University of Alberta

WHEELCHAIR ERGOMETRY EXERCISE AND SENSEWEAR PRO ARMBAND (SWA): A PRELIMINARY STUDY WITH HEALTHY CONTROLS

by

JUTIKARN CHAROENSUK

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In

REHABILITATION SCIENCE – PHYSICAL THERAPY

FACULTY OF REHABILITATION MEDICINE

Fall 2010
Edmonton, Alberta

Examining Committee

Dr. Trish Manns (Supervisor), Associate Professor, Department of Physical Therapy

Dr. Robert G. Haennel, Professor, Chair of the Department of Physical Therapy, Faculty of Rehabilitation Medicine

Dr. Sharon Warren, Professor, Director of the Rehabilitation Research Centre (RRC), Faculty of Rehabilitation Medicine

DEDICATION

I dedicate this thesis to my parents for their

continued support and to my wife and my sons, who has been

a great source of motivation and inspiration

ABSTRACT

Purpose. To investigate the validity of the Sense Wear Pro Armband (SWA) to measure energy expenditure (EE) in healthy participants using wheelchair ergometry as an exercise modality.

Method. Minute by minute EE was measured simultaneously using the SWA and indirect calorimetry during three different wheeling speeds including self-selected speed (0.81 m/s), moderate speed (1.11 m/s), and fast speed (1.73 m/s).

Results. Twenty healthy community-dwelling volunteers (age = 34.0 (5.8) years and BMI = 23.6 (3.8) kg/m^2) participated. An intraclass correlation coefficient (ICC) was used to assess agreement between two EE measurement methods. The ICCs were 0.50 (p=0.010), 0.59 (p=0.003), and 0.68 (p=0.000) for the self-selected speed, moderate speed, and fast speed wheeling, respectively. The SWA overestimated EE observed from indirect calorimetry by 57.8%, 57.4 %, and 63.7% for self-selected speed, moderate speed, and fast speed, respectively.

Conclusions. The SWA failed to provide an accurate estimate of EE as measured by indirect calorimetry for wheelchair ergometry exercise in healthy subjects. The SWA overestimated EE for all exercise intensities. Exercise-specific algorithms need to be developed to improve the estimate of EE in wheelchair related activities.

ACKNOWLEDGEMENTS

I would like to take this opportunity to give my sincere gratitude to my supervisor, Dr. Trish Manns, who was very generous with time, financial support, words of encouragement, and the most valuable guidance throughout my program. A special thank to Dr. Robert G. Haennel, my co-supervisor, for allowing me to work in his laboratory. His superb helpful and suggestion in my academic life will never be forgotten. I am extremely grateful to Dr. Sharon Warren, my supervisory committee member, for her continued support and advice throughout my academic endeavor.

Without the assistance of many others professional and personal, my thesis project would not be success. I would like to extend my gratitude and special appreciation to Dr. Martin Ferguson- Pell, the dean of the Faculty of Rehabilitation Medicine, for allowing me to work in his laboratory in the last parts of my experiments. His kindly help and support will never be forgotten. I would also like to thank the volunteers for their participation in my study. Their participation has been greatly appreciated. A special thank to all my friends for your assistance and support. You all made me feel comfortable as if I was at home. I will miss you all.

I realize the value of my family has been to my success. To my mother, my brothers, your interest in my well-being has always been excellent. Thank you for caring. To my wife, Vichaya, and my sons, Wittawat and Weerapat, my success is a credit to your courage, support and patience. Thank you for being with me, always.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

ADL	Activities of daily living	**ml/kg/min**	Milliliters per kilogram per minute
BMR	Basal metabolic rate	**mph**	Miles per hour
bpm	Beats per minute	**MS**	Multiple sclerosis
CP	Cerebral palsy	**O_2**	Oxygen
CO_2	Carbon dioxide	**^{18}O**	^{18}Oxygen
COPD	Chronic obstructive pulmonary disorder	**PA**	Physical activity
CSA	Computer Science and Application accelerometers	**PASIPD**	Physical Activity Scale for Individuals with Physical Disabilities
DLW	Doubly labeled water	**PADS**	Physical Activity and Disability Survey
EE	Energy expenditure	**PAEE**	Physical activity energy expenditure
EEIHR	Hearth rate version of the energy expenditure index	**PARA-SCI**	Physical Activity Recall Assessment for People with Spinal Cord Injury
FFM	Fat free mass	**PWD**	People with disabilities
^{2}H	Deuterium	**RER**	Respiratory change ratio
HBE	Harris-Benedict Equations	**RMR**	Resting metabolic rate
HR	Heart rate	**SCF**	Schofield height weight equations
HRM	Heart-rate monitoring	**SCI**	Spinal cord injury
IC	Indirect calorimetry	**SWA**	SenseWear Pro Armband
ICC	Intraclass correlation coefficient	**TDEE**	Total daily energy expenditure
MET	Metabolic equivalent	**TEE**	Total energy expenditure
kcal/min	Kilocalories per minute	**TEF**	Thermic effect of food
kg	Kilogram	**UE**	Upper extremity
ml/min	Milliliters per minute	**VCO_2**	Carbon dioxide production
mmHg	Millimeters of mercury	**VO_2**	Oxygen consumption
m/s	Meters per second		

CHAPTER ONE

INTRODUCTION

Sedentary and hypoactive lifestyles as well as imbalance in energy expenditure (EE) cause serious health-related problems in all populations (1). However, research shows that people with disabilities are more inactive and obese than people without disabilities (PWD) (2-11). Thus, the measurement of EE in real life for all populations, perhaps especially for PWD, is increasingly important. Measurement of EE is the most accurate method for determining energy requirements (12-14), which is necessary for the development of individualised nutritional interventions (15). Accurate measurement of EE can provide information about the relationships between physical activity (PA) and health (16,17), as well as provide objective data regarding the success of interventions aimed at increasing PA levels (18).

Measuring EE may be more challenging with PWD than with the non-disabled population (19). Disabling conditions limit the amount of active muscle mass available during activity (20), and locomotor activity may be performed differently and use different muscles (i.e., arms vs. legs) compared to non-disabled populations.

Hand-rim-propelled manual wheelchairs are the most commonly used type of assistive device for mobility in people with mobility impairments (21,22). As manual wheelchair propulsion is an important mode of mobility, studies that test

the validity of EE measurement devices during upper extremity (UE) work are necessary with disabled populations (19).

EE can be measured in a variety of ways. Although doubly labeled water (DLW) and indirect calorimetry (IC) techniques are considered the gold standard measurement of EE (23), they are expensive and require specialized personnel and lab facilities. Heart rate (HR) monitors have been widely used to quantify physiological stress, but their efficiency at low intensity PA has been questioned due to the potential interference of environmental conditions and emotional stress (11,24-26). Furthermore, for PWD who have sympathetic nervous system dysfunctions, HR responses to exercise may be abnormal and thus affect the utility of HR monitors for EE estimation (27).

Motion detectors such as pedometers and accelerometers have also been used to measure PA and EE in both non-disabled and able-bodied populations. Pedometers are generally small and inexpensive. Some pedometers have an algorithm to estimate EE, based on steps and body weight. Their characteristics, size, cost, and self-monitoring capability allow pedometers to play a key role in health promotion campaigns and walking intervention studies (28). Although they produce accurate step counts in selected populations, pedometers do not provide information during non-ambulatory activities (e.g., cycling, weight training, and swimming), isometric exercises, and activities that involve the upper body, so they are less feasible in the assessment of EE (28,29).

Accelerometers have been used to assess PA and EE in free-living individuals. They provide objective data regarding frequency, duration, intensity,

level, and total amount of PA (30,31) and have been shown to be a valid and reliable device for measuring PA in both non-disabled and able-bodied populations (32-37). Previous studies reported that accelerometers provided the most accurate estimate of EE during periods of level walking (38,39). However, they are inaccurate to quantify many low- and high-intensity activities, such as standing, childcare, house and yard work, occupational activities, swimming, weight lifting, upper body activities, static work, or activities where the body weight is partially supported, as in bicycling or rowing (40-42).

