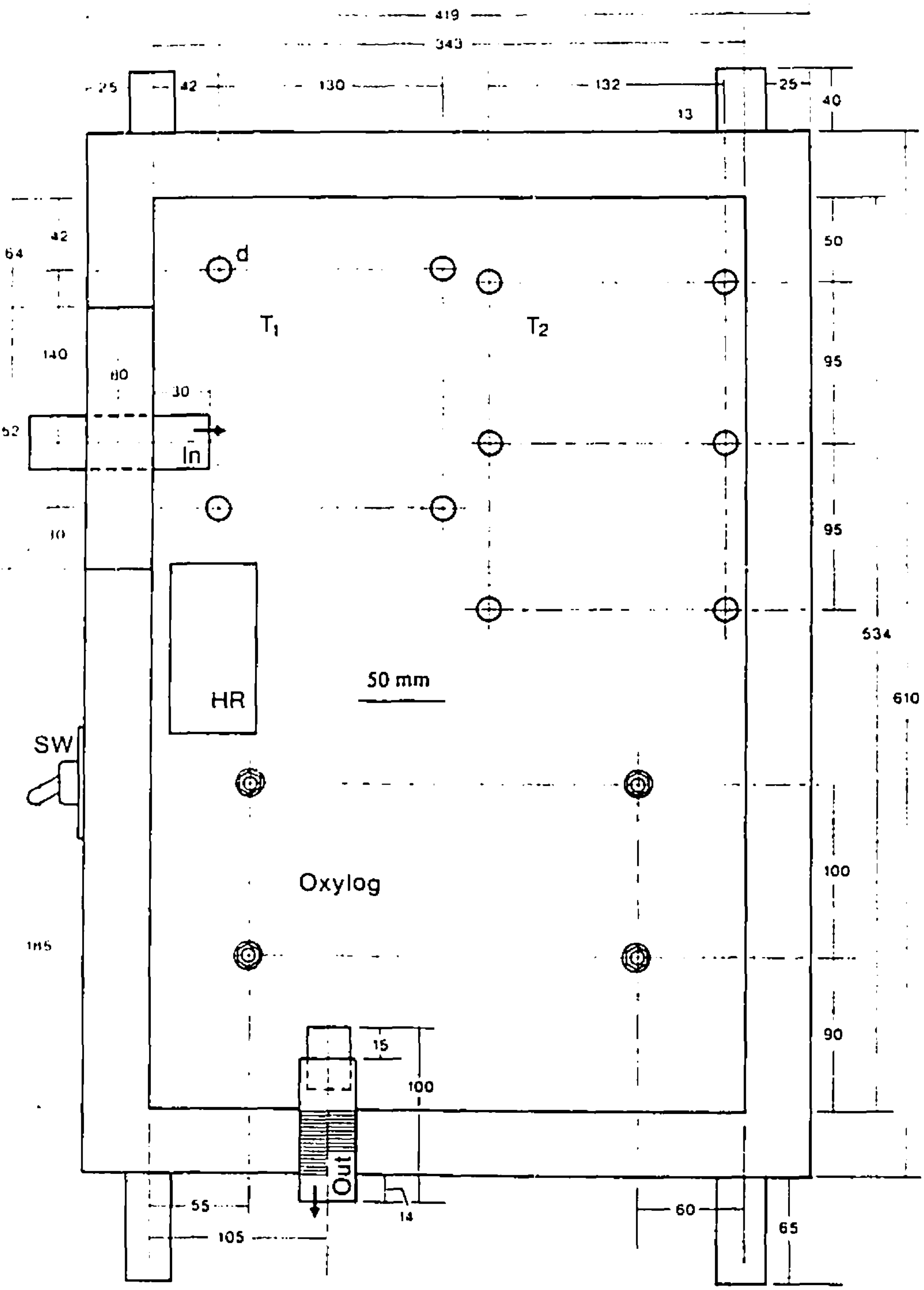


Fig. E2.2. Interior layout of the EXP_1 backpack base.

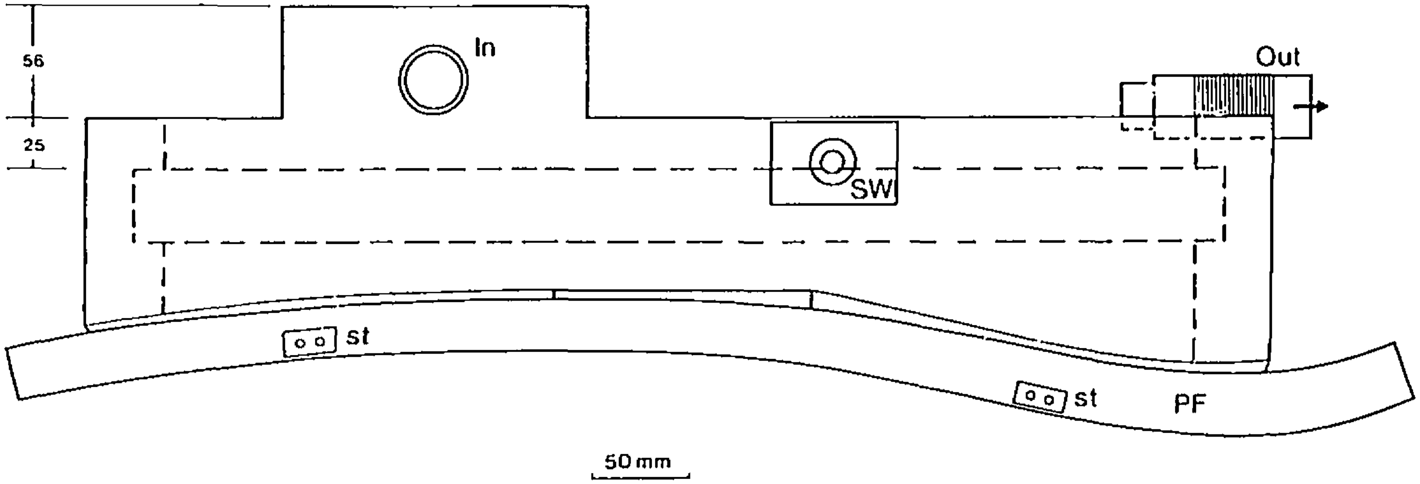


Fig. E2.3. EXP$_1$ backpack base (side view).

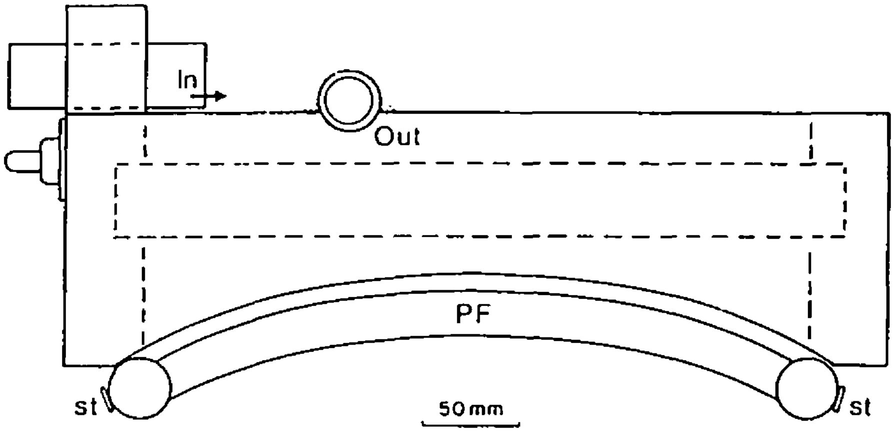


Fig. E2.4. EXP$_1$ backpack base (end view).

Figs. E2.5 - E2.7. EXP_1 backpack lid.

Fig. E2.5. EXP_1 backpack lid (viewing port detail). The temperature/Oxylog viewing ports: the center port under the switch (SW) is the Oxylog-viewing port; the switch controlled lights to illuminate the temperature displays. The ports were cut through the polyurethane foam prior to fiberglassing, and covered with a 6-mm plexglass window (inverted L-shaped area surrounding ports). The lid was fastened to the base with straps (st); the straps were riveted to aluminum plates fiberglassed onto the lid surface.

Fig. E2.6. EXP_1 backpack lid (exterior view). Note the plexiglass window over the viewing ports. Outlets for thermometer and ECG rate leads are indicated at I_1 and I_2; these plastic tubes were plugged with rubber stoppers attached to the leads. Note position of straps (s) used to fasten lid to base.

Fig. E2.7. EXP_1 backpack lid (interior view), showing a longitudinal section at A. Note the notch that fits over the Oxylog inlet adapter.

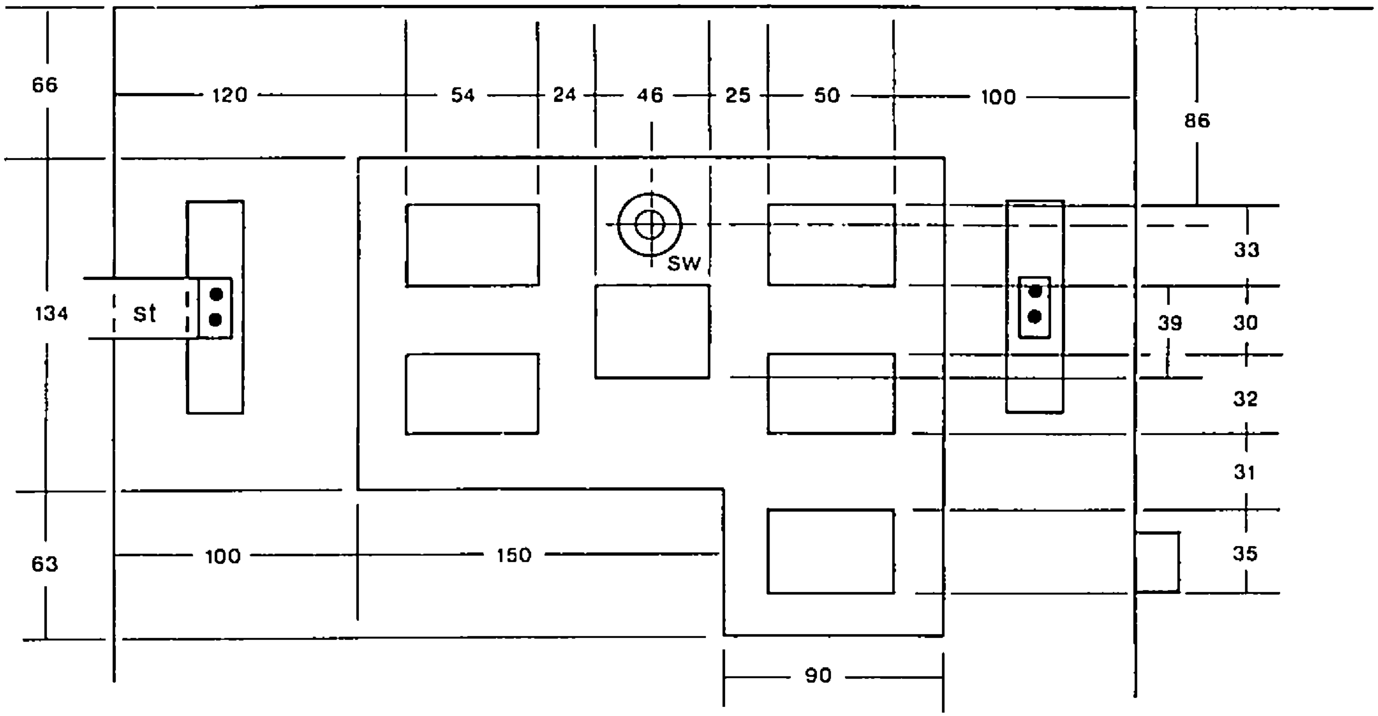


Fig. E2.5. EXP$_1$ backpack lid (viewing port detail).

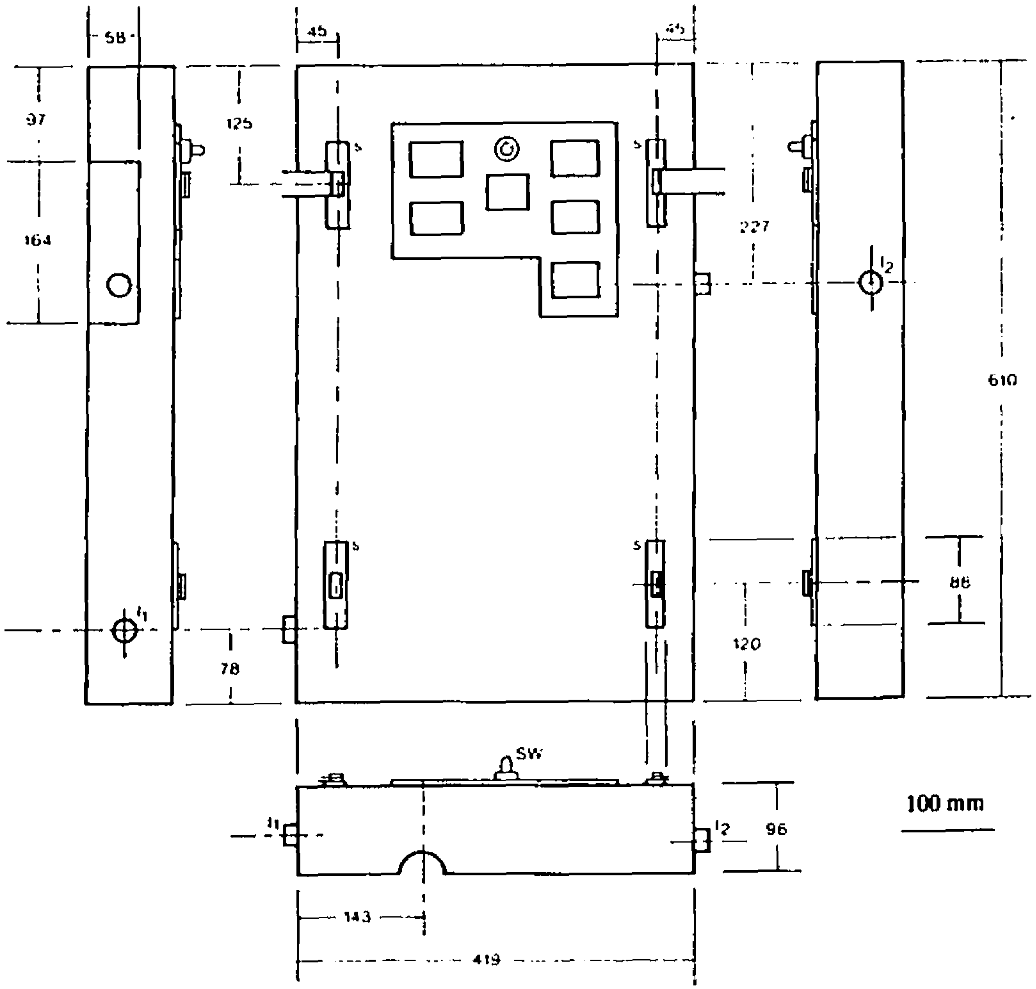


Fig. E2.6. EXP$_1$ backpack lid (exterior view).

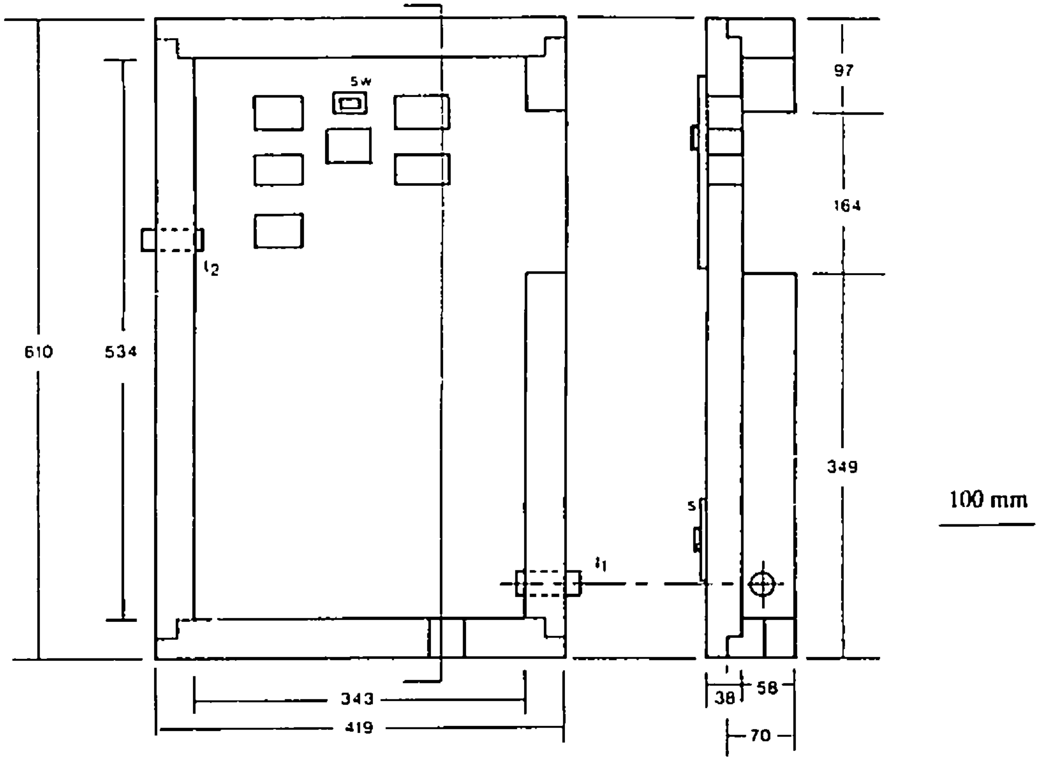
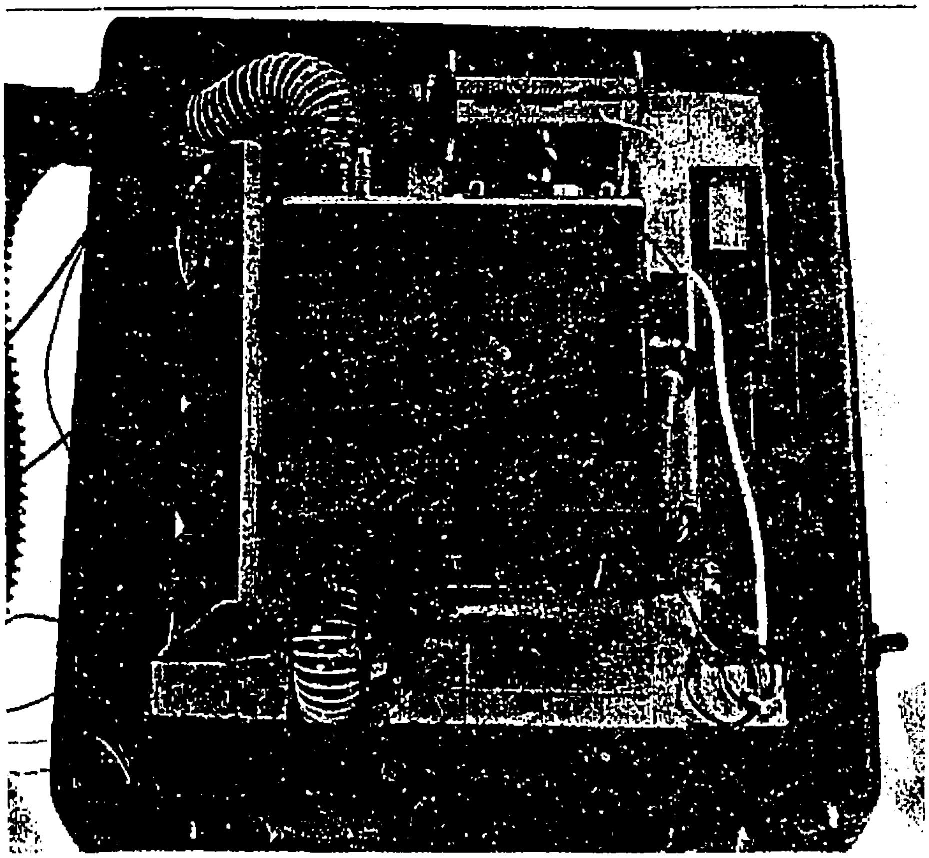


Fig. E2.7. EXP$_1$ backpack lid (interior view).