Several studies have investigated the possibility of using accelerometers to objectively measure PA and EE in people with mobility impairments, including those in manual wheelchair users (32,33,43-45). Warms et al. (45) reported a 60% increase in PA as measured by a wrist-worn actigraph (Actiwatch) after individuals with spinal cord injury (SCI) participated in 6-week health promotion program aimed at improving PA health behaviors. In validity studies, Postma et al. (43) indicated that the ADXL202 piezo-resistive accelerometers (each sensor attached to the skin at thighs, wrists, and sternum) effectively measured activity levels for wheelchair propulsion activities in individuals with SCI, using video recording as a reference method. Warms et al. (33) reported an association of EE data measured with a wrist-worn Actigraph and the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) in adult wheelchair users. Another study by Warms (44) presented strong inter-unit reliability and concurrent validity between EE measured by a wrist-worn Actiwatch accelerometer and a self-report survey in wheelchair users. However, this

evidence should be interpreted with caution because of the use a subjective measure (self-report measure) to validate an objective measure (Actiwatch accelerometer). This study also revealed that the Actiwatch accelerometer registered spasticity as activity counts, which may be a major problem with the use of this device for populations in which spasticity is common (44). Washburn and Copay's (32) study to validate wrist-worn Computer Science and Application accelerometers (CSA) using an Aerosport TEEM 100 Total Metabolic Analysis System as a criterion method reported significant associations between CSA's data and Aerosport TEEM 100's EE data during three wheelchair pushing speeds in manual wheelchair users.

The SenseWear Pro Armband (SWA) is a newer device worn on the right upper arm to capture and store minute-by-minute physiological data. This device incorporates an accelerometer as well as multiple sensors, including heat flux sensors, skin temperature sensors, near-body temperature sensors, and galvanic skin response sensors to provide a measure of EE (46). Incorporating a 2-axis accelerometer with other heat- related sensors may improve the performance of SWA to estimate EE compared to traditional accelerometers. Most studies with non-disabled populations reported moderate to good agreement between EE as measured by the SWA and gold standard measures of EE such as IC and DLW (47-56). However, some studies reported a low agreement between a SWA and IC in measuring of EE (57-61). Because the SWA is designed to be worn on the upper extremity (UE), it is device that should be tested to determine if it can

accurately measure EE during UE activities. The SWA may be an appropriate device to quantify EE during arm exercise.

To our knowledge, there are only three studies that have examined the validity of SWA for measuring EE during arm exercise (53,62,63). These investigators reported that when the general proprietary algorithm was used, the SWA provided an accurate estimate of EE compared to IC during arm ergometry exercise in healthy subjects (63) and in cardiac rehabilitation patients (53). In people who use wheelchairs, Hiremath et al. (62) reported a high degree of agreement (ICC=0.79) between EE estimated by the SWA and measured by IC during wheelchair-related activities, including wheelchair propulsion, arm ergometer exercise, and deskwork. The SWA overestimated EE for all activities in this study. Because the study sample was a small group of subjects, further validity studies need to be done to confirm the validity of SWA for measurement of EE in wheelchair-related activities.

To this point, no studies have tested the validity of the SWA during wheelchair ergometry exercise in healthy subjects. The primary purpose of this investigation is to examine the criterion validity of the SWA version 6.1 to estimate the EE during wheelchair ergometry exercise with healthy non-disabled participants. The use of healthy participants in this initial study with wheelchair ergometry reduces the potential confounding of EE measurement that may result from pathology (i.e., autonomic dysfunction). If our findings reveal that the SWA is a valid measure of EE during wheelchair ergometry exercise in healthy subjects, future studies may test its validity with disabled populations.

REFERENCES

(1) Twisk JW, Kemper HC, Van Mechelen W, Post GB. Clustering of risk factors for coronary heart disease. the longitudinal relationship with lifestyle. Ann.Epidemiol. 2001 Apr;11(3):157-165.

(2) Hurvitz EA, Green LB, Hornyak JE, Khurana SR, Koch LG. Body mass index measures in children with cerebral palsy related to gross motor function classification: a clinic-based study. Am.J.Phys.Med.Rehabil. 2008 May;87(5):395-403.

(3) Patradoon-Ho P, Scheinberg A, Baur LA. Obesity in children and adolescents with acquired brain injury. Pediatr.Rehabil. 2005 Oct-Dec;8(4):303-308.

(4) Shepherd K, Roberts D, Golding S, Thomas BJ, Shepherd RW. Body composition in myelomeningocele. Am.J.Clin.Nutr. 1991 Jan;53(1):1-6.

(5) Westerterp KR. Assessment of physical activity level in relation to obesity: current evidence and research issues. Med.Sci.Sports Exerc. 1999 Nov;31(11 Suppl):S522-5.

(6) Zanardi MC, Tagliabue A, Orcesi S, Berardinelli A, Uggetti C, Pichiecchio A. Body composition and energy expenditure in Duchenne muscular dystrophy. Eur.J.Clin.Nutr. 2003 Feb;57(2):273-278.

(7) Buchholz AC, McGillivray CF, Pencharz PB. Physical activity levels are low in free-living adults with chronic paraplegia. Obes.Res. 2003 Apr;11(4):563-570.

(8) Gater DR,Jr. Obesity after spinal cord injury. Phys.Med.Rehabil.Clin.N.Am. 2007 May;18(2):333-51, vii.

(9) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(10) Munakata M, Kameyama J, Kanazawa M, Nunokawa T, Moriai N, Yoshinaga K. Circadian blood pressure rhythm in patients with higher and lower spinal cord injury: simultaneous evaluation of autonomic nervous activity and physical activity. J.Hypertens. 1997 Dec;15(12 Pt 2):1745-1749.

(11) Yamasaki M, Irizawa M, Komura T, Kikuchi K, Sasaki H, Kai K, et al. Daily energy expenditure in active and inactive persons with spinal cord injury. J.Hum.Ergol.(Tokyo) 1992 Dec;21(2):125-133.

(12) Jequier E, Schutz Y. Long-term measurements of energy expenditure in humans using a respiration chamber. Am.J.Clin.Nutr. 1983 Dec;38(6):989-998.

(13) Soares MJ, Sheela ML, Kurpad AV, Kulkarni RN, Shetty PS. The influence of different methods on basal metabolic rate measurements in human subjects. Am.J.Clin.Nutr. 1989 Oct;50(4):731-736.

(14) Flancbaum L, Choban PS, Sambucco S, Verducci J, Burge JC. Comparison of indirect calorimetry, the Fick method, and prediction equations in estimating the energy requirements of critically ill patients. Am.J.Clin.Nutr. 1999 Mar;69(3):461-466.

(15) Bauer J, Reeves MM, Capra S. The agreement between measured and predicted resting energy expenditure in patients with pancreatic cancer: a pilot study. JOP 2004 Jan;5(1):32-40.

(16) Blair SN, Kohl HW, Gordon NF, Paffenbarger RS,Jr. How much physical activity is good for health? Annu.Rev.Public Health 1992;13:99-126.

(17) Schoeller DA, Racette SB. A review of field techniques for the assessment of energy expenditure. J.Nutr. 1990 Nov;120 Suppl 11:1492-1495.

(18) Katzmarzyk PT, Tremblay MS. Limitations of Canada's physical activity data: implications for monitoring trends. Can.J.Public Health 2007;98 Suppl 2:S185-94.

(19) Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. Fam.Community Health 2006 Jan-Mar;29(1 Suppl):78S-88S.

(20) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(21) Spaepen, A., Vanlandewijck, Y., Lysens, R. Relationship between energy expenditure and muscular activity patterns in handrim wheelchair propulsion. International Journal of Industrial Ergonomics. 1996;17:163-173.

(22) Cooper RA, Boninger ML, Shimada SD, Lawrence BM. Glenohumeral joint kinematics and kinetics for three coordinate system representations during wheelchair propulsion. Am.J.Phys.Med.Rehabil. 1999 Sep-Oct;78(5):435-446.

(23) Westerterp KR. Assessment of physical activity level in relation to obesity: current evidence and research issues. Med.Sci.Sports Exerc. 1999 Nov;31(11 Suppl):S522-5.

(24) Davidson L, McNeill G, Haggarty P, Smith JS, Franklin MF. Free-living energy expenditure of adult men assessed by continuous heart-rate monitoring and doubly-labelled water. Br.J.Nutr. 1997 Nov;78(5):695-708.

(25) Melanson EL,Jr, Freedson PS. Physical activity assessment: a review of methods. Crit.Rev.Food Sci.Nutr. 1996 May;36(5):385-396.

(26) Spurr GB, Prentice AM, Murgatroyd PR, Goldberg GR, Reina JC, Christman NT. Energy expenditure from minute-by-minute heart-rate recording: comparison with indirect calorimetry. Am.J.Clin.Nutr. 1988 Sep;48(3):552-559.

(27) Hayes AM, Myers JN, Ho M, Lee MY, Perkash I, Kiratli BJ. Heart rate as a predictor of energy expenditure in people with spinal cord injury. J.Rehabil.Res.Dev. 2005 Sep-Oct;42(5):617-624.

(28) Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. Res.Q.Exerc.Sport 2000 Jun;71(2 Suppl):S21-9.

(29) Bassett DR,Jr, Cureton AL, Ainsworth BE. Measurement of daily walking distance-questionnaire versus pedometer. Med.Sci.Sports Exerc. 2000 May;32(5):1018-1023.

(30) Welk GJ. Use of the accelerometry-based activity monitors to assess physical activity. Physical activity assessment for health-related research. Champaigne, IL: Human Kinetics; 2002.