Appendix E3. EXP$_2$ Backpack

Fig. E3.1. Photograph of the backpack used for EXP$_2$ and EXP$_3$, showing the arrangement of equipment in the pack. The pack base was a mixed plywood/balsa/fiberglass construction, while the lid was made of fiberglass-coated balsa wood. The backpack weighed 3.1 kg unloaded. Note the rubber gasket around the perimeter of the pack base.



Figs. E3.2 – E3.5. EXP_2 backpack base.

Fig. E3.2. Interior layout of the EXP_2 backpack base (gasket removed). The frame of the base was made with 13-mm plywood. The base proper was constructed of 3 × 38-mm balsa ribs (Fig. E3.3) connected by 3 × 6-mm stringers, overlaid with 0.8-mm balsa sheets (19-mm plywood inserts were added for supporting the Oxylog – Fig. E3.4). This structure was glued into the plywood frame, and the unit covered with a thin layer of fiberglass. Hollow areas of the base (shaded areas) were left exposed to accomodate specific equipment. The ECG transmitter fit into a space (HR) above the position of the Oxylog; the space to the right was a continuation of the HR space used for receiving the Amphenol connector from the subject's ECG leads. A similar Oxylog inlet adapter (In) was used as in the EXP_1 pack. The adapter entered below the base surface; it was connected to the Oxylog inlet with snugly-fitting hairdryer hose. Similarly, the Oxylog outlet passed out below the base surface (Out), using an adapter system similar to the inlet. A small plastic hose (Air) penetrating the pack base was used for the Oxylog to sample ambient air. Plastic tubing inlets for thermometer (I_1, I_2) and ECG (I_3) leads are indicated. SW_1 was used to switch "Total V_E/VO_2" on the Oxylog; SW_2 was used to operate internal illumination. The thermometer cases were set into slots T_1 and T_2.

Fig. E3.3. EXP_2 backpack base (cross section A), and detail of the thermometer case inset. Note the balsa rib (r) and stringers (s). The structure of the thermometer notches parallels the design of the thermometer cases (Fig. C4.2).

Fig. E3.4. EXP_2 backpack base (cross section B and end view). Two 13-mm pieces of plywood were added to support bolts for clamping down the Oxylog; they extended between the balsa ribs visible in Fig. E3.2. The bolts (6-mm brass) were firmly screwed into place and sealed with fiberglass resin. The end view shows outside dimensions of the inlets (I_{1-3}) and Oxylog outflow (Out) adapter.

Fig. E.5. EXP_2 backpack base (left side view), showing the outer dimensions of the Oxylog inlet adapter (In) and inlet for the flowmeter Lemo connector (I_4) from the oronasal mask. Four 6-mm holes were drilled along the edge of the base for bolting the pack to a packframe.

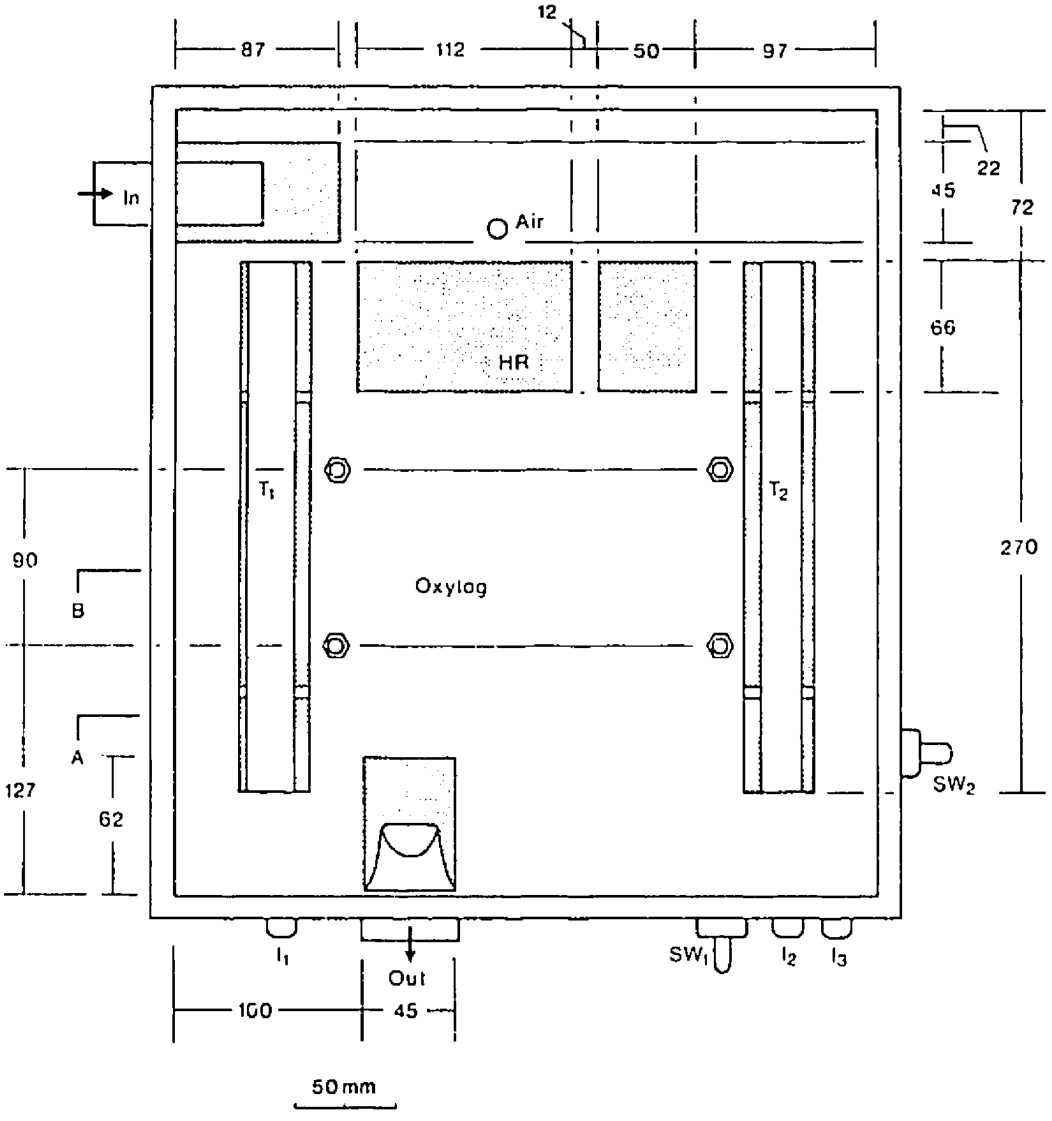


Fig. E3.2. Interior layout of the EXP$_2$ backpack base.

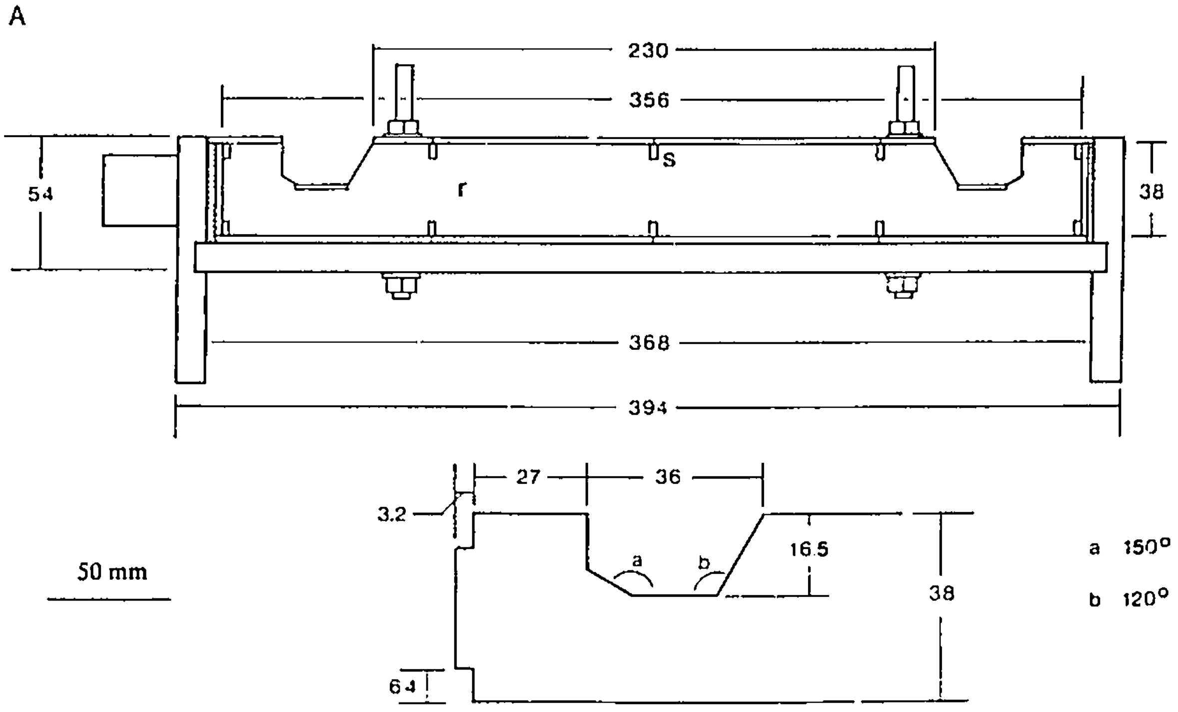


Fig. E3.3. EXP_2 backpack base (cross section A).

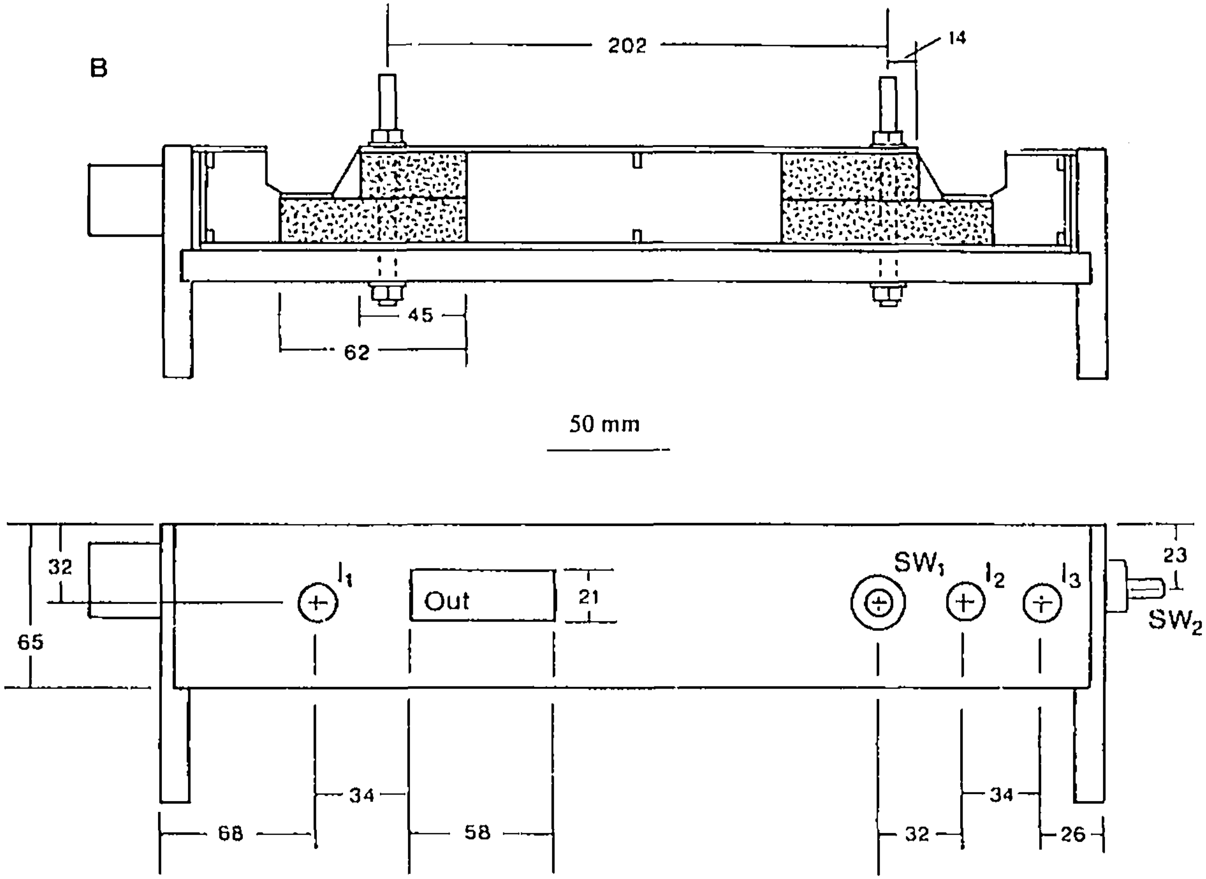


Fig. E3.4. EXP_2 backpack base (cross section B and end view).

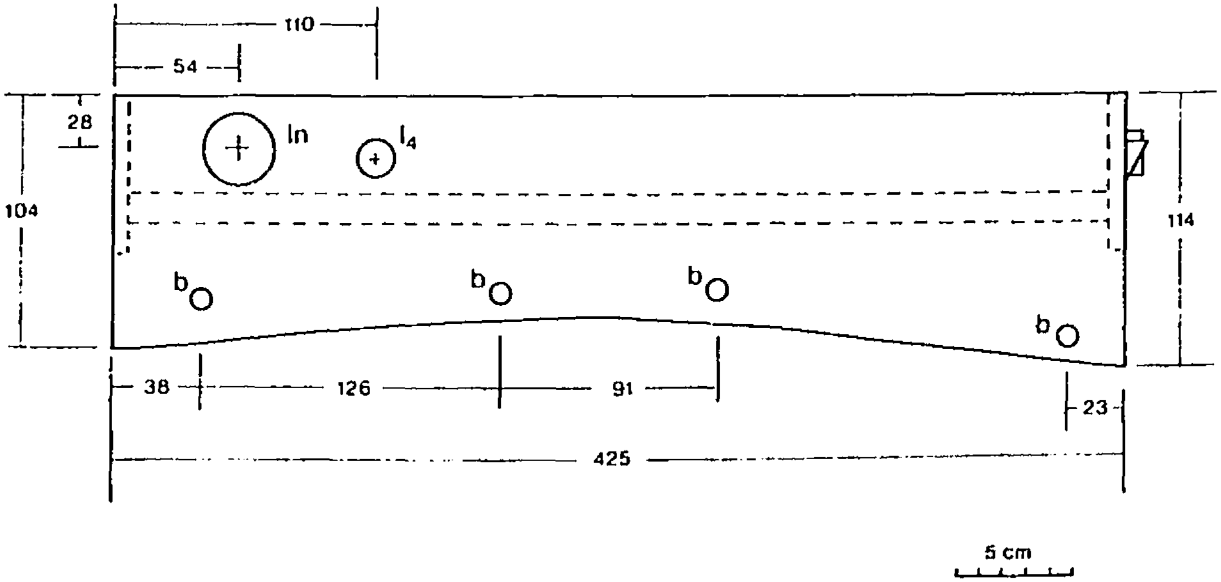


Fig. E3.5. EXP$_2$ backpack base (side view).

Figs. E3.6 – E3.9. EXP$_2$ backpack lid.

Fig. E3.6. EXP$_2$ backpack lid (exterior view), showing the Oxylog and thermometer display ports (refer to Fig. E3.1). Similar to the internal base, the lid was constructed of balsa ribs (3 × 25 mm) linked by balsa stringers (3 × 6 mm), covered with a thin sheet (0.8 mm) of balsa. After the 1.5-mm plexiglass windows were glued to the surface, the lid was covered with a thin layer of fiberglass. During use, the lid was strapped to the base using a length of surgical tubing.

Fig. E3.7. EXP$_2$ backpack lid (cross section interior plan), showing angle structure in detail. The internal structure was developed on the basis of the thermometer cases discussed in Appendix C4. An internal width of 12" (304.8 cm) and wall thickness of 1" (25.4 mm) was used as the base factors in determining internal dimensions using triangle geometry functions (HP33E calculator).

Fig. E3.8. EXP$_2$ backpack lid (XS at A and B; end view). Cross section A passes through the Oxylog viewing port, an opening through the lid; it was covered externally by a plexiglass window. Cross section B illustrates the structure of the thermometer-display viewing ports. The upper/lower edges of the window are at 90° to the slope of the lid. The end view shows the relative position of the plexiglass windows.

Fig. E3.9. EXP$_2$ backpack lid (LS at C and exterior right side view). The position of the temperature display viewing ports is indicated in this diagram.

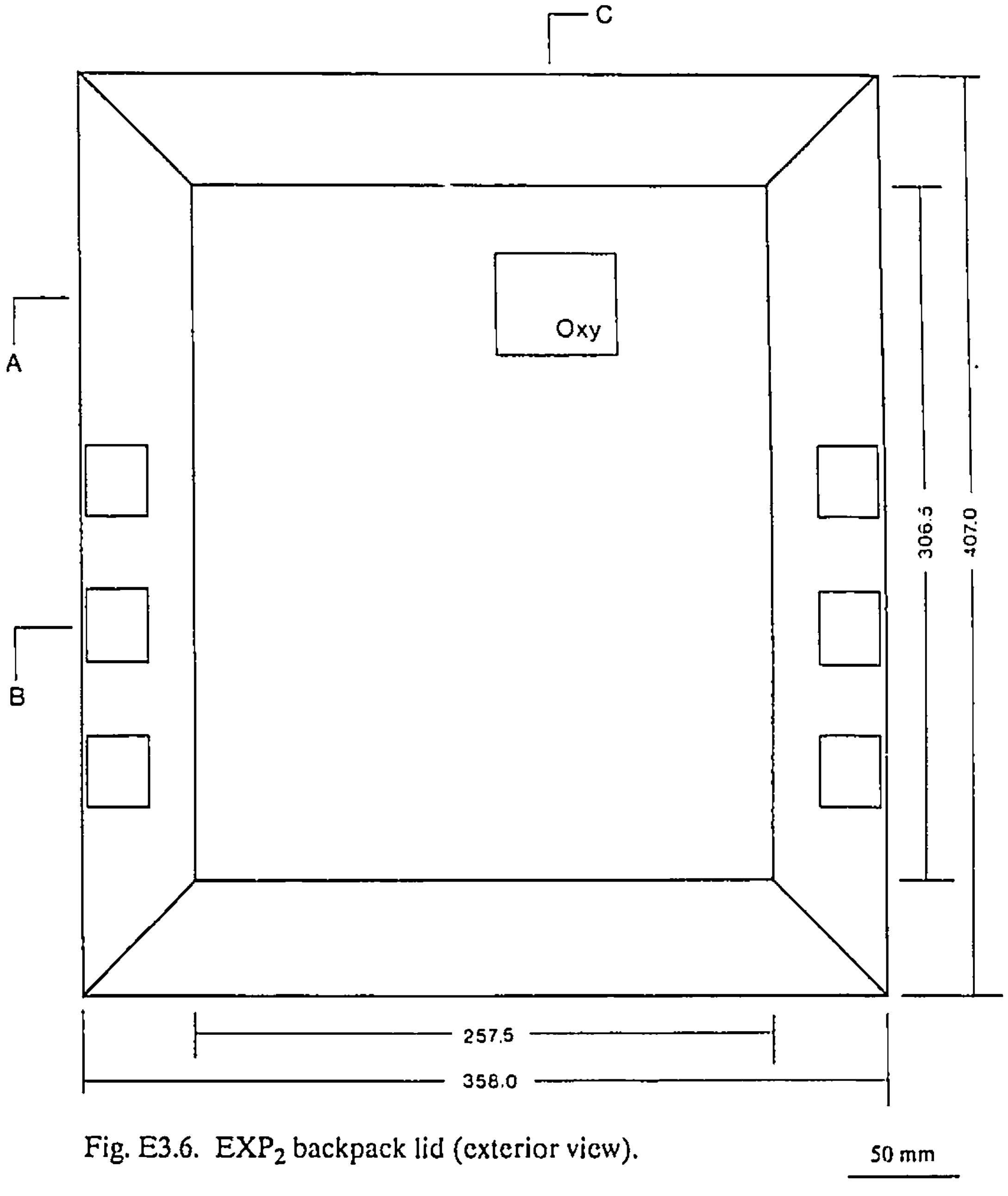


Fig. E3.6. EXP$_2$ backpack lid (exterior view).