(31) Bouten CV, Westerterp KR, Verduin M, Janssen JD. Assessment of energy expenditure for physical activity using a triaxial accelerometer. Med.Sci.Sports Exerc. 1994 Dec;26(12):1516-1523.

(32) Washburn, R.A., Copay, A.G. Assessing physical activity during wheelchair pushing: Validity of a portable accelerometer. Adapt Phys Act Q. 1999;16(3):290-299.

(33) Warms CA, Belza BL, Whitney JD. Correlates of physical activity in adults with mobility limitations. Fam.Community Health 2007 Apr-Jun;30(2 Suppl):S5-16.

(34) Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. Med.Sci.Sports Exerc. 1998 May;30(5):777-781.

(35) Melanson EL,Jr, Freedson PS. Validity of the Computer Science and Applications, Inc. (CSA) activity monitor. Med.Sci.Sports Exerc. 1995 Jun;27(6):934-940.

(36) Trost SG, Ward DS, Moorehead SM, Watson PD, Riner W, Burke JR. Validity of the computer science and applications (CSA) activity monitor in children. Med.Sci.Sports Exerc. 1998 Apr;30(4):629-633.

(37) Ekelund U, Tingstrom P, Kamwendo K, Krantz M, Nylander E, Sjostrom M, et al. The validity of the Computer Science and Applications activity monitor for use in coronary artery disease patients during level walking. Clin.Physiol.Funct.Imaging 2002 Jul;22(4):248-253.

(38) Levine JA, Baukol PA, Westerterp KR. Validation of the Tracmor triaxial accelerometer system for walking. Med.Sci.Sports Exerc. 2001 Sep;33(9):1593-1597.

(39) Pambianco G, Wing RR, Robertson R. Accuracy and reliability of the Caltrac accelerometer for estimating energy expenditure. Med.Sci.Sports Exerc. 1990 Dec;22(6):858-862.

(40) Rennie K, Rowsell T, Jebb SA, Holburn D, Wareham NJ. A combined heart rate and movement sensor: proof of concept and preliminary testing study. Eur.J.Clin.Nutr. 2000 May;54(5):409-414.

(41) Haskell WL, Yee MC, Evans A, Irby PJ. Simultaneous measurement of heart rate and body motion to quantitate physical activity. Med.Sci.Sports Exerc. 1993 Jan;25(1):109-115.

(42) Montoye, H.J. Kemper, H.C.G., Saris, W.H.M., et al. Measuring physical activity and energy expenditure. Champaign, IL: Human Kinetics.; 1996.

(43) Postma K, van den Berg-Emons HJ, Bussmann JB, Sluis TA, Bergen MP, Stam HJ. Validity of the detection of wheelchair propulsion as measured with an Activity Monitor in patients with spinal cord injury. Spinal Cord 2005 Sep;43(9):550-557.

(44) Warms CA, Belza BL. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. Nurs.Res. 2004 Mar-Apr;53(2):136-143.

(45) Warms CA, Belza BL, Whitney JD, Mitchell PH, Stiens SA. Lifestyle physical activity for individuals with spinal cord injury: a pilot study. Am.J.Health Promot. 2004 Mar-Apr;18(4):288-291.

(46) Andre, D., Pelletier, R., Farringdon, J., Safier, S., Talbott, W., Stone, R., Vyas, N., Trimble, J., Wolf, D., Vishnubhatla, S., Boehmke, S., Stivoric, J., Teller, A. The Development of the SenseWear® armband, a Revolutionary Energy Assessment Device to Assess Physical Activity and Lifestyle. 2006; Available at: http://www.bodybugg.com/pdf/wp_accuracy_ee.pdf. Accessed Sept 24, 2010.

(47) Malavolti M, Pietrobelli A, Dugoni M, Poli M, Romagnoli E, De Cristofaro P, et al. A new device for measuring resting energy expenditure (REE) in healthy subjects. Nutr.Metab.Cardiovasc.Dis. 2007 Jun;17(5):338-343.

(48) Fruin ML, Rankin JW. Validity of a multi-sensor armband in estimating rest and exercise energy expenditure. Med.Sci.Sports Exerc. 2004 Jun;36(6):1063-1069.

(49) Wadsworth, D.D., Howard, T., Hallam, J.S., Blunt, G.A. Validation Study of A Continuous Body-monitoring Device: Assessing Energy Expenditure At Rest And During Exercise. Medicine and Science in Sports and Exercise 2005;37 (5 Suppl):S 24.

(50) Charoensuk J, Haennel R, Manns PJ. Validation of the SenseWear Pro ArmbandTM for the assessment of energy expenditure (EE) in healthy subjects: a pilot study. Accepted for poster presentation at the Canadian Society of Exercise Physiology (CSEP) Annual Meeting. Oct 2008.

(51) St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. Am.J.Clin.Nutr. 2007 Mar;85(3):742-749.

(52) Patel SA, Benzo RP, Slivka WA, Sciurba FC. Activity monitoring and energy expenditure in COPD patients: a validation study. COPD 2007 Jun;4(2):107-112.

(53) Cole PJ, LeMura LM, Klinger TA, Strohecker K, McConnell TR. Measuring energy expenditure in cardiac patients using the Body Media Armband versus indirect calorimetry. A validation study. J.Sports Med.Phys.Fitness 2004 Sep;44(3):262-271.

(54) Cereda E, Turrini M, Ciapanna D, Marbello L, Pietrobelli A, Corradi E. Assessing energy expenditure in cancer patients: a pilot validation of a new wearable device. JPEN J.Parenter.Enteral Nutr. 2007 Nov-Dec;31(6):502-507.

(55) King GA, Torres N, Potter C, Brooks TJ, Coleman KJ. Comparison of activity monitors to estimate energy cost of treadmill exercise. Med.Sci.Sports Exerc. 2004 Jul;36(7):1244-1251.

(56) Mignault D, St-Onge M, Karelis AD, Allison DB, Rabasa-Lhoret R. Evaluation of the Portable HealthWear Armband: a device to measure total daily energy expenditure in free-living type 2 diabetic individuals. Diabetes Care 2005 Jan;28(1):225-227.

(57) Dorminy CA, Choi L, Akohoue SA, Chen KY, Buchowski MS. Validity of a multisensor armband in estimating 24-h energy expenditure in children. Med.Sci.Sports Exerc. 2008 Apr;40(4):699-706.

(58) Berntsen S, Hageberg R, Aandstad A, Mowinckel P, Anderssen SA, Carlsen KH, et al. Validity of physical activity monitors in adults participating in free living activities. Br.J.Sports Med. 2008 Jul 15.

(59) Arvidsson D, Slinde F, Larsson S, Hulthen L. Energy cost of physical activities in children: validation of SenseWear Armband. Med.Sci.Sports Exerc. 2007 Nov;39(11):2076-2084.

(60) Bertoli S, Posata A, Battezzati A, Spadafranca A, Testolin G, Bedogni G. Poor agreement between a portable armband and indirect calorimetry in the assessment of resting energy expenditure. Clin.Nutr. 2008 Apr;27(2):307-310.

(61) Papazoglou D, Augello G, Tagliaferri M, Savia G, Marzullo P, Maltezos E, et al. Evaluation of a multisensor armband in estimating energy expenditure in obese individuals. Obesity (Silver Spring) 2006 Dec;14(12):2217-2223.

(62) Hiremath SV, Ding D. Evaluation of activity monitors to estimate energy expenditure in manual wheelchair users. Conf.Proc.IEEE Eng.Med.Biol.Soc. 2009;Pgs 721-1078:835-838.

(63) Jakicic JM, Marcus M, Gallagher KI, Randall C, Thomas E, Goss FL, et al. Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. Med.Sci.Sports Exerc. 2004 May;36(5):897-904.

CHAPTER TWO

REVIEW OF LITERATURE

The measurement of EE in free-living conditions is important for health care. Information from accurate measurement of EE can help in nutritional management for weight management programs (1) and evaluation of health promotion intervention programs aimed at increasing PA (2). It also helps in monitoring physiologic and metabolic responses to illness (3). As an outcome measure, EE can inform health care professionals about the success of therapy, treatments, and counseling (1). The accurate measurement of EE in PWD has been a challenge to researchers because disabling conditions limit the amount of active muscle mass available during activity (4), and locomotor activity may be performed differently and use different muscles (i.e., arms vs. legs) than non-disabled populations. Therefore, selecting the best method for measuring EE in PWD requires knowledge of capabilities and limitations of each EE measurement method as well as knowledge of the characteristics of the population studied (5).