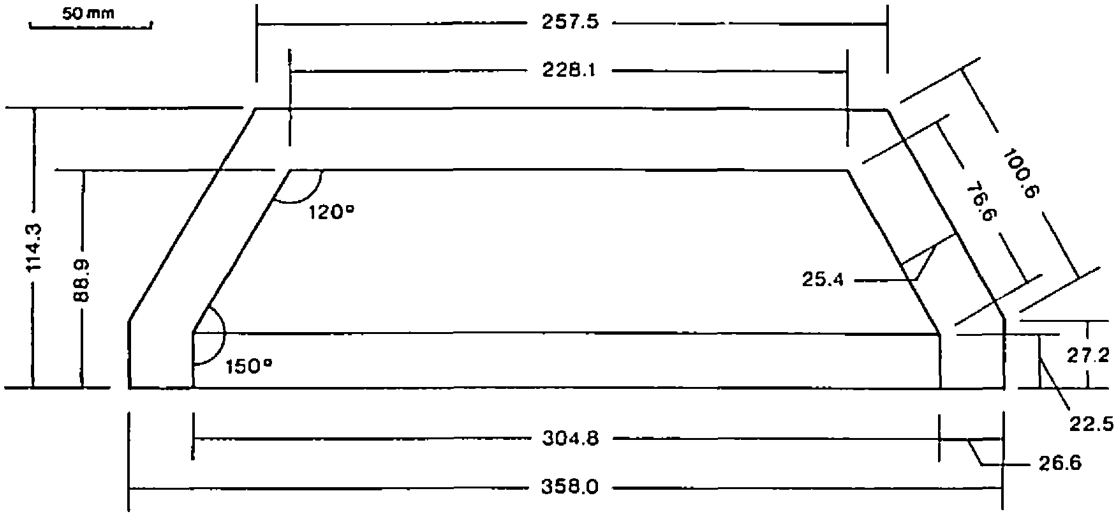


Fig. E3.7. EXP$_2$ backpack lid (cross section interior plan).

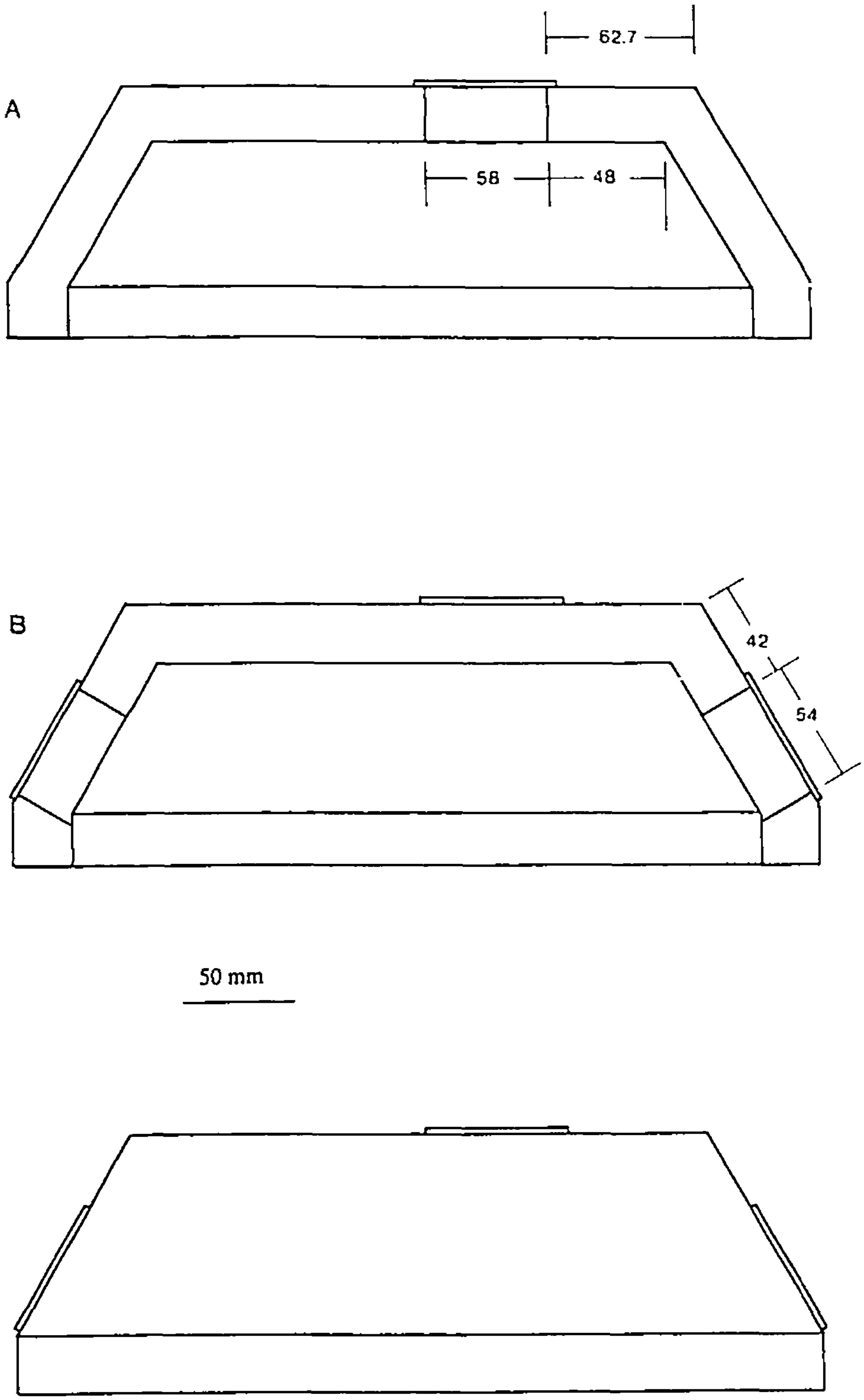


Fig. E3.8. EXP_2 backpack lid (XS at A and B; end view).

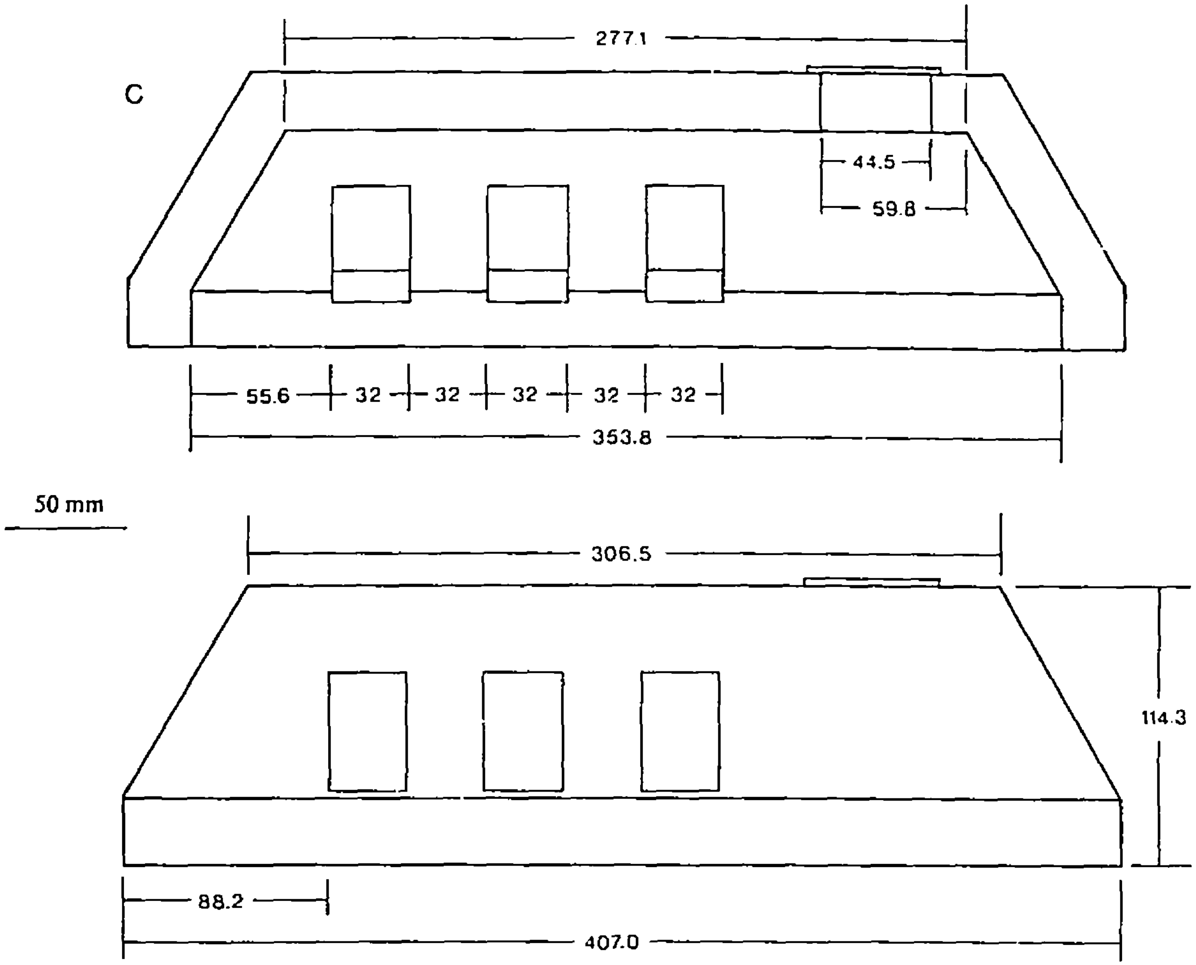


Fig. E3.9. EXP_2 backpack lid (LS at C and exterior side view).

APPENDIX F. MOTOR PERFORMANCE TESTS

F1. Grip Dynanometer

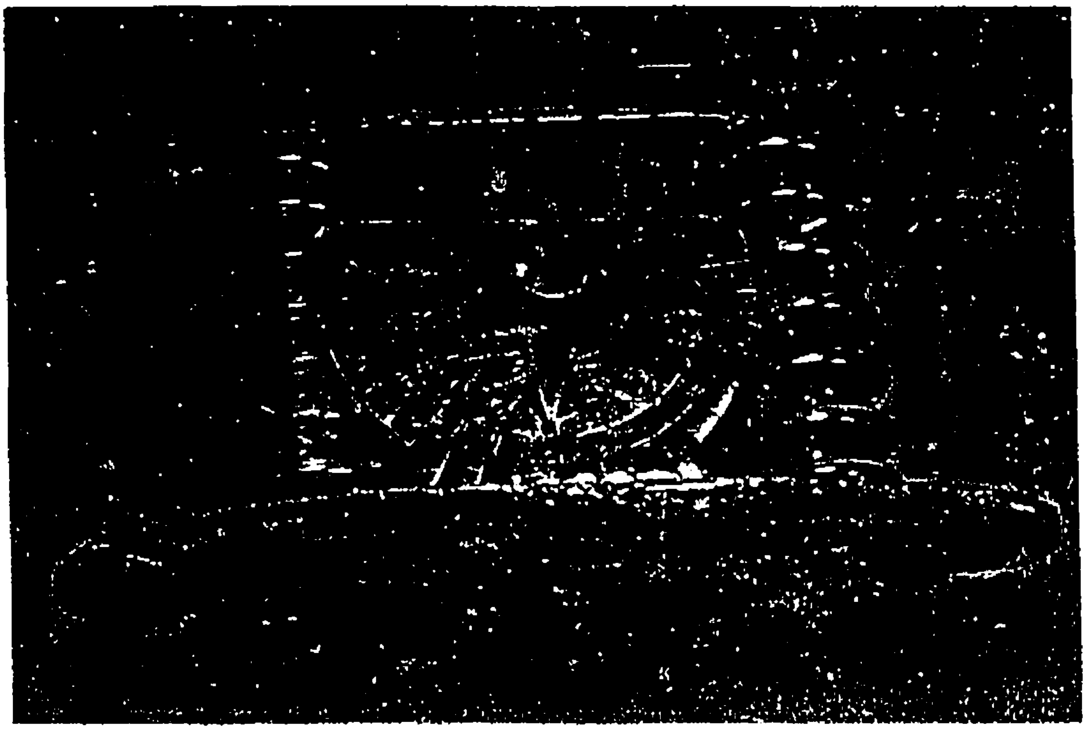
F2. Threading Test

F3. Balance Beam

F4. Target Shoot

Appendix F1. Grip Dynanometer

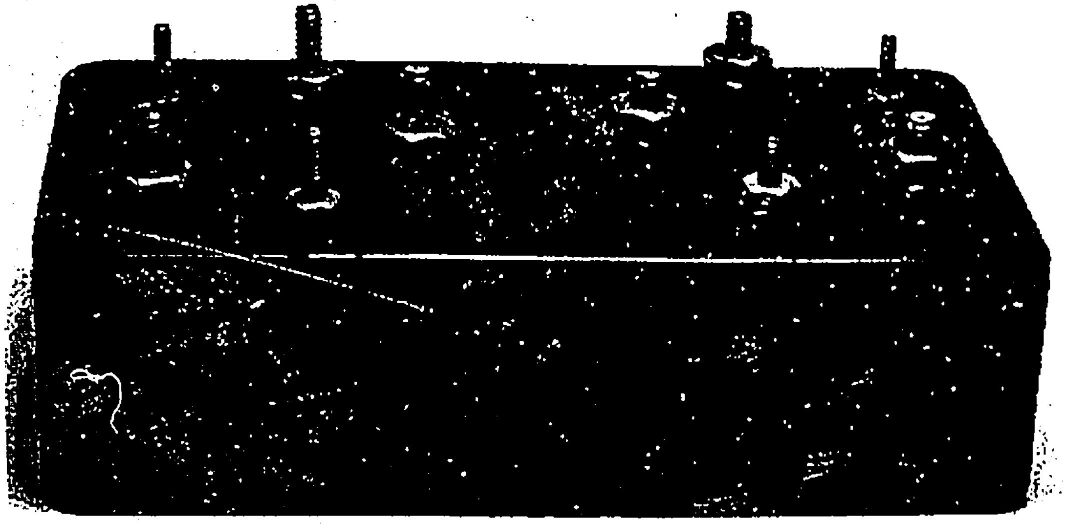
Fig. F1.1. The Narragansett grip dynanometer. The subject held the dynanometer in the palm of his preferred hand, the scale facing up and the pointer directed distally.



Appendix F2. Threading Test

Fig. F2.1. The *Wet Walk* threading test: (a) top, (b) side, and (c) end views. The threading test was made from a small plastic utility box (Hammond Manufacturing 1591 BS), with bolts projecting from the underside of the lid in a symmetrical, mirrored pattern. The task was to transfer the bolts from the left to right side as quickly as possible; Fig. F2.1 shows a completed test (only the upper nut was transferred; the lower nut was epoxied to the box).

Fig. F2.2. The *Wet Walk* threading test (construction detail). Five different-sized bolts (machine screws) were used: (1) 10/32; (2) 2/56; (3) 6/32; (4) 8/32; and (5) 4/40. The machine screws were permanently affixed to the lid with epoxy; the base nut was immoveable. The bolts were cut off to a constant length of 10 mm.



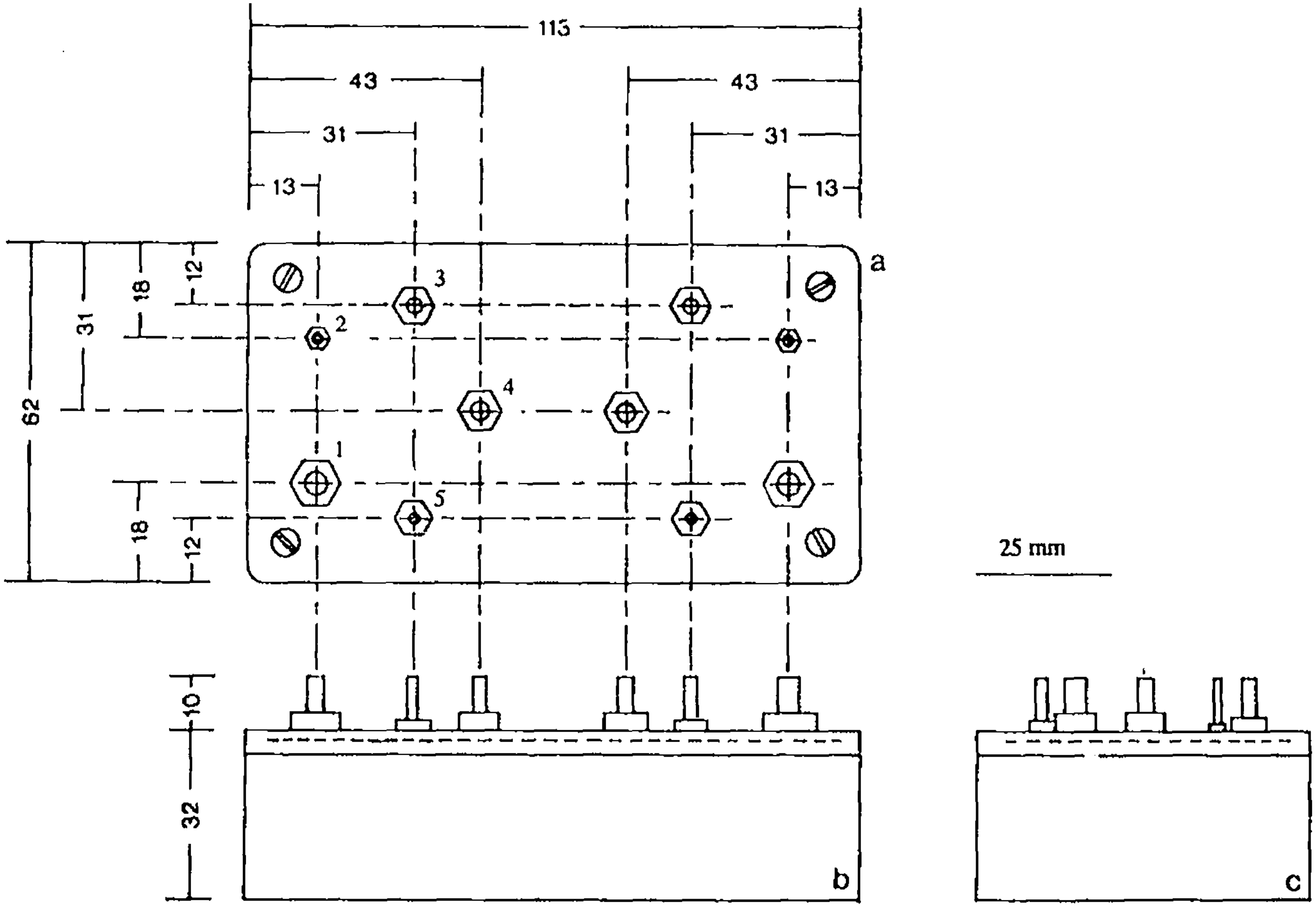


Fig. F2.2. The *Wet Walk* threading test (construction detail).

Appendix F3. Balance Beam

Fig. F3.1. The *Wet Walk* balance beam. The balance beam was a 305-cm length of 2 × 6-in kiln-dried fir set on edge in three 35-cm half-rounds of fir. The ground level–beam surface elevation was 14 cm. Step on/off marking plates were placed 30 cm in front of the beam. The balance beam was located on level ground adjacent to the *Wet Walk*.

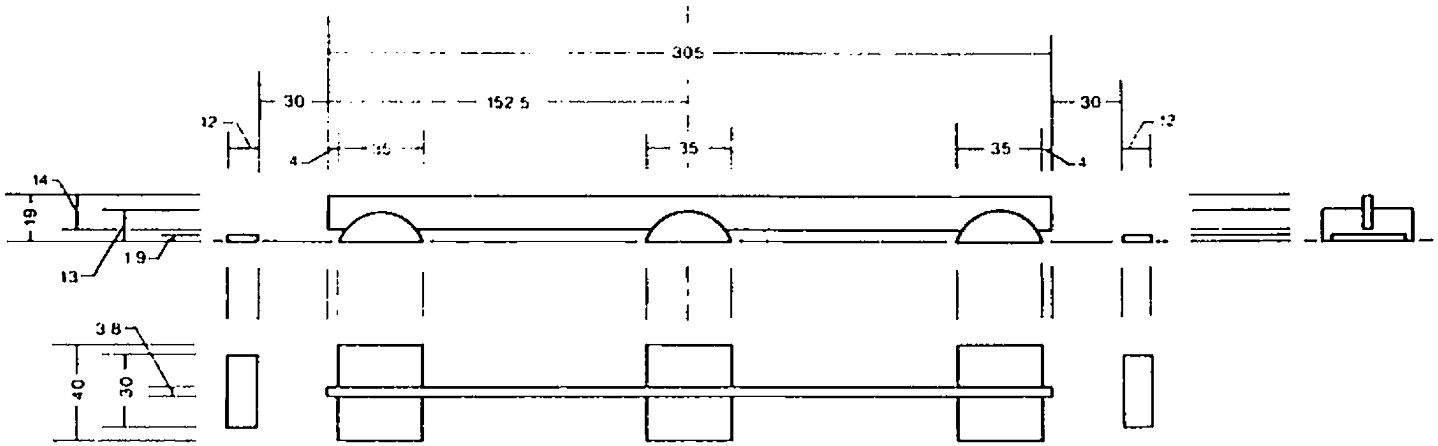


Fig. F3.1. The *Wet Walk* balance beam (construction detail).

Appendix F4. Target Shoot

A target shoot was devised as a general measure of coordination. The description of the target shoot is given in three parts: (a) description of the camera "gun"; (b) description of the target; and (c) negative image and scoring. The target is seen in position at the *Wet Walk* in Fig 3.1.

Figs. F4.1 - F4.3. The target camera gun.

Fig. F4.1. The *Wet Walk* camera shoot camera mount. The camera (Pentax Spotmatic II with Takumar 105 macro lens) was mounted on a tripod mount (C) embedded in an 18-mm plywood base bolted onto a gun stock. The bolt holes were centered in the gunstock. The complete unit is shown in Fig. 3.1(d); it weighed 2.15 kg (gun stock and mount 1.12 kg).

Fig. F4.2. Base for the target shoot camera mount (top view). The threaded camera tripod mount (C) was inserted and epoxied into the base. The shutter release cable ran up from the trigger mechanism to the camera through a hole (S) drilled in the plywood base.

Fig. F4.3. Cable release trigger mechanism. The trigger mechanism was a thin steel 90° bracket attached to the stock through the rear bolt; the hole in the bracket is at (b). A shutter cable release ran throught the 1-cm diameter hole in the bracket (a) and kept in place with a sleeve attached on the opposite side. The cable release mechanism is visible in Fig. 3.1(d).

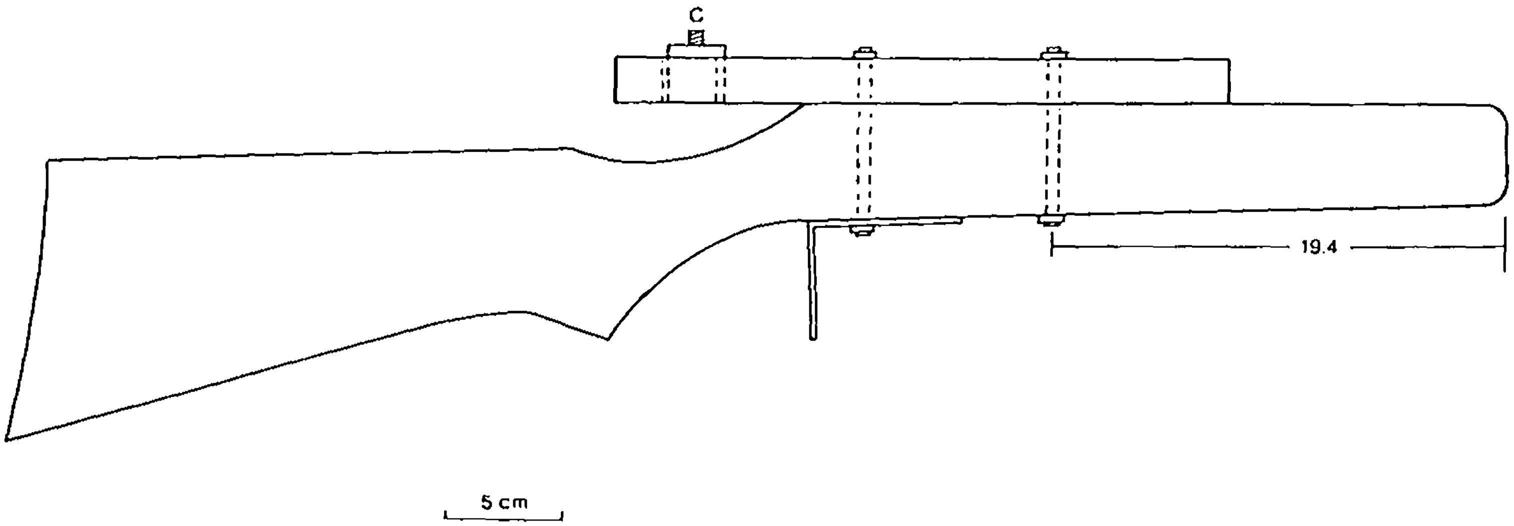


Fig. F4.1. The *Wet Walk* target shoot camera mount (detail).

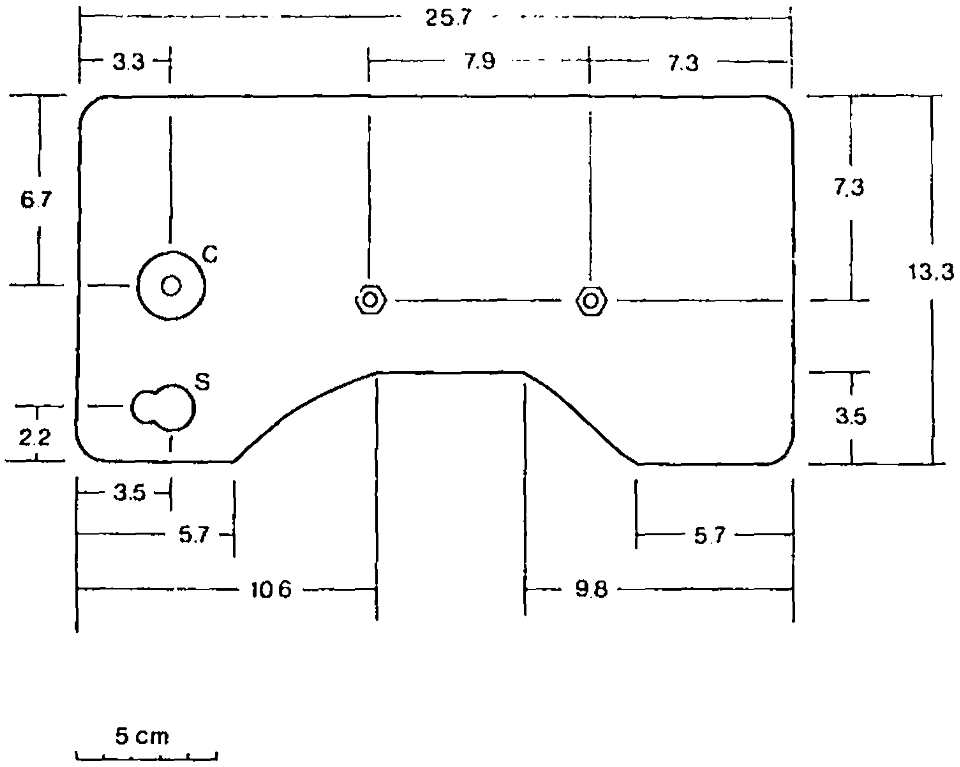


Fig. F4.2. Base for the target shoot camera mount.

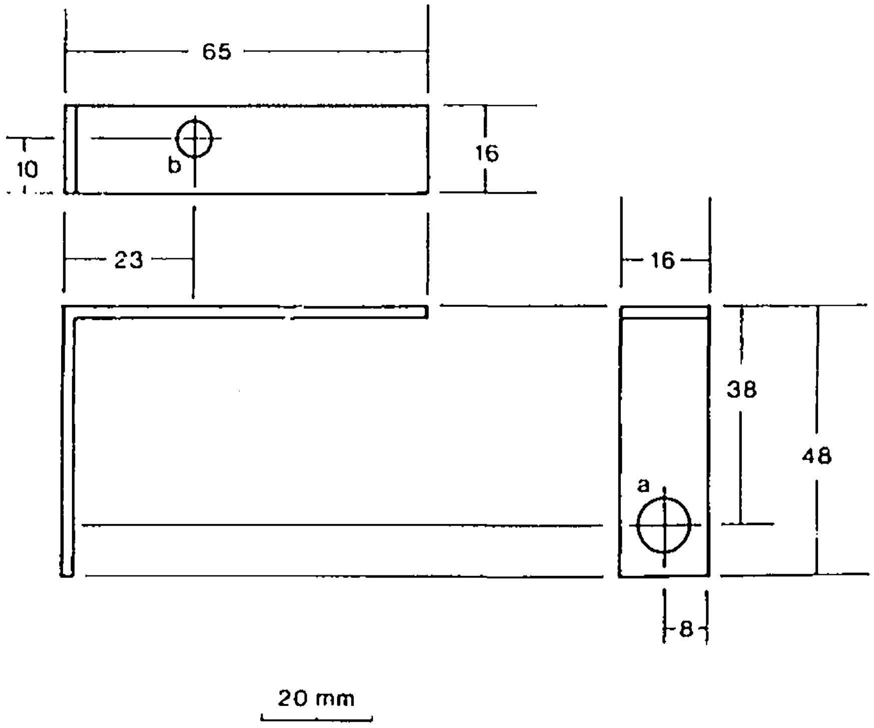


Fig. F4.3. Cable release trigger mechanism.

Figs. F4.4 - F4.5. The target shoot target.

Fig. F4.4. The *Wet Walk* target shoot target (detail). The target was a 6.7-cm-diameter black circle painted on a large sheet of white, opaque 3-mm plexiglass, with a 1-mm white crosshair in the center. Holes (0.5 cm) were drilled in the plastic to attach the target to a steel fence post.

Fig. F4.5. Target location detail (target shoot). The target was attached to a steel fence post with plastic ties and set firmly into the ground on a slight rise at the west end of the balance beam adjacent to the *Wet Walk*. The target center was at an elevation of 1.75 cm at the point of shooting, 5.05 m from the target.

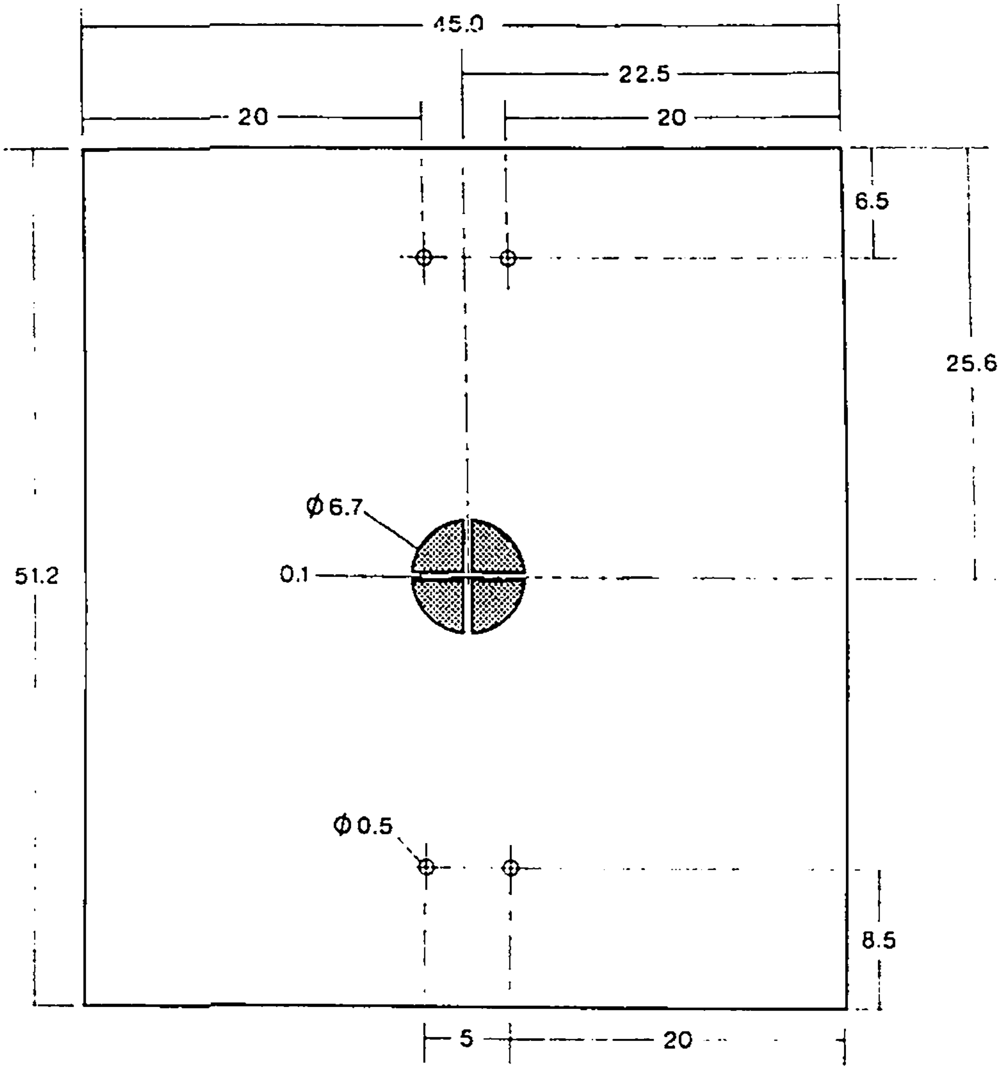


Fig. F4.4. The *Wet Walk* target shoot target (detail).