2.1 DEFINITION AND COMPONENTS OF ENERGY EXPENDITUTE

Energy expenditure refers to the loss of thermal energy from the body as a by-product of human metabolism (6) or the amount of energy in calories, that a person uses for respiration, blood circulation, food digestion, and performing physical activity. Total energy expenditure (TEE) refers to the total number of calories a person expends over a period of time. TEE is composed of three

components: resting energy expenditure (REE), physical activity energy expenditure (PAEE), and thermic effect of food (TEF) (7,8). REE is the EE during a period of rest and accounts for 60-75% of TEE (7,9). It represents the minimum rate of EE needed to support human vital functions for maintaining body temperature and autonomic muscular contraction for functions such as circulation and respiration. PAEE is the amount of energy expended in performing PA. It is the most variable component of TEE and accounts for 25-30% of TEE (10). PAEE measurement is used to assess the energy cost of a specific exercise task or it may be used to estimate the average of EE of human being during PA periods. TEF represents the energy needed for eating, digesting, absorbing, transporting, metabolizing, and storing useable forms of energy derived from food. It accounts for approximately 3-10 % of TEE (11).

EE is influenced by body weight, body composition (7,12), and other factors such as age, gender, fitness level, and health condition (13-15). Previous study has shown that weight gain can increase REE (16) and REE is significantly higher in obese than in non-obese individuals (17).

Fat-free mass (FFM) accounts for 70-85 % of the variation in REE. Higher FFM is associated with higher REE (11,18-20). Both TEE and REE progressively decrease as a result of ageing (21), mostly due to concomitant decreases in fat- free mass (FFM) (22-24). Men exhibit greater REE values than women (25). A single bout of resistance and aerobic exercise can increase REE (26,27). Athletes have higher TEE and PAEE compared to sedentary individuals (28). Research studies indicate that EE is lower in PWD, especially in people

with lower extremity impairments, than in non-disabled people as a result of a reduction in fat-free mass and PA level (15,29-31).

2.2 ENERGY EXPENDITURE MEASUREMENT METHODS

The measurement of EE uses different methods, including self-report methods, predictive equations, and objective methods. Each method has advantages and limitations when used to assess EE in free-living individuals. This literature review aims to provide a summary of available techniques for measuring EE in able-bodied persons and in PWD focusing on advantages and limitations of each technique in assessing EE. In this review, both direct and indirect methods that have been accepted among researchers and clinicians will be discussed.

2.2.1 Self-report methods

Self-report methods typically involve the assignment of a score or value to a reported PA, which are then summed over the measurement period and converted to EE (32). Self-report methods have been used to assess PA and EE in epidemiological research studies. Examples include PA records (diaries and logs), PA questionnaires, and interviews (32,33). The advantages of self-report methods are that they are easy and inexpensive to administer and can be administered to large population groups (34). Type, frequency, intensity, and duration of PA can be assessed. Given these advantages, self-report surveys have played an important role in generating the epidemiological data used to formulate

PA prescriptions and guidelines for the general population (34). However, there are some limitations, including misinterpretation of instructions and questions by responders and inaccurate recall of PA performed in the past in detail (35), especially in children and the elderly who have cognitive problems (36). In addition, some kinds of self-report surveys such as PA diaries need more intensive effort, cooperation and motivation by the participants (36).

Most self-report surveys have been developed and evaluated for their validity and reliability in able-bodied populations. They generally aim at measuring PA and EE focusing on participation in intense leisure time sport and recreational activities that require independent ambulation. Therefore, they may not be sufficiently sensitive for measuring PA and EE in PWD (37) who mostly use wheelchair for locomotion in everyday activities (38,39). However, several studies have developed, evaluated, and applied self-report surveys for measuring PA and EE in PWD. Validity and reliability studies of self-report surveys in PWD mostly used accelerometers as a criterion measure. One previous study reported moderate correlation between self-report activities using every 30-minute activity log and Actigraph data (r=0.57 for ankle and r=0.59 for wrist) in ambulatory multiple sclerosis (MS) patients (40). Another study used a 7-day self-reported recall questionnaire developed and evaluated validity and reliability in able-bodied populations and reported that this questionnaire was less sensitive than a three-dimensional accelerometer (TriTrac-R3D) (worn on the waist) for detecting differences of PA in ambulatory MS patients (41).

The Physical Activity and Disability Survey (PADS) is a self-reported measure that has been developed and tested for its validity and reliability in PWD. Previous study reported significant correlations between PADS subscales and peak VO_2 in PWD (42). The Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) has also been tested for its validity in PWD. This 7-day self-reported recall questionnaire gather information regarding the number of days a week and hours of daily participation in recreational, household, and occupational activities. Previous studies reported no statistically significant correlation between PASIPD scores and Actigraph data (r=0.19) (43) in wheelchair users and one study reported low criterion validity (r=0.30) and high test-retest reliability(r=0.77) in non-wheelchair dependent subjects including those with stroke, SCI, whiplash, neurological disorders, and orthopedic or back disorders (44). The PASIPD showed a significant negative correlation with age , objective neighborhood environment, and obesity-related risk factors(43,45) but a significant positive correlation with stage of change, self-rated health, healthcare visits in which exercise was discussed , and social support for exercise in PWD (43). A construct validity study by Washburn et al. (46) also reported significant correlations between each survey item of PASIPD and the PASIPD total score with Cronbach α coefficient ranged from 0.37 to 0.65, indicating low to moderate internal consistency within factors (46). However, the authors stated that additional validation studies using an external criterion should be employed.

In individuals with SCI who use manual wheelchairs as their primary mode of mobility, a Physical Activity Recall Assessment for People with SCI

(PARA-SCI) was developed (47) to measure type, frequency, duration, and intensity of PA. Results from validity studies revealed significant correlations between PARA-SCI scores and indirect calorimetry (IC) estimates of PA (r= 0.27-0.88) (47) and between scores from the leisure time PA (LTPA) and cumulative activity categories of PARA-SCI and objective parameters of aerobic fitness (r=0.26-0.35) and muscular strength(r=0.21-0.36) (48).

2.2.2 Predictive equations for the estimation of energy expenditure

To estimate REE for the general population, prediction equations were developed using EE obtained via gold standard techniques as the outcome variable and using factors such as age, gender, body weight, and height as the predictors (49-52). Most previous studies reported overestimation from predictive equations to estimate REE in various populations, including those with mobility impairments. The Harris-Benedict Equations (HBE), the most widely used predictive equations for REE (53), overestimated measured REE by 7-24% in healthy men and women (54-56). These studies also demonstrated that body weight and fat-free mass (FFM) were highly correlated with REE. In children, Molnar (57) reported overestimation by 7.5% to 18.1% of five predictive equations to estimate REE compared to the IC method in 10-16 year-old children. Additionally, Kaplan et al. (58) reported a significant difference between measured basal metabolic rate (BMR) and estimated BMR calculated by the World Health Organization (WHO) equation in obese children. However, no

significant difference was found between the measured BMR and estimated BMR by the HBE and Schofield (SCF) height/weight equations (58).

In children with disabilities, Havalad et al. (59) reported a significant difference (>10%) between estimated REE using the HBE and measured REE in children with head injury, and Patt et al. (60) reported overestimation of prediction equations to estimate REE in children with SCI using a portable IC as a criterion measure. Results also showed that height and level of injury were the only variables that correlated with REE in this population (60). In adults with SCI, research findings from various studies revealed that equations validated in able-bodied populations to predict REE overestimated energy requirements in individuals with chronic SCI by 5-32% (4,49-52), most obviously in individuals with tetraplegia (4,49). Rodriguez et al. (61) also indicated that predicted EE by multiplying the HBE by an activity factor of 1.2 (an activity factor for bed rest) and then by an injury factor of 1.6 (an injury factor for major trauma) (62) overestimated energy requirements in 12 individuals with varying levels of acute SCI.

2.2.3 Room calorimetry

Room calorimetry or direct calorimetry measures EE by measuring the total heat released by the body at rest or during exercise in a confined environment over a given period of time. Measuring EE by using direct calorimetry is considered the gold standard for EE assessment in the laboratory or controlled environment (23). This is a non-invasive technique that provides data

with excellent accuracy with an error of less than 1% (63). Consequently, it is useful as a criterion method in validation of TEE measured by using other EE measurement methods (64). However, this method is a technically complex, expensive and time-consuming method for measuring EE. In this method, only one individual can be monitored at a time. In addition, its equipment is not transportable, so it does not allow the person to perform lifestyle activities. Therefore, this method is used primarily in small research studies. It is impractical for validating other EE measurement methods for lifestyle activities of a large population group, including those with mobility impairments (47).

2.2.4 Doubly-labeled water method (DLW)

The DLW technique is a non-invasive method of measuring TEE in free-living individuals (7). This method is typically considered a gold standard to evaluate validity of other EE measurement methods in free-living individuals (65). This technique is performed over longer periods than with other EE measurement techniques and therefore it is more likely to provide an accurate estimate of TEE without influencing subject's normal activity patterns (66).