10 cm

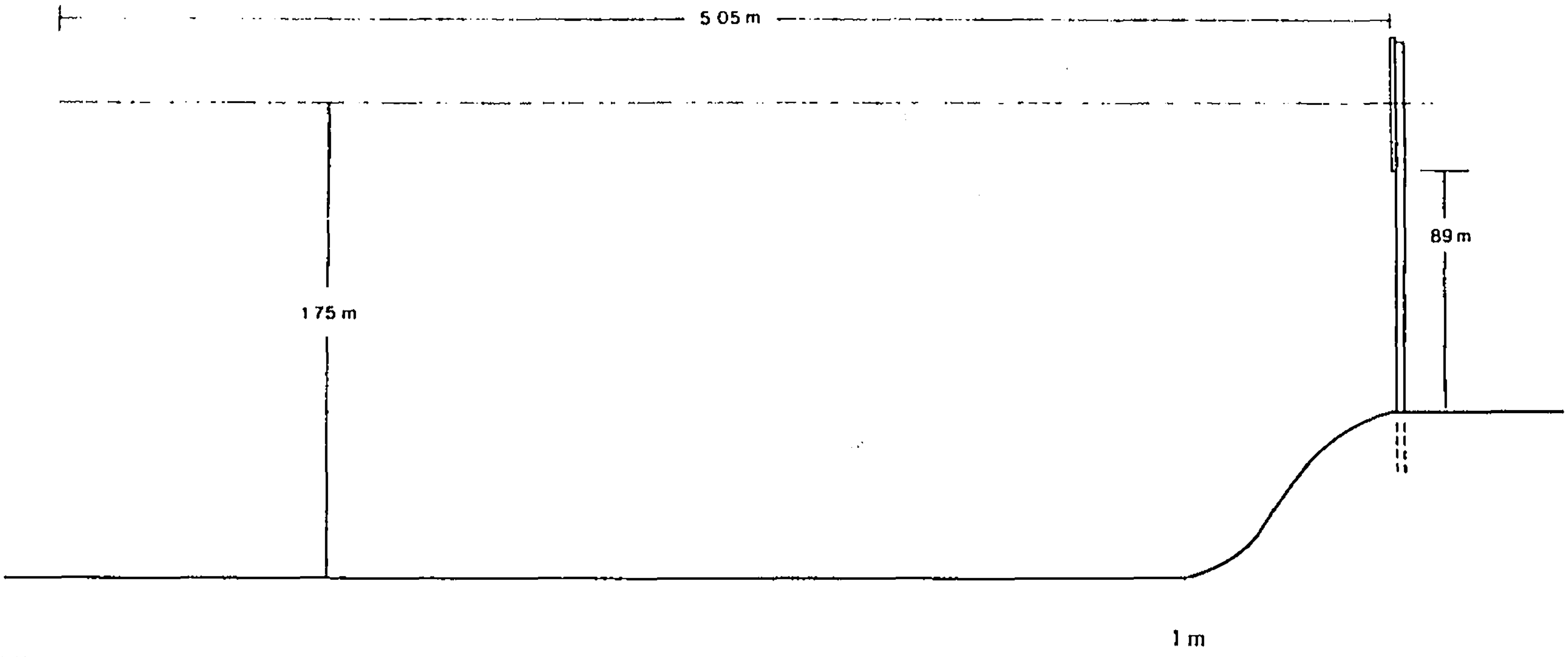
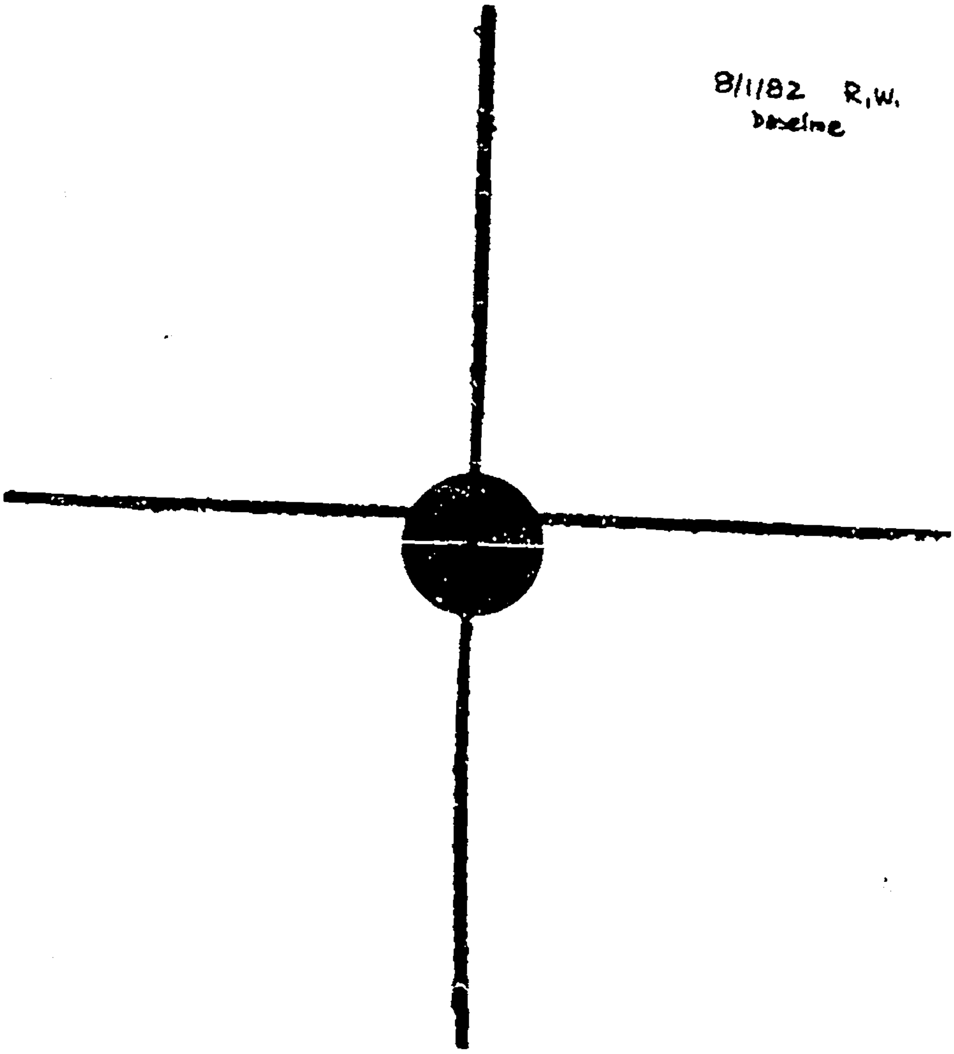


Fig. F4.5. Target location detail (target shoot).

Fig. F4.6. A "shot" (positive image) of the target shoot. During each test sequence, a subject took 10 pictures of the target; over the course of an experimental session, 7 sequences of 10 shots were recorded. When the film was developed, the negative was placed in a film projector, and difference between the camera center (thin black crosshair) and target center (white crosshair) measured.



8/1/82 R.W.
Baseline

APPENDIX G. PSYCHOLOGICAL TESTS AND SCALES

G1. *PETER* Subtest

G2. Baddeley Test

G3. Sensory Scale Tray

Appendix G1. *PETER* Subtest

The *PETER* subtest was generated by the U.S. Naval Health Research Center, San Diego, California. A sample of the test is included in this appendix. The original was printed on large format paper (27.9 × 35.6 cm); the sample version is a 64% reduction, with the exception of the tapping test (55%). The subtest includes four tests: Baddeley reasoning test (including instructions/practice sheet), code substitution test (no instructions or practice sheet; printed on 21.6 × 27.9-cm paper), number comparision test (instruction/ practice sheet included; only 1 of the 5 pages of this test have been included), and tapping test (no instructions/practice sheet included). The tests were stapled together in sequence.

NAME: ______________________

Session: ______________________

Date/Time: ______________________

PETER SUBTEST*: U.S. Naval Health Research Center
San Diego, California

Contents:

Instructions to Volunteer
Baddeley Test
Code Substitution Test
Number Comparison Test
Tapping Test

Instructions to Volunteer:

This test consists of 4 parts. Each part is timed. The purpose of the test is to determine how well you can answer the questions during the breaks in the 6-hour hike. Do your best on each test, even though you feel fatigue or discomfort. It is important that you start and stop each test when indicated by the test administrator. Clear up any questions about the test during the practice session. The test is to be completed 8 times: The first is a baseline test before the hike; the second through the fifth will be during the hike, and the last test will be given after you have rested at the end of the session. When working on the tests, remember that is is more important to be accurate than to be fast but inaccurate.

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*Derived from Kennedy, R.S., Carter, R.C., & Bittner, A.C., Jr. A Catalogue of Performance Evaluation Tests for Environmental Research. Proceedings of the 24th Annual Meeting of the Human Factors Society, Los Angeles, CA., October 1980.

NAVAL AEROSPACE MEDICAL RESEARCH LAB
BOX 29407
MICHOUD STATION
NEW ORLEANS LOUISIANA 70189

BY C.C.I. INC.
FOR
HUMAN FACTORS DIVISION

NAME: SSN: DATE/TIME:

THIS IS A TEST TO SEE HOW QUICKLY AND ACCURATELY YOU CAN UNDERSTAND COMPLEX STATEMENTS. IT IS NOT EXPECTED THAT YOU WILL FINISH ALL THE PROBLEMS IN THE TIME ALLOWED.

YOU ARE TO PLACE A SLASH THROUGH THE CORRECT ANSWER, T OR F, DEPENDING ON WHETHER EACH STATEMENT IS TRUE OR FALSE. SEVERAL PRACTICE PROBLEMS ARE GIVEN, AND THE FIRST TWO ARE CORRECTLY WORKED FOR YOU.

THIS PRACTICE MAY HELP YOUR SCORE.

PRACTICE PROBLEMS:

```
1.  A FOLLOWS B ---------- [BA]    /     F
2.  B PRECEDES A --------- [AB]    T     /
3.  A IS FOLLOWED BY B --- [AB]    T     F
4.  B IS NOT FOLLOWED BY A [BA]    T     F
5.  B IS PRECEDED BY A --- [BA]    T     F
6.  A DOES NOT PRECEDE B - [BA]    T     F
```

YOUR SCORE ON THIS TEST WILL BE THE NUMBER OF PROBLEMS ANSWERED CORRECTLY.

DO NOT TURN THIS PAGE UNTIL YOU ARE ASKED TO DO SO.

TEST GENERATION ID
DATE= 111380 QLI# 161311
NBR= 3 COPY= 14

```
                    BADDELEY TEST NBR  3 COPY 14                        DATE= 111380 CEIN  161311




  1.   B IS NOT FOLLOWED BY A [BA]      T       F
  2.   B DOES NOT FOLLOW A    [BA]      T       F
  3.   B FOLLOWS A            [BA]      T       F
  4.   B DOES NOT PRECEDE A   [BA]      T       F
  5.   B IS FOLLOWED BY A     [BA]      T       F
  6.   B IS FOLLOWED BY A     [AB]      T       F
  7.   B IS NOT PRECEDED BY A [AB]      T       F
  8.   A PRECEDES B           [AB]      T       F
  9.   A DOES NOT PRECEDE B   [BA]      T       F
 10.   B IS PRECEDED BY A     [BA]      T       F
 11.   B IS NOT PRECEDED BY A [BA]      T       F
 12.   B IS NOT FOLLOWED BY A [AB]      T       F
 13.   A DOES NOT PRECEDE B   [AB]      T       F
 14.   A IS FOLLOWED BY B     [AB]      T       F
 15.   B DOES NOT FOLLOW A    [AB]      T       F
 16.   A IS PRECEDED BY B     [AB]      T       F
 17.   B PRECEDES A           [BA]      T       F
 18.   A IS NOT PRECEDED BY B [AB]      T       F
 19.   A FOLLOWS B            [AB]      T       F
 20.   A IS PRECEDED BY B     [BA]      T       F
 21.   A IS NOT FOLLOWED BY B [BA]      T       F
 22.   A FOLLOWS B            [BA]      T       F
 23.   A IS FOLLOWED BY B     [BA]      T       F
 24.   A IS NOT FOLLOWED BY B [AB]      T       F
 25.   B PRECEDES A           [AB]      T       F
 26.   B DOES NOT PRECEDE A   [AB]      T       F
 27.   A DOES NOT FOLLOW B    [BA]      T       F
 28.   B IS PRECEDED BY A     [AB]      T       F
 29.   A PRECEDES B           [BA]      T       F
 30.   B FOLLOWS A            [AB]      T       F
 31.   A DOES NOT FOLLOW B    [AB]      T       F
 32.   A IS NOT PRECEDED BY B [BA]      T       F
```

DAY 3
DATE________________

NAME________________ ______

CODING TEST

CODE	B	L	M	F	S	Z	X	H	J
DIGIT	(1)	(5)	(4)	(9)	(3)	(7)	(6)	(2)	(8)

S X B J F J X J L B M J Z F S B J L
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J S H L Z B H F L J F J M S B F J H
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M B S X H B X H J S J L X J F X J M
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L X B X H Z H X X F H L S F Z H F L
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B Z F M F H X S Z L M L H J B S X S
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F S L B Z B M L S H B L H B X S J X
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H B X H L M S X H Z X F S L H X F L
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B M L H F Z J F B X S M H X L B Z F
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S H M F J M J M H M S B S H B H L F
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J S H X Z H S X H M H Z X J M S F Z
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S J S L H B H M Z L J X M S X Z H F
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X M J F H X F J S Z S X Z B M J F M
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F M Z S B M S S M S L J Z L B X M Z
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NAME: SUBJECT NUMBER: DAY/DATE/TIME:

NUMBER COMPARISON TEST,FORM 3

INSTRUCTIONS

THIS IS A TEST OF HOW QUICKLY YOU CAN COMPARE TWO NUMBERS AND DECIDE WHETHER THEY ARE THE SAME.IF THE NUMBERS ARE THE SAME, PUT S ON THE LINE BETWEEN THEM. IF THE NUMBERS ARE DIFFERENT, PUT D ON THE LINE BETWEEN THEM. SEVERAL EXAMPLES ARE GIVEN BELOW WITH THE FIRST THREE MARKED CORRECTLY. PRACTICE FOR SPEED ON THE OTHERS. WORK FROM LEFT TO RIGHT, ROW BY ROW.

123456789--S--123456789 135465--D--125465 7013487--S--7013487

29998-----29998 851217-----801217 16726842-----16726872

130-----150 65475067-----65475867 7782478-----6782428

8980851-----9980851 44956-----44556 283580226-----283580228

879758-----878759 72307-----62307 742-----727

892-----892 5555-----5555 1274243-----1274243

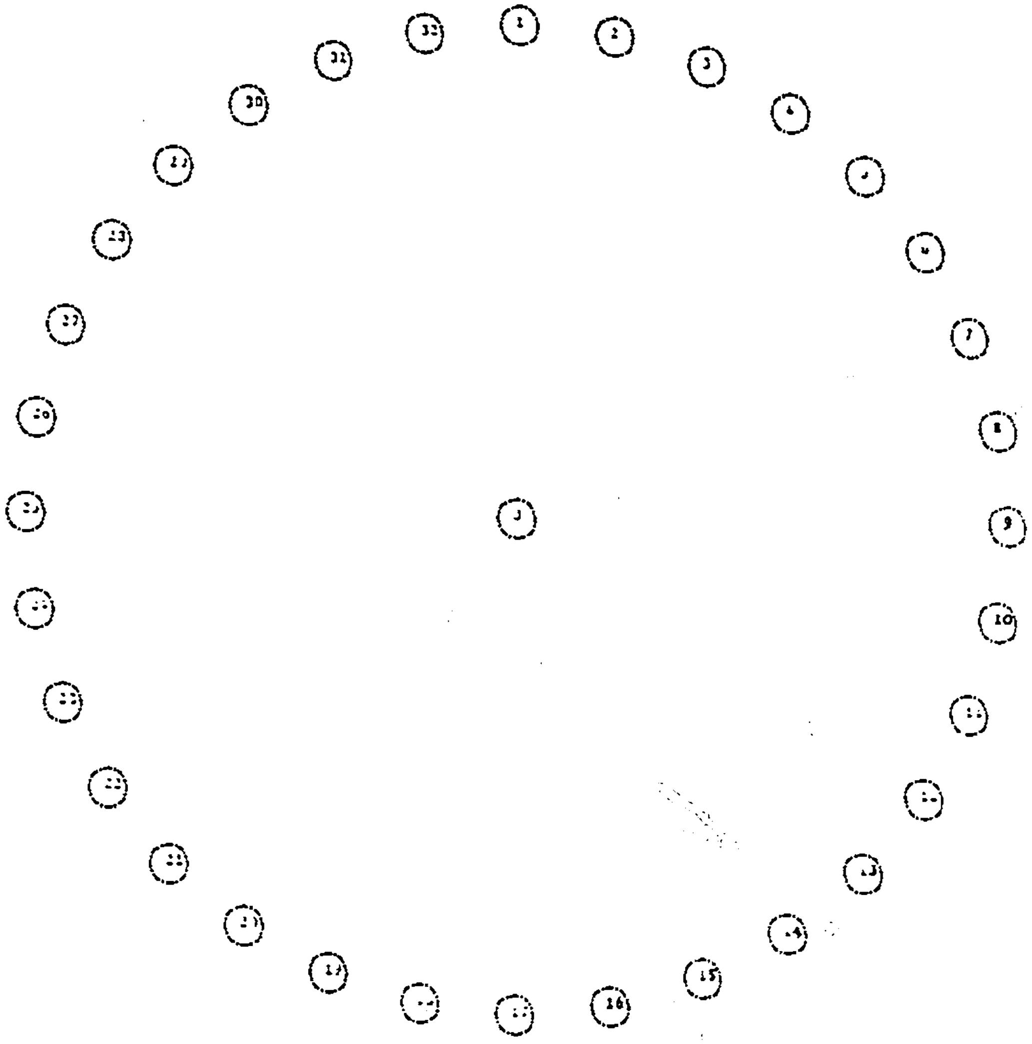
192-----190 977213585-----977213585 402-----802

3087-----3087 73141989-----53141989 1543-----1943

YOUR SCORE WILL BE THE NUMBER OF PAIRS MARKED CORRECTLY MINUS A FRACTION OF THE NUMBER MARKED INCORRECTLY. THEREFORE IT WILL NOT BE TO YOUR ADVANTAGE TO GUESS UNLESS YOU HAVE SOME IDEA OF WHETHER OR NOT THE NUMBERS ARE THE SAME.
YOU WILL HAVE THREE (3) MINUTES FOR THIS TEST. IT HAS SEVERAL PAGES.
SO WHEN YOU FINISH ONE PAGE PLEASE GO ON TO THE NEXT UNTIL YOU ARE ASKED TO STOP.

DO NOT TURN THIS PAGE UNTIL ASKED TO BEGIN.

```
21649037-----21649037      176-----156              7337-----7339

407001-----407001          3129512-----3129512      698826116-----698826116

912452-----912452          586923012-----586923012  5119-----5118

54702147-----54702147      9437956-----9434958      7243-----7243

4352-----4452              43904114-----43904114    324608-----324308

941509294-----941509294    3314-----3314            929145-----929145

430145-----430145          908005281-----908005281  518-----618

88561-----88561            76700510-----76708518    8265-----8265

50062907-----59062907      951-----956              427-----428

648034684-----643034684    990-----950              472-----476

381683930-----381883930    829-----899              017999-----017999

97866-----77066            643828155-----643828158  1336-----1336

441-----444                58580992-----58580992    0015032-----0015032

034762-----034762          79459776-----79489778    443-----449
```


32
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31

Appendix G2. Baddeley Test

A sample of the Baddeley test used in EXP_2 is included in this section. The original, generated by N.H.R.C. (San Diego, CA) includes the cover and 10 consecutive tests stapled together. The sample given here is an 85% reduction of the original.

NAVAL AEROSPACE MEDICAL RESEARCH LAB
Box 29407
Michoud Station
New Orleans, Louisiana 70189

Human Factors Division

Name: SSN: Date/Time:

This is a test to see how quickly and accurately you can understand complex statements. It is not expected that you will finish all the problems in the time allowed.

You are to place a slash through the correct answer, T or F, depending on whether each statement is true or false. Several practice problems are given, and the first two are correctly worked for you.

This practice may help your score.

Practice Problems:

1. A follows B ------------- [BA] / F
2. B precedes A ------------ [AB] T /
3. A is followed by B ------ [AB] T F
4. B is not followed by A -- [BA] T F
5. B is preceded by A ------ [BA] T F
6. A does not precede B ---- [BA] T F

Your score on this test will be the number of problems answered correctly. Do not turn this page until you are asked to do so.