The DLW technique requires the administration of a standardized amount of two stable isotopes, deuterium (^{2}H) and ^{18}oxygen (^{18}O). These two isotopes mix with the normal hydrogen and oxygen in the body water within a few hours of ingestion. As energy is expended in the body, the ^{2}H is eliminated from the body as water, whereas ^{18}O is eliminated as water and carbon dioxide. Urine is measured over a 7-to-14 day period to determine the elimination rates of these

two isotopes. The difference between the isotope elimination rates reflects the rates of CO_2 production and O_2 consumption, which are used to calculate TEE (7,67,68).

The DLW technique provides the most accurate measure of free-living TEE, with a reported precision of ± 5% in humans compared to room calorimetry (67,69,70). Although the DLW technique is an accurate technique for measuring EE in a free-living environment, there are disadvantages that limit its wide use in research and clinical situations (71,72). DLW cannot be used to differentiate the duration, frequency, intensity, or type of PA, and it can provide only a representation of the average TEE per day during the measuring period. Therefore, precise energy costs of PAs are not acquired (2). Calculating PAEE involves subtracting EE due to food, rest, and perhaps growth, from TEE, which increases the error involved and decreases the advantages DLW methods have over other methods for assessing EE (73). Furthermore, its relatively high price of administrating per subject for each measurement period, the need for mass spectrometry instrumentation, and the required specialized personnel and lab facilities have limited its widespread application in epidemiological research (71,74).

The DLW technique is also considered a gold standard method of EE measurement in PWD including in disabled older women with coronary heart disease (75), in Parkinson's disease patients (76), and in wheelchair users (77). However, this method exhibits similar limitations as in the non-disabled population. Additionally, this method requires collection of complete urine

samples that may limit its usefulness for measuring EE in people who may have incontinence or use urinary-collection equipment (5,78) such as those with SCI.

2.2.5 Indirect calorimetry (IC)

The IC technique provides an indirect assessment of calories expended during specific activities. The IC method is useful for clinical application in healthy and obese individuals, for guiding daily nutrition support in critical illnesses, and for evaluating validity of other EE measurement methods (47,60,79-89). The IC method is based on the principle that foods are oxidized to produce heat in the body. O_2 is consumed and CO_2 is produced in proportion to the heat produced (64). Requiring a hood, a face mask and/or mouthpiece and nose clip, this method estimates EE by measuring the oxygen and carbon dioxide that a person inhales and exhales and then indirectly computes the calories burned during the period of measurement. This technique is widely accepted as a gold standard in the research community (1,7,89). IC uses a closed-circuit method or an open-circuit method. In the closed-circuit method, the study participant is isolated from outside air and inhales pure O_2. Expired air goes back to the gas container and passes a special CO_2 absorber. CO_2 produced by the participant is continuously removed by the absorber. As the participant consumes O_2 the volume of gas in the container gradually decreases (90), and the rate of decrease is a measure of the rate of O_2 consumption. The closed-circuit method is suitable for measuring BMR (91) but cannot estimate the energy expended through PA performed under free-living conditions. This system is rarely used at present (92).

The open-circuit method is the most widely used for measuring EE. The method uses the ventilated hood system, the Douglas bag or other modern laboratory electronic equipment, and portable calorimeters. In the ventilated-hood system for measuring REE, a large volume of air equivalent to outside air passes through a hood worn by the subject. The subject inhales and exhales into the air stream flowing through the hood. Air flow and percentage of O_2 and CO_2 are precisely measured to calculate VO_2 that will be used to calculate EE. For the Douglas-bag procedure, the subject wears a nose clip and a mouthpiece, or a facemask. In this method, the subject breathes through a non-rebreathing valve that separates inhaled from exhaled air and directs all exhaled air into a plastic bag or other analysis system for gas analyses (7,63,89).

The IC method has been widely used and accepted as a gold standard for measuring EE in both able-bodied and in PWD population. In PWD populations, a comparison study by Monroe et al. (15) using respiratory chamber, one of IC method for measuring EE(92) indicated that both REE and TEE was lower in individuals with SCI compared to age-matched controls. van den Berg-Emons et al. (93) reported that the ratio between the total daily energy expenditure (TDEE) and sleeping metabolic rate (SMR) as measured by IC which was used as an index for the level of daily PA in the children with cerebral palsy (CP) was significantly lower ($p < 0.05$) than in their healthy peers.

Although the IC method is accurate in measuring EE under various conditions, this method exhibits some limitations in measuring EE in epidemiological research. Most metabolic carts are rather large and bulky;

therefore they are not suitable for monitoring EE outside the laboratory setting (81,94). Expense is also a major prohibitive factor in the use of these devices for individual health monitoring.

Currently, there are commercially available IC systems called "portable metabolic carts," designed to measure gas exchange on a true breath-by-breath basis during various kinds of activities outside laboratory setting. They are appropriate for measuring EE under field conditions (68). Portable metabolic carts are able to monitor a wider set of activities compared to stationary metabolic carts. While measuring EE, the subject wears analyzer modules comfortably on the chest or on the back and breathes through a mouthpiece or face mask. Several previous studies have utilized the portable IC as a criterion measure for validity studies in PWD. Example includes the use of a COSMED K4b^2 portable gas exchange system to examine the validity of SWA and RT3 for measuring EE during wheelchair-related activities (82) and to examine the validity of heart rate monitoring during rest and activities of daily living (ADL) in individuals with SCI (87). A MedGraphics portable metabolic unit has been utilized to examine the criterion validity of the PARA-SCI questionnaires (47). A MedGem handheld, portable IC has also been used to measure REE, to determine variables that are correlated to REE, and to develop a regression equation to estimate REE in children with SCI (60).

Although portable metabolic carts are able to monitor a wider set of activities for a reasonably short period of time, these devices are expensive and have higher error rates than stationary metabolic carts (64,94). Furthermore, EE

measured by using portable ICs is valid only for activities in which steady-state is achieved (2). Additionally, their technical complexities limit their use for measuring EE outside of a laboratory (63).

2.2.6 Heart-rate monitoring (HRM)

HRM has been used to measure EE because of its ability to measure different intensities of PA, and its relationship with EE during aerobic PA (95). HRM is a relatively inexpensive and easy method for assessing free-living PA patterns and EE (12,68,71,96,97). It provides information about duration, frequency, and intensity of activity (98). However, there are numerous disadvantages. For example, the HR–EE relationship is linear only for high PA intensities (97). This is because factors other than PA such as emotional stress, high environmental temperature, high humidity, dehydration, total amount of muscle work, type of muscle group, type of muscle contraction, fatigue, physical fitness, caffeine, posture and illness can all cause changes in HR without associated changes in VO_2. Previous studies reported that HR and VO_2 are linearly related only during dynamic work up to about 85% of maximum heart rate, and particularly between heart rates of 110 to 150 bpm (97,99-102).

HRM alone may not provide an accurate estimation of EE or classifications of exercise intensity, so researchers have tried to develop methods to improve the estimation of PAEE using HRM. Studies have shown that the simultaneous use of HRM and motion sensors such as accelerometers can provide accurate estimation of EE during free-living activities (74,103-106). However,

this technique requires the participant to do multiple activities for development of individual HR-VO_2 equations. In addition, data management and data analysis is time-consuming (107,108). Previous study reported that a minimum of 2 hours per subject was needed for checking and editing data (108). For this reason, it increases the burden on the participant and researcher, thus limiting the feasibility of this technique for epidemiological studies (107,108).

Previous studies also reported that the FLEX-HR method can improve the accuracy of HRM to estimate PAEE (2,109). The assumption of this method is that, above a given intensity threshold, there is a linear relationship between HR and oxygen consumption (VO_2). Below this threshold, the relationship is more variable. Therefore, to estimate VO_2 or EE from HR, the linear prediction is used above the HR FLEX point, a point defined as the average of the lowest HR during exercise and the highest HR during rest. In this method, each individual needs to be monitored for HR and VO_2 simultaneously while lying down, sitting, standing, and performing various intensities of PA to develop calibration curves (110,111). This process is time-consuming and costly. In addition, activities the subject performed under controlled laboratory conditions to establish HR vs.VO_2 calibration curves may not accuracy reflect EE during free-living activities (2,65,97). These may limit the application of this method for measuring EE in large population studies (109).

HRM has also been used to estimate EE in PWD. A study investigating the use of the HR version of the EE index (EEIHR) as a proxy for measurement of VO_2 during treadmill walking in children with CP revealed no association

between net VO_2 and EEIHR at slow walking speed (0.67 and 0.89 m/s), but a moderate association (r=0.64; $p<0.05$) was found for fast walking speed (1.12 m/s) (112). Examination of individual data revealed that most participants displayed an unmatched pattern of response between net VO_2 and EEIHR. The investigators in this study suggested that caution should be applied when using EEIHR to estimate walking EE in children with CP.