①

1.	A IS NOT PRECEDED BY B	[BA]	T	F
2.	B IS PRECEDED BY A	[AB]	T	F
3.	B PRECEDES A	[BA]	T	F
4.	B IS NOT FOLLOWED BY A	[AB]	T	F
5.	A FOLLOWS B	[BA]	T	F
6.	A IS PRECEDED BY B	[BA]	T	F
7.	A IS NOT FOLLOWED BY B	[AB]	T	F
8.	A PRECEDES B	[BA]	T	F
9.	B IS FOLLOWED BY A	[AB]	T	F
10.	B IS FOLLOWED BY A	[BA]	T	F
11.	A IS PRECEDED BY B	[AB]	T	F
12.	A FOLLOWS B	[AB]	T	F
13.	B FOLLOWS A	[BA]	T	F
14.	A DOES NOT FOLLOW B	[BA]	T	F
15.	B IS NOT FOLLOWED BY A	[BA]	T	F
16.	B DOES NOT PRECEDE A	[AB]	T	F
17.	A IS FOLLOWED BY B	[BA]	T	F
18.	A IS FOLLOWED BY B	[AB]	T	F
19.	B DOES NOT FOLLOW A	[BA]	T	F
20.	B IS PRECEDED BY A	[BA]	T	F
21.	B IS NOT PRECEDED BY A	[AB]	T	F
22.	A DOES NOT FOLLOW B	[AB]	T	F
23.	A DOES NOT PRECEDE B	[BA]	T	F
24.	A IS NOT PRECEDED BY B	[AB]	T	F
25.	B PRECEDES A	[AB]	T	F
26.	A DOES NOT PRECEDE B	[AB]	T	F
27.	B DOES NOT PRECEDE A	[BA]	T	F
28.	B IS NOT PRECEDED BY A	[BA]	T	F
29.	A PRECEDES B	[AB]	T	F
30.	B DOES NOT FOLLOW A	[AB]	T	F
31.	B FOLLOWS A	[AB]	T	F
32.	A IS NOT FOLLOWED BY B	[BA]	T	F

Appendix G3. Sensory Scale Tray

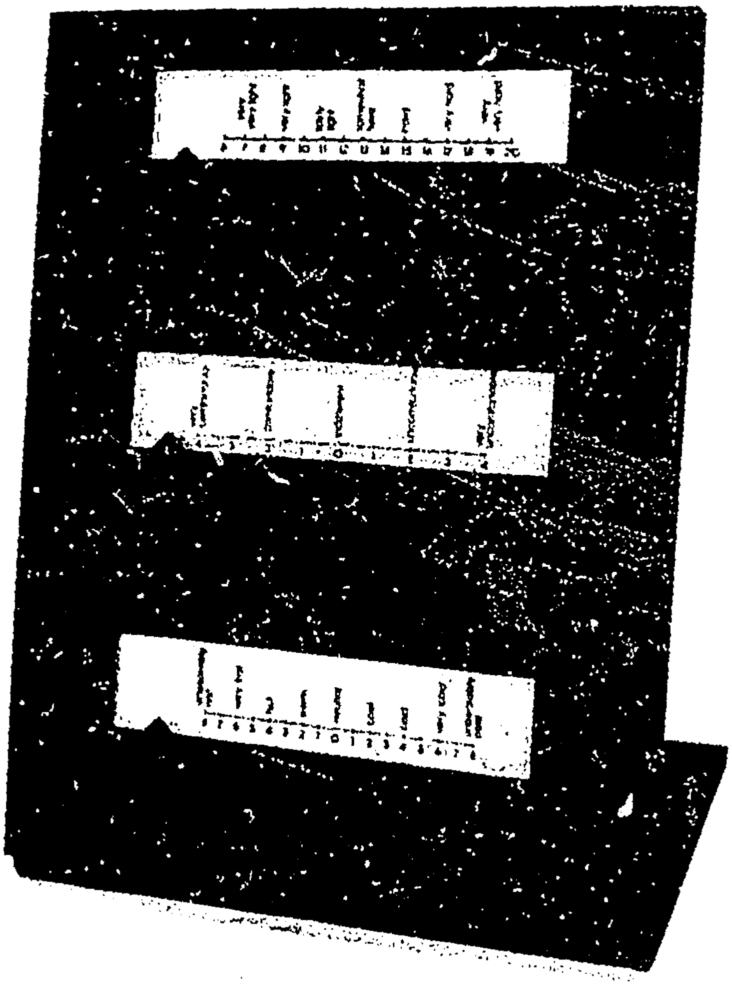
Fig. G3.1. Sensory scale tray. The self-reporting scales described in EXP_2 and EXP_3 were placed in this tray attached to a bench adjacent to the *Wet Walk* in the observation area. The purpose of the system was to provide a simple reporting system and simultaneously protect the scales from wetting. The subject slid the pointer to the appropriate point on the scale; the data was recorded and the scales reset.

Fig. G3.2. General plan of the *Wet Walk* sensory scale tray, showing the (a) left side, (b) front, and (c) back views. Note in (a) that the tray is made of two plates: an angled, rear support plate, and a flat, front cover plate, both made from clear 6-mm plexiglass.

Fig. G3.3. Detail of the angled support plate. Shallow grooves (1.5 mm) were cut in the plate to hold the paper scales. The angle was supported by a piece of plexiglass.

Fig. G3.4. Detail of the cover plate, showing (a) front, and (b) rear views. Slots (s) were cut in the cover (see cross-section A) for the pointers. The outer surface of the cover plate was painted flat black except for clear windows (w) for viewing the scales. The cover plate was screwed onto the angled support plate with plastic screws.

Fig. G3.5. Construction detail of the moveable pointer. The pointer was made of four plexiglass pieces: a red arrow (b), a knob (c), a shaft (d), and a rear locking plate (e). The complete unit is shown in (a). A spring was placed in a hole was drilled through the locking plate and shaft. A small plastic bearing was placed at the head of the spring when the pointer was mounted in the tray. The pressure forced the locking plate against the front cover plate, holding the pointer in position; light inward pressure freed the pointer.


6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
4 3 2 1 0 1 2 3 4
8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8

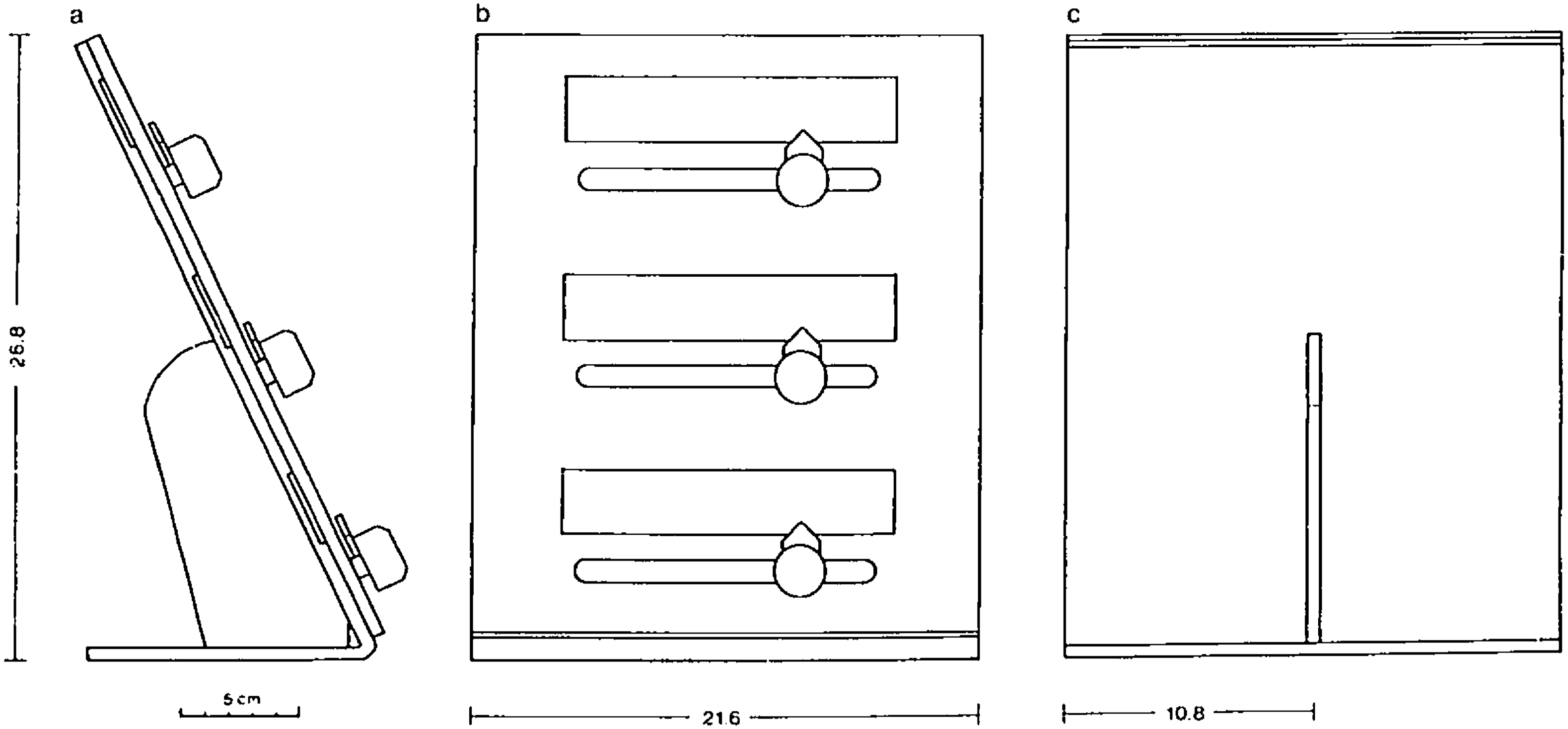


Fig. G3.2. General plan of the *Wet Walk* sensory scale tray.

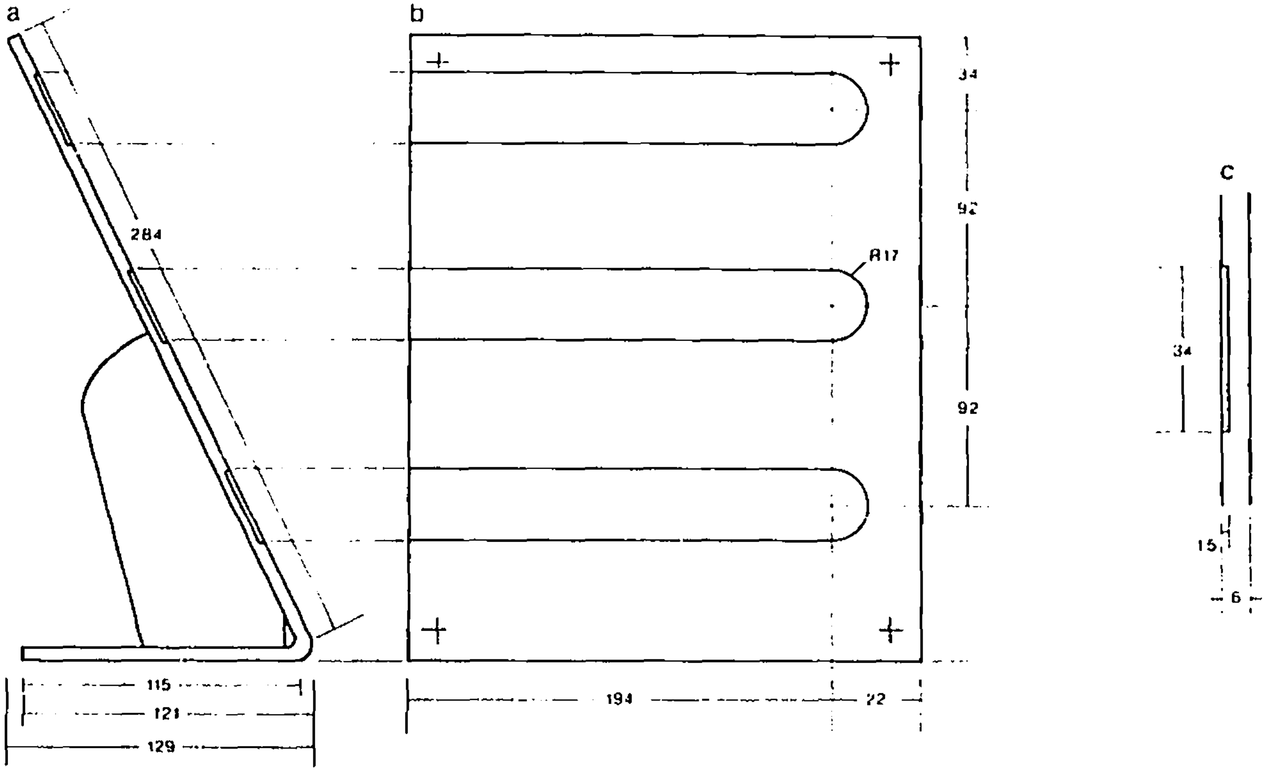


Fig. G3.3. Detail of the angled support plate.

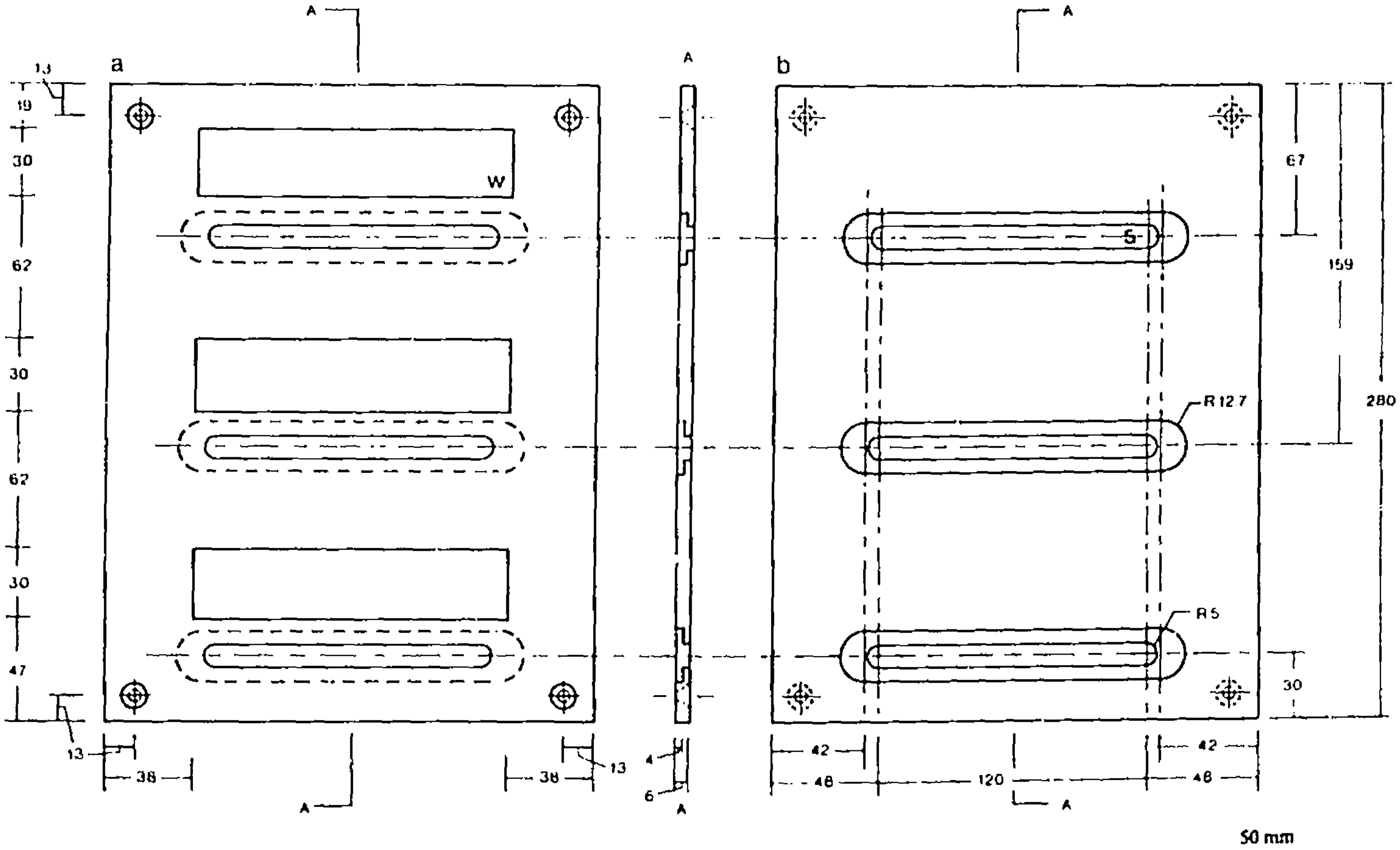


Fig. G3.4. Detail of the cover plate.

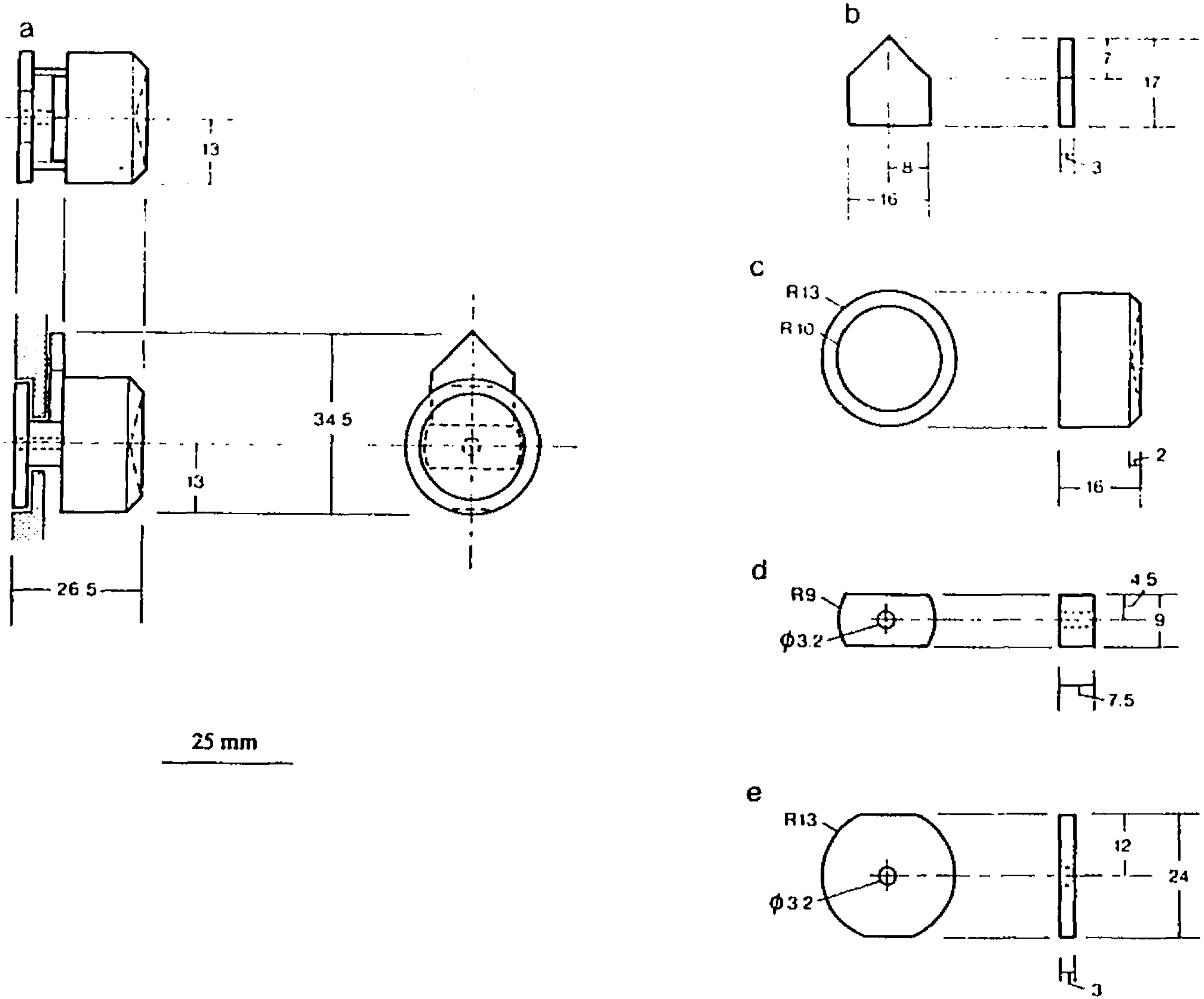


Fig. G3.5. Construction detail of the moveable pointer.

APPENDIX H. VIGILANCE TEST

Appendix H1. Preliminary Studies

The vigilance test was initially conceived to measure a characteristic behaviour shown by subjects during EXP_1. While walking in the rain, subjects spent much of the time looking downward at the ground; the general impression was that subjects were psychologically withdrawing from this stressful experience. Therefore it was presumed that a test of vigilance or attention would be appropriate; this goal was jointly pursued with the Naval Health Research Center (N.H.R.C.) in San Diego.