In individuals with SCI, Sawatzky et al. (113) reported limitations of HR for estimating EE in 8-minute constant self-selected speed wheeling. HR was shown to have a good correlation with VO_2 only in individuals with lesions below T5. In individuals with tetraplegia, Valent et al. (114) similarly reported that the HR-VO_2 relationship appeared linear in only 8 out of 18 subjects during a discontinuous graded exercise hand cycle test. Because individuals with tetraplegia have abnormal HR response to exercise due to autonomic nervous system dysfunctions, the use of HR to prescribe training intensity should be considered in this population (115). Conversely, a preliminary study by Hayes revealed that HR, when derived from an individualized regression equation based on maximum exercise tests, can accurately estimate EE during ADL activities in individuals with tetraplegia and paraplegia (87). The estimation was more accurate for higher intensity activities, but HR alone, without individual calibration from a maximum exercise test, poorly estimated EE. However, EE estimated with calibrated HR overestimated EE at rest and for all five activities of daily living (ADL) by 5 to 48 percent (87).

2.2.7 Motion detectors

When a human moves, the body is accelerated in relation to the muscular forces responsible for the acceleration. The movement can be converted into EE by using prediction equations (116). Motion detectors are mounted on the body in order to quantify ambulation or motion during various activities. Motion detectors include the pedometer and the accelerometer.

2.2.7.1 Pedometers

Pedometers are small, belt-mounted devices primarily used for quantifying the daily number of steps accumulated (97,117). Most pedometers contain a horizontal, spring-suspended lever arm that moves up and down with each step. This action opens and closes an electrical circuit response to the hip's vertical accelerations, and the accumulated step count is then shown on a digital display. Some pedometers have an algorithm to estimate EE, based on steps and body weight. These devices serve as motivational tools for promoting PA (97). Their size, cost, and self-monitoring capability allow them to play a key role in health promotion campaigns and walking intervention studies (97). The limitations of pedometers are that they do not provide information during non-ambulatory activities (i.e., cycling, weight training, and swimming) or isometric exercises or activities that involve the upper body, so they are less feasible in the assessment of EE (97,117). A major issue regarding the use of pedometer for PWD is that they may underestimate steps taken at slow gait speeds (118-120) or with irregular or unsteady gait patterns (119,120). Previous studies revealed that a Walk4Life Duo pedometer placed at five positions around the waist exhibited

low levels of agreement for step counting using video tape record as a criterion measure in youth with developmental disabilities (121). Study to examine the relationship among various measures of walking ability and the outputs from StepWatch Activity Monitor reported moderate to high correlations(rho=0.51-0.73) between data from the six-minute walk test (6MWT) and ten-meter walk test (10MWT) and StepWatch outputs in individuals with stroke (122). Previous study reported that the Yamax digi-walker pedometer underestimated steps during self-selected walking speeds in adults with neurological conditions including those with stroke, MS, muscular dystrophy, SCI, and traumatic brain injury using manual counting as a criterion measure (123).

2.2.7.2 Accelerometers

An accelerometer, which uses electronic sensors to measure the quantity and intensity of movement, can vary in size, weight, sensitivity, cost, memory, and software capabilities. This device measures segment or limb acceleration rather than overall body acceleration. Data recorded by an accelerometer can be easily retrieved and downloaded on a computer (124,125). This method of assessing EE is a convenient and non-invasive procedure (18) that involves minimal burden to the participant (126).

Classification of accelerometers depends on the number of planes in which movement is monitored. Uniaxial accelerometers measure acceleration in one plane (usually vertical), whereas triaxial accelerometers measure acceleration in three directions (127) capturing more detailed information about free-living

activities (2,97). Studies have shown that the accuracy of accelerometers varies with different brands (8). The accelerometers provided the most accurate estimate of EE during periods of level walking (128,129). Errors of accelerometers are associated with many low- and high-intensity activities, such as standing, childcare, house and yard work, occupational activities, swimming, weight lifting, upper body activities, static work, or activities where the body weight is partially supported, as in bicycling or rowing (74,130,131). The Caltrac uniaxial accelerometer overestimated EE during horizontal walking (88,129) but underestimated EE for 24-h TEE, sedentary daily EE, and waking EE (132). Triaxial accelerometers overestimated EE during sedentary activities and underestimated PAEE of low-, moderate-, and vigorous-intensity activities (97,125,133).

Several studies have investigated the use of accelerometers to objectively measure PA and EE in people with mobility impairments, including manual wheelchair users (43,134-137). A novel microprocessor-linked Step Watch Activity Monitor (SAM) (worn on the ankle) showed high test-retest reliability (r=.96, p<.001) in people with stroke (138). A uniaxial accelerometer (MTI Actigraph), worn on the waist, provided a valid index of PA in ambulatory patients with acquired brain injury (ABI) using a portable IC as a criterion measure (139). A TriTrac RT3, worn on the waist, appeared to distinguish levels of PA better than the 7-day recall questionnaire in measuring free-living PA in adults with neurologic dysfunctions, including those with stroke, Parkinson's disease, and MS (140). For people who use wheelchairs, previous study (135)

reported significant associations between the Computer Science Application (CSA) accelerometer (worn on both wrists) data and EE as measured by metabolic system. The ADXL202 piezo-resistive accelerometer data was correlated to PA data as recorded by video camera (134). Significant associations have also been reported between EE as measured by the Actigraph and PASIPD (43). Moreover, the wrist-worn accelerometer (Actiwatch) showed strong inter-unit reliability and concurrent validity with a self-report measure of PA (136). However, the same study revealed that the Actiwatch accelerometer registered spasticity as activity counts, which may be a major problem with the use of this device for populations in which spasticity is common (136).

For able-bodied people in a free-living environment, movement of the UEs accounts for only a small part of total EE (141). A large proportion of PWD use wheelchairs for locomotion and UE movement accounts for a greater portion of total EE in this population. Therefore, quantifying UE movement is necessary for an adequate measure of EE in wheelchair users (5,136).

Previous studies in PWD used accelerometers to measure PA or activity counts, which may be surrogates of EE. However, none of the studies used accelerometers to directly measure of EE. From those studies, accelerometers have been worn on different parts of body such as on the wrist (43,135,136), ankle (138), and waist (139,140). Wrist-mounted accelerometers may be more appropriate than waist-mounted accelerometers for measuring EE in wheelchair users (136).

2.2.8 SenseWear Pro Armband™ (SWA)

The SenseWear Pro Armband™ (SWA) (Figure 2-1) is a newly developed commercially available device that gathers physiological information from the body to estimate EE in free living environments utilizing proprietary equations developed by the manufacturer. The SWA can be worn on the right upper arm over the belly of the triceps muscle, capturing and storing minute-by-minute physiological data. The SWA is composed of multiple sensors including a 2-axis accelerometer that monitors the movement of the upper arm and provides information about body position, heat-flux sensors that measure the amount of heat being dissipated by the body, thermistor-based sensors that measure skin temperature and near-armband temperature, and galvanic skin response sensors that measure electrical conductivity between two points on the wearer's arm (1). Data from each of these sensors, in addition to demographic characteristics (age, gender, weight, height, handedness, and smoking habit), are used in proprietary algorithms to estimate EE (1,142).

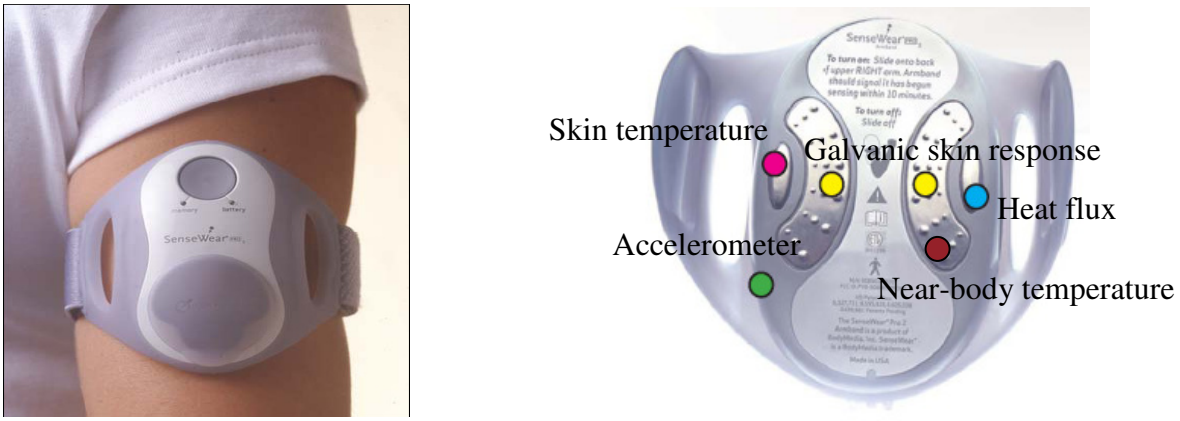


Figure 2-1 SenseWear Pro Armband™(SWA)

The SWA can be worn comfortably for almost all types of activities and environmental conditions, and as a result it may overcome the limitations of other EE measurement devices. The SWA can be an alternative method for measuring PA and EE (1,142) that may help health care professionals and individuals monitoring PA and EE in everyday activity. Incorporating a 2-axis accelerometer with other heat-related sensors in the SWA may improve accuracy in estimating EE compared to traditional accelerometers. It is worn on the UE and for PWD who use wheelchairs; this positioning may provide the most accurate estimate of PAEE. Many studies have investigated the validity and reliability of the SWA as an EE measurement device. Most studies with various populations reported good agreement between REE as measured by the SWA and gold standard measures of EE such as DLW and IC (82,143-146). Several studies have investigated the validity and reliability of the SWA during various kinds of exercise. Examples of these studies and their findings in various populations are provided below.

2.2.8.1 Validity and reliability studies of SWA in leg exercise

There were several modes of leg exercise reported in previous SWA validity studies including treadmill walking, stepping, cycling, six-minute walking, and incremental shuttle-walking. Studies in healthy subjects using treadmill as the mode of exercise have demonstrated both high correlation coefficients (83,144) and moderate correlation coefficient between EE as measured by IC and estimated by the SWA (81). In clinical populations, previous studies have reported low agreement between EE as measured by IC and

estimated by the SWA in obese individuals (147) but strong agreement in patients with cystic fibrosis (80) and in cardiac rehabilitation patents (79). Most studies reported overestimation of the SWA (80,81,83,84,147-149) but some studies reported underestimation of the SWA during treadmill walking(79,81,83,150)

Previous studies reported strong agreement between EE estimated by the SWA and measured by IC during stair stepping exercise in healthy subjects (83,146) but poor agreement in obese population (147). The SWA underestimated EE in healthy subjects (83,146,150) but overestimated EE in obese population (147).

All studies have indicated poor agreement between EE as measured by IC and estimated by the SWA (81,83,146,147) for cycling exercise when the general algorithms were applied to the data. Most studies reported underestimation of the SWA (81,83,146,148) but one study in obese population reported overestimation of the SWA during this mode of exercise (147). A possible explanation for the poor agreement during cycling exercise is that the SWA is designed to be worn on the upper arm to detect arm movement during exercise (142). There is a small degree of arm movement for cycling exercise, so that the SWA was less accurate to measure EE during this mode of exercise.

For other modes of leg exercise such as six-minute walking tests and incremental shuttle-walking tests, Patel et al. (85) reported that EE estimated from the SWA correlated well to EE as measured by IC, with very high session correlations (r=0.93) during six-minute walking tests and incremental shuttle-walking tests in patients with chronic obstructive pulmonary disorder (COPD).

The test-retest reproducibility was also high for both types of tests (ICC=0.84 and 0.86). The SWA underestimated EE 15.5 % and 4.7 % for six-minute walking tests and incremental shuttle-walking tests, respectively.

2.2.8.2 Validity and reliability studies of SWA in arm exercise

To our knowledge, there are only three studies that have examined the validity of SWA for measuring EE during arm exercise using IC as a criterion measure (79,82,83). Hiremath et al. (82) indicated strong agreement (ICC=0.79) between EE as measured by IC and estimated by SWA for wheelchair related activities in manual wheelchair users. In spite of strong agreement, the SWA overestimated EE by 46.2-138.2% for wheelchair ergometry exercise, 26.9-55.1% for arm ergometry exercise, and 13.1% for deskwork. Jakicic et al. (83) reported ICC=0.74 when the general algorithm was applied and ICC=0.66 when an exercise-specific algorithm was applied to estimate EE for arm ergometry exercise in healthy subjects. The SWA overestimated EE by 29.3 % for the general algorithm but underestimated EE 3.8 % for the exercise-specific algorithm. Cole et al. (79) reported a higher level of correlation between EE as measured by IC and estimated by the SWA during arm ergometry exercise in cardiac rehabilitation patients. The correlation coefficients were (*r)* = 0.9, 0.85, and 0.9 for software version 2.2, 4.0, and preliminary cardiac software, respectively. The SWA underestimated EE 2.3% for SWA's software version 2.2 and 0.04% for preliminary cardiac software but overestimated EE 5.6 % for SWA's software version 4.0.

In summary, the SWA appeared to provide more accurate measurement of EE during arm ergometry exercise than cycling exercise. Poor agreement between EE as measured by the IC and estimated by the SWA during cycling exercise has been reported in healthy subjects (81,83,146,148,150) and in individuals with obesity(r=0.18)(147), whereas strong agreement between EE as measured by the IC and estimated by the SWA during arm ergometry exercise has been reported in healthy subjects (83), in cardiac rehabilitation patents (79), and in wheelchair users (82). A possible explanation for the difference of correlation coefficients between arm ergometry exercise and cycling exercise is that the SWA was designed to be worn on the upper arm; therefore it is more likely to detect arm movement during arm exercise (142). There is a small degree of arm movement during cycling exercise, so that the SWA appeared to be less accurate to estimate EE during cycling exercise. Previous studies also reported significant relationship between EE as measured by IC and estimated by the SWA for activities that incorporated movement of the arm in those activities such as during treadmill walking (79-81,83,84,144), stair stepping (83,146), six-minute walking tests, and incremental shuttle-walking tests(85).

2.2.8.3 Summary of results of SWA studies for estimation of energy expenditure

Most studies with various non-disabled populations and clinical populations reported moderate to good agreement between EE as measured by the SWA and gold standard measures of EE such as IC and DLW method. However,

some studies reported low agreement between the SWA and IC in measuring EE. From our knowledge, there were only 3 studies (79,82,83) that examined the validity of SWA for measuring EE during arm exercise. No study has been published in the scientific literature concerning the validity of the SWA during wheelchair ergometry exercise in healthy subjects. Therefore, this investigation aims to examine the criterion validity of the SWA (version 6.1) to estimate EE during wheelchair ergometry exercise with healthy, non-disabled participants. The use of healthy participants in this initial study with wheelchair ergometry reduces potential confounding of EE measurement that may result from pathology (i.e., autonomic dysfunction). If our findings reveal that the SWA is a valid measure of EE during wheelchair ergometry exercise in healthy subjects, future studies may test its validity with disabled populations.

REFERENCES

(1) Andre, D., Pelletier, R., Farringdon, J., Safier, S., Talbott, W., Stone, R., Vyas, N., Trimble, J., Wolf, D., Vishnubhatla, S., Boehmke, S., Stivoric, J., Teller, A. The Development of the SenseWear® armband, a Revolutionary Energy Assessment Device to Assess Physical Activity and Lifestyle. 2006; Available at: http://www.bodybugg.com/pdf/wp_accuracy_ee.pdf. Accessed Sept 24, 2010.

(2) Ainslie P, Reilly T, Westerterp K. Estimating human energy expenditure: a review of techniques with particular reference to doubly labelled water. Sports Med. 2003;33(9):683-698.

(3) da Rocha EE, Alves VG, da Fonseca RB. Indirect calorimetry: methodology, instruments and clinical application. Curr.Opin.Clin.Nutr.Metab.Care 2006 May;9(3):247-256.

(4) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(5) Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. Fam.Community Health 2006 Jan-Mar;29(1 Suppl):78S-88S.

(6) Dufour DL, Piperata BA. Energy expenditure among farmers in developing countries: what do we know? Am.J.Hum.Biol. 2008 May-Jun;20(3):249-258.

(7) Montoye, H.J. Kemper, H.C.G., Saris, W.H.M., et al. Measuring physical activity and energy expenditure. Champaign, IL: Human Kinetics.; 1996.

(8) Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. Med.Sci.Sports Exerc. 1998 May;30(5):777-781.

(9) Lamonte MJ, Ainsworth BE. Quantifying energy expenditure and physical activity in the context of dose response. Med.Sci.Sports Exerc. 2001 Jun;33(6 Suppl):S370-8; discussion S419-20.

(10) Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med.Sci.Sports Exerc. 2000 Sep;32(9 Suppl):S498-504.

(11) Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. Res.Q.Exerc.Sport 2000 Jun;71(2 Suppl):S1-14.

(12) Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985 Mar-Apr;100(2):126-131.

(13) Lamonte MJ, Ainsworth BE. Quantifying energy expenditure and physical activity in the context of dose response. Med.Sci.Sports Exerc. 2001 Jun;33(6 Suppl):S370-8; discussion S419-20.

(14) Tudor-Locke CE, Myers AM. Challenges and opportunities for measuring physical activity in sedentary adults. Sports Med. 2001 Feb;31(2):91-100.