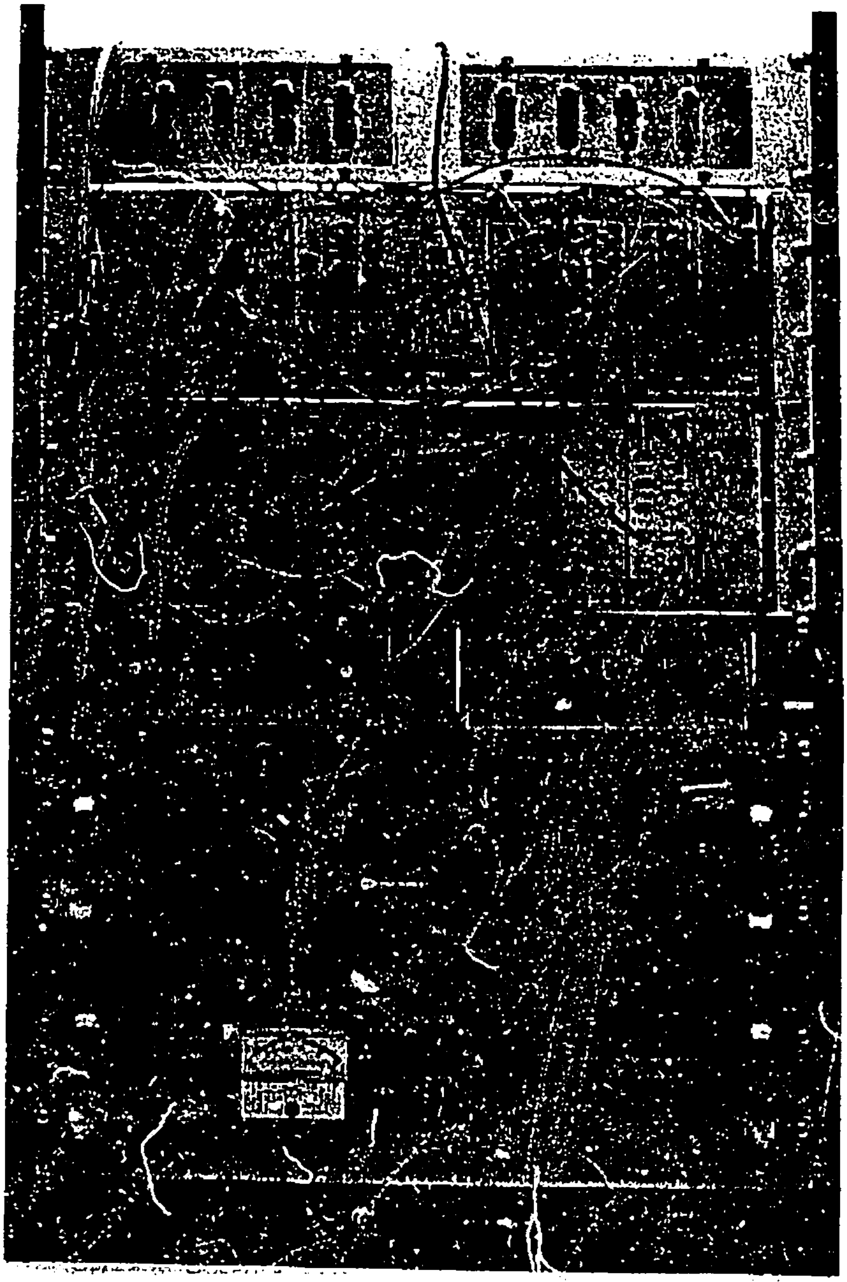
N.H.R.C. provided a system designed to produce signal outputs previously determined on a random basis; it included a paper tape reader (and paper tape with the predetermined random signal pattern), a logic system with output to eight 12V plugs (connected to light signals), and a pressure-sensitive foot pad placed on the *Wet Walk* for input into the system. The light-generating system provided by N.H.R.C. is shown in Fig. H1.1. The initial signal was a 4-inch-high illuminated numeral (from 1 to 8); eight signal lights were placed around the *Wet Walk*.

Difficulties were encountered immediately. Primarily, a significant change in behaviour occurred: subjects no longer showed the characteristic "heads-down" behaviour, but actively searched the environment for signals! As well, the hardware did not operate efficiently in the damp cold environment. Due to these inconsistencies, the vigilance test was not included in EXP_2.

In the next series of pilot studies, the numeral signal was discarded. The large size of the numeral, necessary for subjects to clearly identify the signal, made the test simple (errors were rare). A smaller signal consisting of three 3-mm points of light was tested; differentiation was based on (a) vertical (three vertically aligned light- points) or horizontal (three horizontally aligned light-points) position, and (b) color (red/blue/green/white). Again, subjects maintained a vigilant state not consistent with the original behaviour, and errors were rare,

Finally, it was decided to try a simple, lower frequency signal, in the hopes that a less distinctive, less frequent event would have less effect on behaviour. The signal frequency was reduced by 50%, from 20 to 10 signals per hour, and the signal was simplified to a single point of light (all signals the same). Initial pilot tests indicated that subjects did not score as consistently high in this test under dry conditions, and that "natural" behaviour was maintained. Therefore, a low frequency, mono-signal vigilance test was adopted.

Fig. H1.1. Vigilance test generator for EXP_2. Eight 12V lights were connected to logic output switches (upper deck). A paper tape reader was located in the lower center of the device. This system stood over 75 cm tall; it served the same function as the switch box (Fig H2.5) used in EXP_3.



Appendix H2. Signal Light Construction

The box containing the light source was constructed of 18-mm plywood. A standard 110V light fixture was mounted on risers in the center of the box (Figs. H2.1 and H2.2), the wire exiting out the bottom of the box. The front plate of the signal box was made of 6 mm plywood. Contruction details are described in Fig. H2.1.

Light sources were placed in long "tunnels" constructed of 13-mm plywood (Fig. H2.3). The opening at the front of the box was reduced to 2 cm by placing two 9.2-cm-wide panels on the front of the tunnel (Fig. H2.4).

Both the signal light box and tunnel were painted flat black.

Each light was connected to a 110V supply with standard lamp cord, in series with a single-pole switch, and assembled in a 9 × 16 cm plastic utility box (Fig. H2.6). The switch box was controlled from the observation area and protected from the subject's view by a screen (Fig. H2.5).

Fig. H2.1. Cross-section in of the signal light box (side view), showing detail of the front plate. The front plate (fp) was a 15 × 20-cm piece of 6-mm plywood, with a hole slightly larger than 4 mm drilled in the center. A piece of 3-mm sanded plexiglass (2 × 9 cm) was affixed to the rear side of plate opposite the hole. Three layers of green acetate film (a) were taped (Scotch transparent tape) to the inside surface of the plexiglass. Two pieces of plexiglass were fixed to the opposite, external surface. The inner pieces was similar to the plexiglass on the internal surface. A 3-mm hole was drilled in the center of the outer plexiglass. The net effect was to produce a green, 3-mm light point.

Fig H2.2. Front view of the signal light box, with (a) front plate in place, and (b) front plate removed. The surface of the signal light box was painted flat black, with the exception of the light hole. Compare to Fig. 4.2.

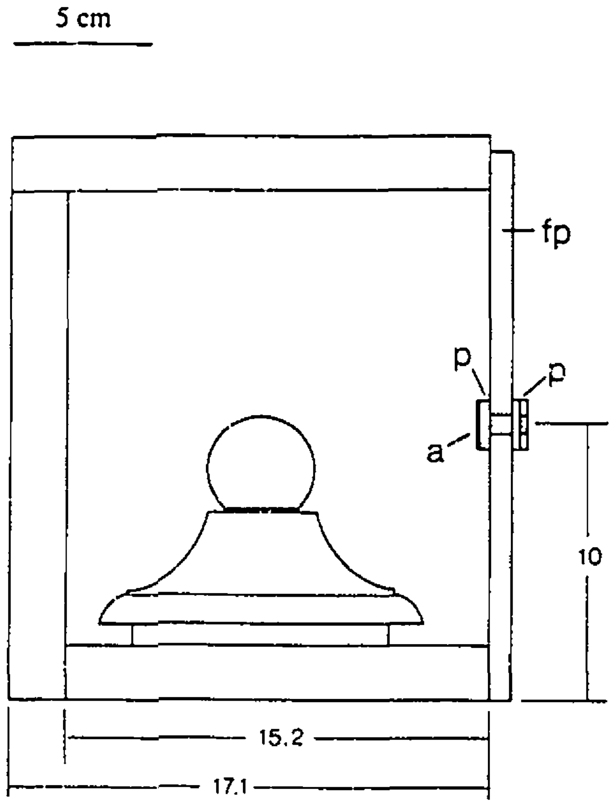


Fig. H2.1. Cross section of the signal light box.

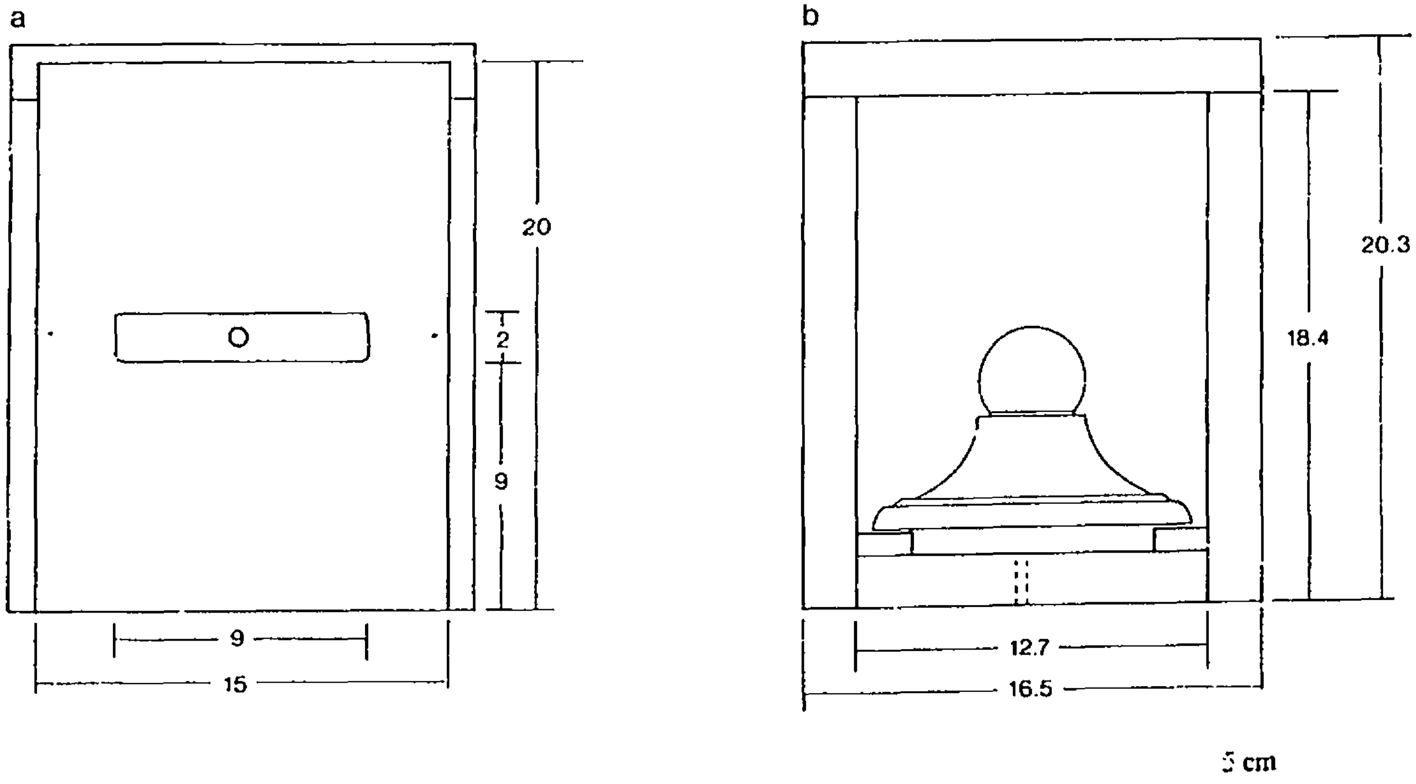


Fig. H2.2. Front view of the signal light box.

Fig. H2.3. The long box "tunnel", showing the position of the signal light box (screened area). The back of the tunnel was open for placement of the light box. The layer of wood behind the front plate (fp) represents the remnants of earlier modifications and serves no function in this design. The distance from the front of the light source to the front of the tunnel was approximately 27 cm.

Fig. H2.4. Front view of the light box tunnel. The narrow opening at the front of the box (2 cm) restricted the angle of view. The U-shaped structure behind the two 9.2 × 24.1-cm pieces of 6-mm plywood represents the remnants of earlier work referred to in Fig. H2.3.

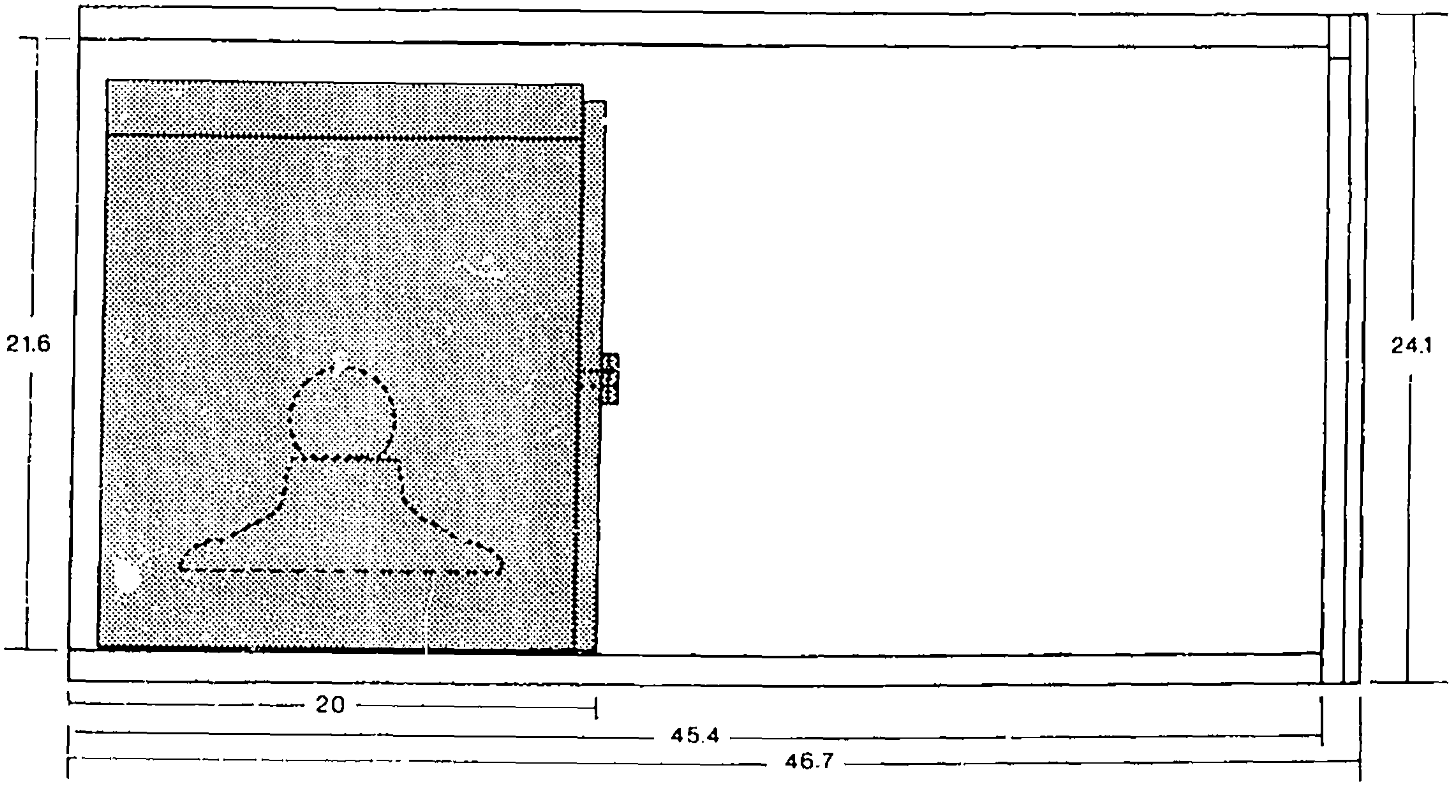


Fig. H2.3. The vigilance test light signal tunnel.

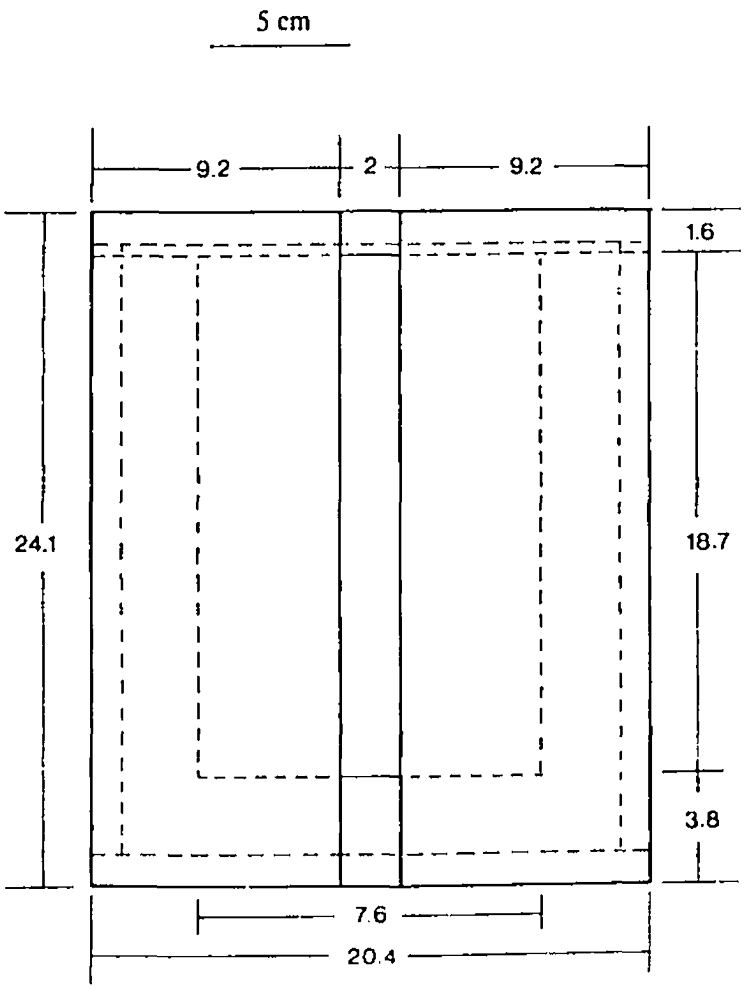
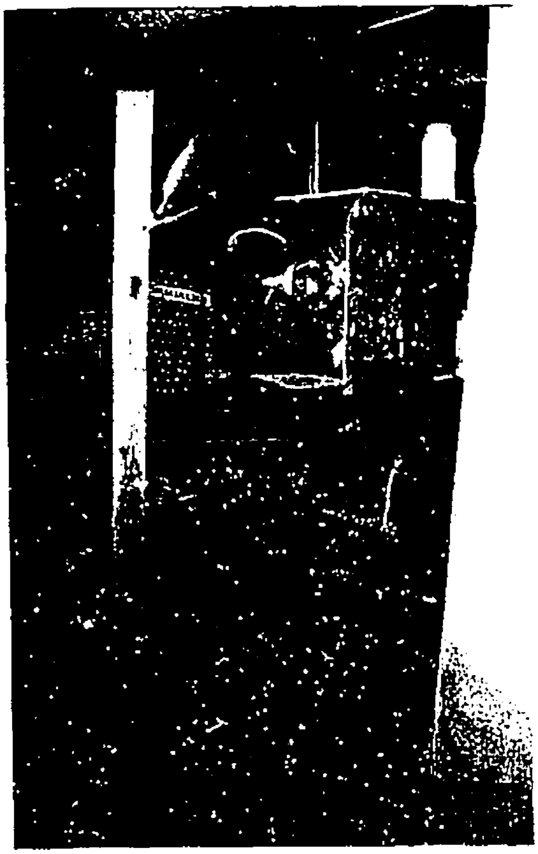
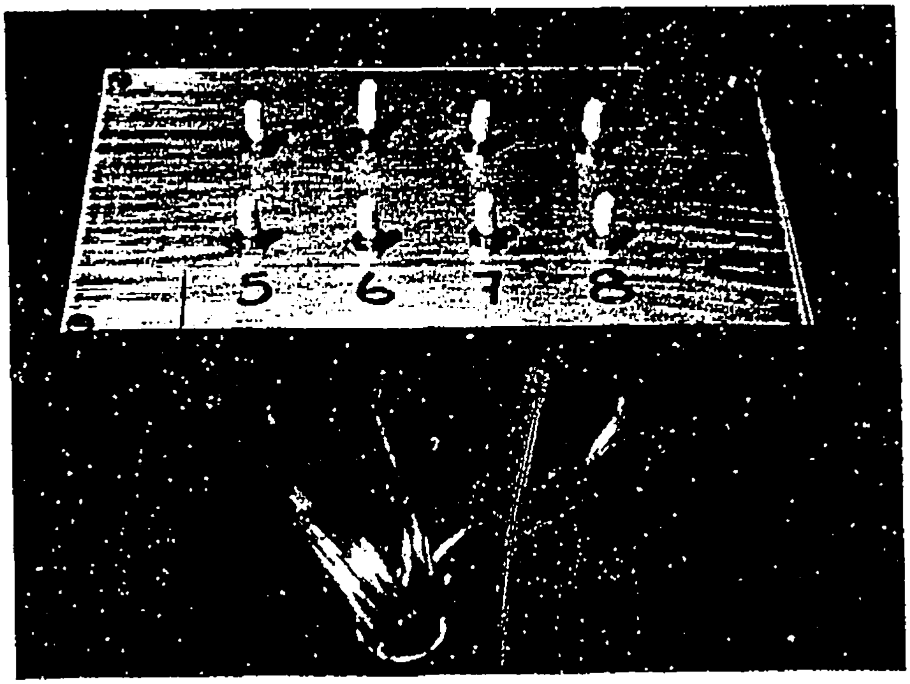


Fig. H2.4. Front view of the signal light tunnel.

Fig. H2.5. The protective screen for the vigilance test in the observation area. Both the switch box (below) and data sheet were kept in this area, out of view to the subject.

Fig. H2.6. The vigilance test switch box, in place behind the protective screen. In this photograph, light #2 is in the "on" position. Lights were turned on and off as the subject walked towards the east end, with his back towards the observation area (Fig. 4.3).





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8

Appendix H3. Location of Signal Lights

Position of the signal lights was determined using triangulation relative to two *Wet Walk* arches (Table H3.1) and plotted on a 1-m^2 grid (Fig. H3.1). Distances refer to the front surface of the long box containing the signal light. To determine the relative vertical position of the signal lights around the *Wet Walk*, a fixed reference point of 1.45 m was selected on arch A_{9S}. A string was extended from this point to the front of the long box, level with the 145-cm mark on arch A_{9S}. The rise/drop was measured as the difference between the top of the long box and the height of the string (Table H3.1). The lights were elevated above ground level in sites where ground cover interfered with viewing. Signal lights were not elevated in open areas, in order to maintain a low profile.

Characteristics of light signals as perceived by subjects during walking are presented in order of view (beginning at arch A_7) in Table H3.2. The viewing distance and drop are relative to the midpoint of the viewing range, and therfore represent an "average" view.

Table H3.1. Fixed-position location of vigilance lights

Light	Distance to Light[1] (m)			Drop[2] (cm)	Description
#	A_{9N}	A_{13S}	A_{15S}	A_{9S}	
1	8.36	9.28		+25	Stump/+37cm
2		10.08	8.65	+110	Ground
3	5.78	12.25		−44	Log/+45cm
4	8.66	10.40		+30	Stump/+50cm
5	5.96	10.81		−10	Log/+60cm
6	9.19	7.58		−135	Stump/+45cm
7		7.45	6.12	−37	Ground
8		8.28	12.35	−123	Ground

[1] Refer to Fig. A2.1.

[2] Drop = height relative to 145-cm mark on arch A_{9S}.

Fig. H3.1. Layout of the vigilance signal lights around the *Wet Walk.* Light position is indicated on a 1-meter-square grid (similar to Fig. A2.1) by a numbered dot enclosed in an open circle, corresponding to the position of the front of the long box containing the signal light. The arrow signifies the direction of the light signal. The dotted line indicates line of view between the light source and the midpoint of subject's viewing range from the *Wet Walk* (Fig. 4.3). For light #5, extrapolate line on Fig A4.1.

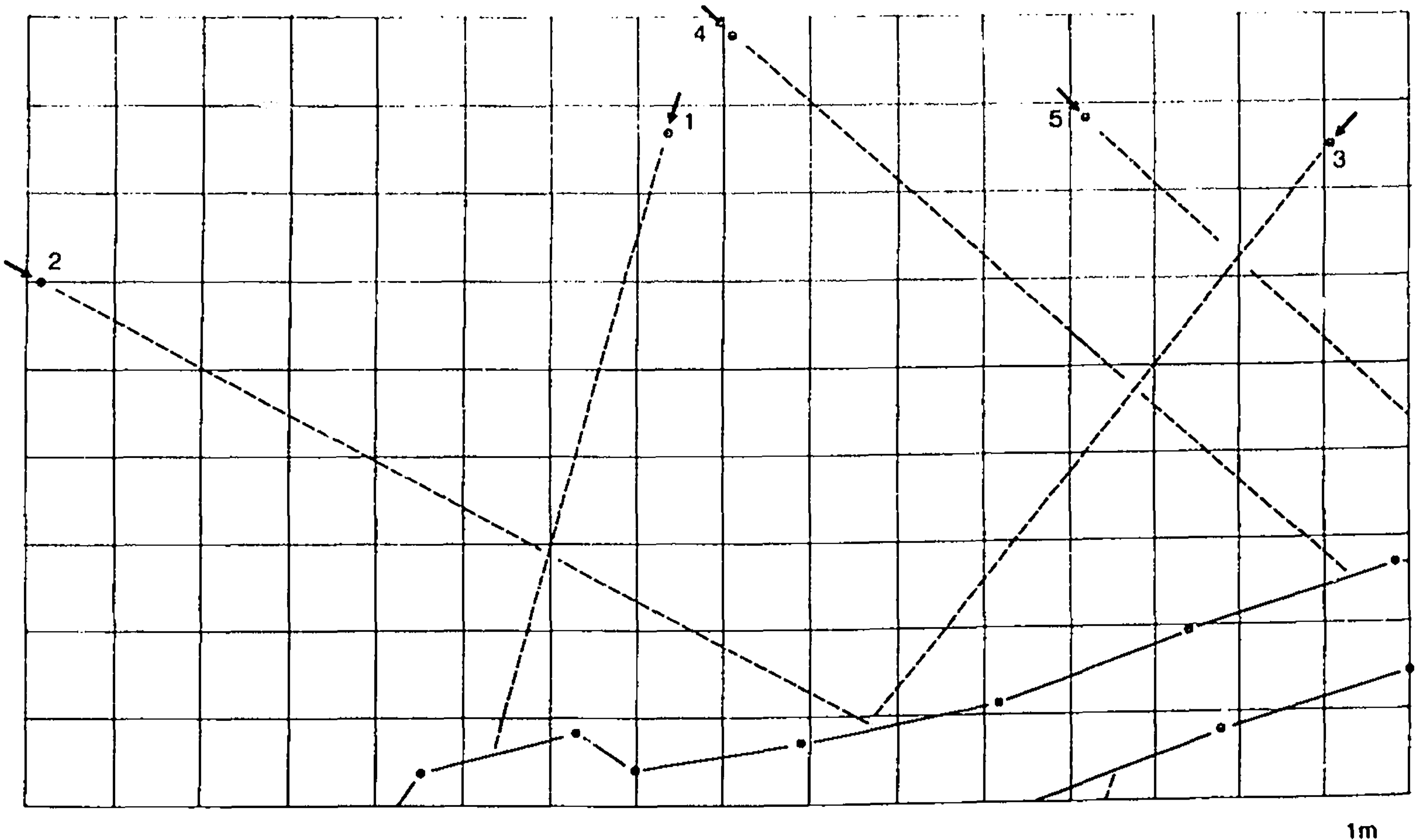

Fig. H3.7a. Layout of the vigilance test lights (north).

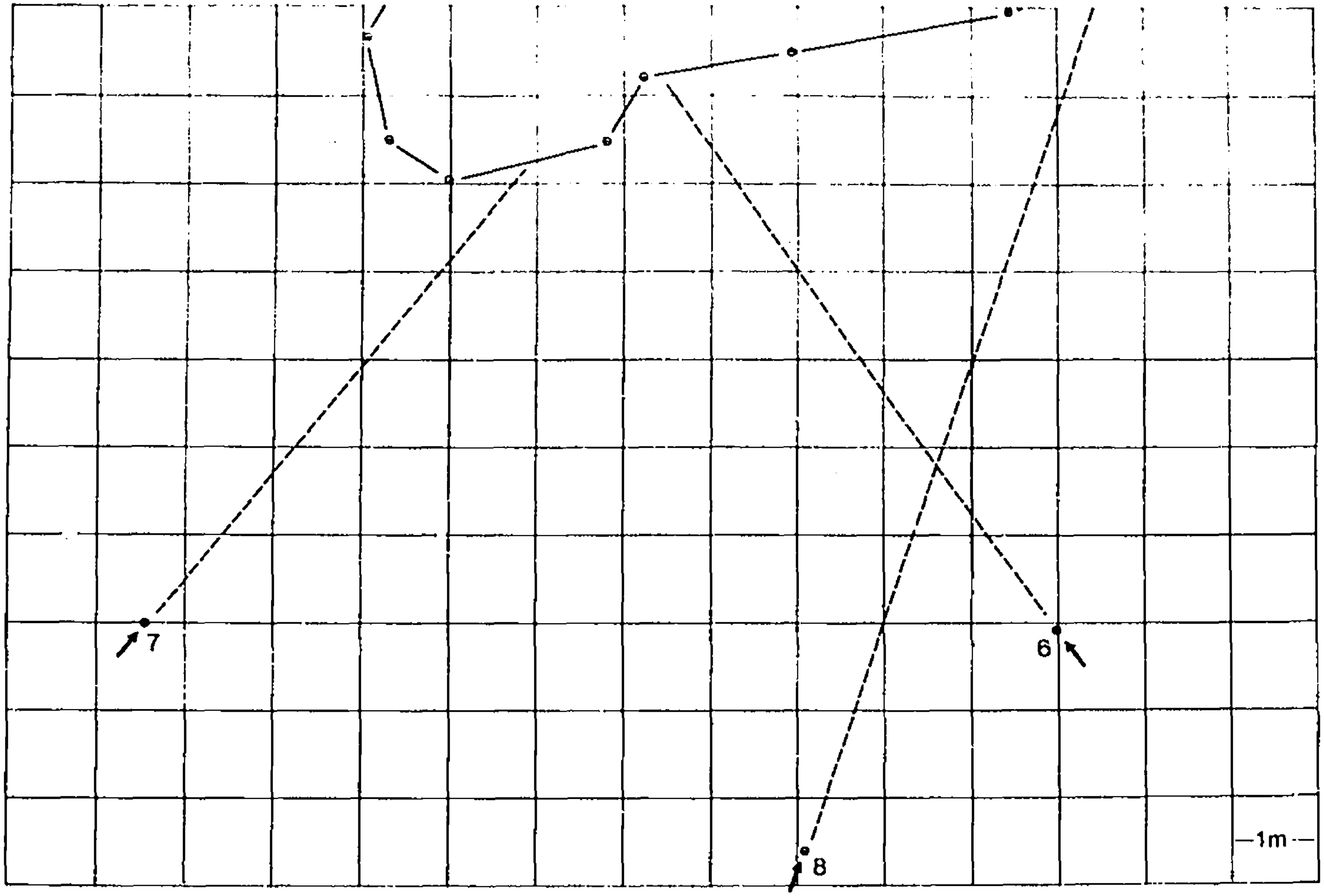

Fig. H3.7b. Layout of the vigilance test lights (south).

Table H3.2. Viewing characteristics of light signals from the perspective of an ambulatory subject (walking pace 25m/17.5 sec). Signals presented in order observed by subject

Light #	Heading/ Side	Arch	Time (sec)	Distance (m)	Drop (m)
5	W/R	A_{7N}	1.1	7.9	-0.3
4	W/R	A_{8N}	1.3	10.1	-0.1
8	W/L	A_{9S}	1.3	11.3	-1.5
2	W/R	A_{10N}	1.4	11.9	+0.7
7	W/L	A_{13S}	1.2	7.2	-1.3
1	E/L	A_{14N}	1.2	8.0	-0.6
6	E/R	A_{13N}	1.3	8.7	-2.1
3	E/L	A_{12N}	1.1	10.0	-1.1

Heading/Side:

Refers to direction subject is walking, and side of track subject looks for signal. For example, W/R = west/right, and E/L = east/left.

Arch:

The arch nearest beginning of search for light signal.

Time:

The time a light signal is visible to subject at a walking pace of 25 m/17.5 sec. The time was calculated by converting the horizontal distance a light signal is visible from the track to time (m × 0.7 sec/m).

Distance:

The distance from the midpoint of the viewing range on the *Wet Walk* to front surface of the long box containing the light signal.

Drop:

This distance was calculated in a two-step process:

(1) Conversion of the vertical drop/rise of a light relative to A_{9S} (Table 1) to relative drop/rise of a given light at the midpoint of the viewing range, based on gradient measurements of the *Wet Walk* (Appendix A).

(2) Conversion of this value from a base height of 1.45 cm to 1.65 cm, equivalent to eye level of an average male.

Appendix H4. Signal Characteristics

The frequency of light signals was based on a presentation rate of 10 per hour. Under ideal conditions, a subject would walk about 100 laps per hour (Appendix B5); however, for a variety of reasons, data-recording stops were often prolonged and the number of laps walked was less than 100. In order to ensure that light signals were presented within the appropriate 10-minute period and on approximately the same lap, a flexible system was adopted. Each 10-minute period included 15 test laps, with flex laps at each end of the period, designed to accomodate individual performance differences when required (Fig. H4.1). The base number of signal events was therefore 90. For example, if a subject began walking at a time indicating that 17 laps would be completed, then the lap preceding the first numbered lap would be checked, and the lap following the 15th numbered lap also checked.

The probability of an event (a light signal occurring on a lap) was 10/90 or 0.11; the probability of a null event (no signal) was 0.89. This value would vary slightly (but insignificantly) between subjects and hour, depending on the actual lap count. The maxixum reduction in frequency would be to 10/100 laps or 0.10 (null event 0.90).

Eight light signals were placed around the *Wet Walk* as previously described. The probability of a specific event (i.e., light 1–8) was 0.014 – the probability of an event (0.11) × the probability of a specific light (0.125)

The presentation of signals was determined using a two-step process: *(1)* random selection of lap on which a signal would appear (5 laps between 1–45 for first half hour; 5 laps from 46–90 for second half hour) for each of 4 hours; *(2)* random selection of light signals (1–8) on previously selected laps. The randomization results are presented in Table H4.1, and relative light frequencies summarized in Table H4.2.

The scoring method is summarized in Table H4.3.

Fig. H4.1. Vigilance test data sheet (EXP_3). Note unnumbered flex laps at beginning and end of each 10-minute period. Start (s) and end (e) times were recorded when necessary.

VIGILANCE TEST

SUBJECT ____________ DATE ____________ HOUR 1

✓
1. ✓ s = 0:00
2. ✓
3. ✓
4. ✓
5. ✓
6. ✓
7. ✓
8.* ✓ 5 CR
9. ✓
10. ✓
11. ✓
12. ✓
13. ✓
14. ✓
15. — e = 9:07
—
—
0:10

—
16. ✓ s = 11:40
17. ✓
18. ✓
19. ✓
20. ✓
21.* ✓ 6 EO
22. ✓
23. ✓
24. ✓
25. ✓
26. ✓
27.* ✓ 8 CR
28. ✓
29. ✓
30. ✓ e = 20:05
✓
—
0:20

—
31.* ✓ 8 CR s = 20:42
32. ✓
33. ✓
34. ✓
35. ✓
36. ✓
37. ✓
38. ✓
39.* ✓ 4 CR
40. ✓
41. ✓
42. ✓
43. ✓
44. ✓
45. ✓ e = 29:58
✓
—
0:30

—
46. ✓ s = 31:25
47. ✓
48. ✓
49. x EC
50. ✓
51. ✓
52. ✓
53. ✓
54. ✓
55.* ✓ 2 CR
56. ✓
57.* ✓ 1 CR
58. ✓
59. ✓
60. ✓ e = 39:59
—
—
0:40

—
61. ✓ s = 40:45
62. ✓
63. ✓
64. ✓
65. ✓
66. ✓
67. ✓
68. ✓
69.* ✓ 4 CR
70. ✓
71. ✓
72. ✓
73. ✓
74. ✓
75. ✓ e = 49:55
✓
—
0:50

—
76. ✓ s = 50:37
77. ✓
78. ✓
79.* ✓ 5 EO
80. ✓
81. ✓
82. ✓
83. ✓
84. ✓
85. ✓
86. ✓
87. ✓
88. ✓
89.* ✓ 3 CR
90. ✓ e = 59:51
✓
—
1:00

Table H4.1. Distribution of vigilance test signals: by lap and light number

Hour 1		Hour 2		Hour 3		Hour 4	
Lap	Light	Lap	Light	Lap	Light	Lap	Light
8	5	9	6	5	6	2	7
21	6	29	5	7	2	8	1
27	8	31	8	9	7	25	5
31	8	37	5	24	1	34	6
39	4	45	3	37	3	39	2
55	2	72	6	48	3	49	8
57	1	73	7	60	2	67	4
69	4	81	2	65	1	69	1
79	5	86	1	66	8	78	8
89	3	89	1	87	6	81	8

Table H4.2. Summary of signal light frequencies

		Hour				Sum	
Light	Position	1	2	3	4	0-3	0-4
1	W/R	1	2	2	2	5	7
2	W/R	1	1	2	1	4	5
3	E/L	1	1	2	0	4	4
4	W/R	2	0	0	1	2	3
5	W/R	2	2	0	1	4	5
6	E/R	1	2	2	1	5	6
7	W/L	0	1	1	1	2	3
8	W/L	2	1	1	3	4	7
		10	10	10	10	30	40

Position:
W (west) or E (east) = direction subject walking;
R (right) or L (left) = direction subject looks.

For hours 0-3:
Signals heading west = 16, heading east = 14;
Signals on right = 15, on left = 15.

Table H4.3. Scoring definitions for vigilance test

Score	Definition	Interpretation
CR	Correct Response	Signal on/signal reported; No signal/signal not reported
EO	Error of Omission	Signal on/signal not reported
EC	Error Commission	No signal/signal reported

Note: No incorrect response (IR) scoring was applied, since signal symbols were identical.

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Title of Dissertation:

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