(15) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(16) Luke A, Durazo-Arvizu R, Cao G, Adeyemo A, Tayo B, Cooper R. Positive association between resting energy expenditure and weight gain in a lean adult population. Am.J.Clin.Nutr. 2006 May;83(5):1076-1081.

(17) Rodriguez G, Moreno LA, Sarria A, Pineda I, Fleta J, Perez-Gonzalez JM, et al. Determinants of resting energy expenditure in obese and non-obese children and adolescents. J.Physiol.Biochem. 2002 Mar;58(1):9-15.

(18) Buchholz AC, Rafii M, Pencharz PB. Is resting metabolic rate different between men and women? Br.J.Nutr. 2001 Dec;86(6):641-646.

(19) Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. Am.J.Clin.Nutr. 1980 Nov;33(11):2372-2374.

(20) Arciero PJ, Goran MI, Poehlman ET. Resting metabolic rate is lower in women than in men. J.Appl.Physiol. 1993 Dec;75(6):2514-2520.

(21) Roberts SB, Dallal GE. Energy requirements and aging. Public Health Nutr. 2005 Oct;8(7A):1028-1036.

(22) Barlett HL, Puhl SM, Hodgson JL, Buskirk ER. Fat-free mass in relation to stature: ratios of fat-free mass to height in children, adults, and elderly subjects. Am.J.Clin.Nutr. 1991 May;53(5):1112-1116.

(23) Bosy-Westphal A, Eichhorn C, Kutzner D, Illner K, Heller M, Muller MJ. The age-related decline in resting energy expenditure in humans is due to the loss of fat-free mass and to alterations in its metabolically active components. J.Nutr. 2003 Jul;133(7):2356-2362.

(24) Poehlman ET, Goran MI, Gardner AW, Ades PA, Arciero PJ, Katzman-Rooks SM, et al. Determinants of decline in resting metabolic rate in aging females. Am.J.Physiol. 1993 Mar;264(3 Pt 1):E450-5.

(25) Poehlman ET. A review: exercise and its influence on resting energy metabolism in man. Med.Sci.Sports Exerc. 1989 Oct;21(5):515-525.

(26) Jamurtas AZ, Koutedakis Y, Paschalis V, Tofas T, Yfanti C, Tsiokanos A, et al. The effects of a single bout of exercise on resting energy expenditure and respiratory exchange ratio. Eur.J.Appl.Physiol. 2004 Aug;92(4-5):393-398.

(27) Osterberg KL, Melby CL. Effect of acute resistance exercise on postexercise oxygen consumption and resting metabolic rate in young women. Int.J.Sport Nutr.Exerc.Metab. 2000 Mar;10(1):71-81.

(28) McArdle, W.D., Katch, F.I., Katch, V.L. Exercise Physiology: Energy, Nutrition and Human Performance. 5th ed. Philadelphia, PA: Lippincott: Williams & Wilkins Inc; 2001.

(29) Warms, C.A., Whitney, J.D., Belza, B. \Measurement and description of physical activity in adult manual wheelchair users. Disabil and Health J. 2008;1:236-244.

(30) van den Berg-Emons RJ, Bussmann JB, Haisma JA, Sluis TA, van der Woude LH, Bergen MP, et al. A prospective study on physical activity levels after spinal cord injury during inpatient rehabilitation and the year after discharge. Arch.Phys.Med.Rehabil. 2008 Nov;89(11):2094-2101.

(31) Wilmet E, Ismail AA, Heilporn A, Welraeds D, Bergmann P. Longitudinal study of the bone mineral content and of soft tissue composition after spinal cord section. Paraplegia 1995 Nov;33(11):674-677.

(32) Keim NL, Blanton CA, Kretsch MJ. America's obesity epidemic: measuring physical activity to promote an active lifestyle. J.Am.Diet.Assoc. 2004 Sep;104(9):1398-1409.

(33) LaPorte RE, Montoye HJ, Caspersen CJ. Assessment of physical activity in epidemiologic research: problems and prospects. Public Health Rep. 1985 Mar-Apr;100(2):131-146.

(34) Kriska A, Casperson CJ. Introduction to a collection of physical activity questionnaires. Med. Sci. Sports Exerc. 1997;29:S5-S9.

(35) Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. Br.J.Sports Med. 2003 Jun;37(3):197-206; discussion 206.

(36) Pate RR. Physical activity assessment in children and adolescents. Crit.Rev.Food Sci.Nutr. 1993;33(4-5):321-326.

(37) Janssen TW, van Oers CA, Veeger HE, Hollander AP, van der Woude LH, Rozendal RH. Relationship between physical strain during standardised ADL tasks and physical capacity in men with spinal cord injuries. Paraplegia 1994 Dec;32(12):844-859.

(38) Cooper RA, Boninger ML, Shimada SD, Lawrence BM. Glenohumeral joint kinematics and kinetics for three coordinate system representations during wheelchair propulsion. Am.J.Phys.Med.Rehabil. 1999 Sep-Oct;78(5):435-446.

(39) Spaepen, A., Vanlandewijck, Y., Lysens, R. Relationship between energy expenditure and muscular activity patterns in handrim wheelchair propulsion. International Journal of Industrial Ergonomics. 1996;17:163-173.

(40) Kos D, Nagels G, D'Hooghe MB, Duquet W, Ilsbroukx S, Delbeke S, et al. Measuring activity patterns using actigraphy in multiple sclerosis. Chronobiol.Int. 2007;24(2):345-356.

(41) Ng AV, Kent-Braun JA. Quantitation of lower physical activity in persons with multiple sclerosis. Med.Sci.Sports Exerc. 1997 Apr;29(4):517-523.

(42) Rimmer JH, Riley BB, Rubin SS. A new measure for assessing the physical activity behaviors of persons with disabilities and chronic health conditions: the Physical Activity and Disability Survey. Am.J.Health Promot. 2001 Sep-Oct;16(1):34-42.

(43) Warms CA, Belza BL, Whitney JD. Correlates of physical activity in adults with mobility limitations. Fam.Community Health 2007 Apr-Jun;30(2 Suppl):S5-16.

(44) van der Ploeg HP, Streppel KR, van der Beek AJ, van der Woude LH, Vollenbroek-Hutten M, van Mechelen W. The Physical Activity Scale for Individuals with Physical Disabilities: test-retest reliability and comparison with an accelerometer. J.Phys.Act.Health. 2007 Jan;4(1):96-100.

(45) Liang H, Tomey K, Chen D, Savar NL, Rimmer JH, Braunschweig CL. Objective measures of neighborhood environment and self-reported physical activity in spinal cord injured men. Arch.Phys.Med.Rehabil. 2008 Aug;89(8):1468-1473.

(46) Washburn RA, Zhu W, McAuley E, Frogley M, Figoni SF. The physical activity scale for individuals with physical disabilities: development and evaluation. Arch.Phys.Med.Rehabil. 2002 Feb;83(2):193-200.

(47) Ginis KA, Latimer AE, Hicks AL, Craven BC. Development and evaluation of an activity measure for people with spinal cord injury. Med.Sci.Sports Exerc. 2005 Jul;37(7):1099-1111.

(48) Latimer AE, Ginis KA, Craven BC, Hicks AL. The physical activity recall assessment for people with spinal cord injury: validity. Med.Sci.Sports Exerc. 2006 Feb;38(2):208-216.

(49) Cox SA, Weiss SM, Posuniak EA, Worthington P, Prioleau M, Heffley G. Energy expenditure after spinal cord injury: an evaluation of stable rehabilitating patients. J.Trauma 1985 May;25(5):419-423.

(50) Shizgal HM, Roza A, Leduc B, Drouin G, Villemure JG, Yaffe C. Body composition in quadriplegic patients. JPEN J.Parenter.Enteral Nutr. 1986 Jul-Aug;10(4):364-368.

(51) Sedlock DA, Laventure SJ. Body composition and resting energy expenditure in long term spinal cord injury. Paraplegia 1990 Sep;28(7):448-454.

(52) Buchholz AC, McGillivray CF, Pencharz PB. Differences in resting metabolic rate between paraplegic and able-bodied subjects are explained by differences in body composition. Am.J.Clin.Nutr. 2003 Feb;77(2):371-378.

(53) Harris JA, Benedict FG. A Biometric Study of Human Basal Metabolism. Proc.Natl.Acad.Sci.U.S.A. 1918 Dec;4(12):370-373.

(54) Daly JM, Heymsfield SB, Head CA, Harvey LP, Nixon DW, Katzeff H, et al. Human energy requirements: overestimation by widely used prediction equation. Am.J.Clin.Nutr. 1985 Dec;42(6):1170-1174.

(55) Owen OE, Kavle E, Owen RS, Polansky M, Caprio S, Mozzoli MA, et al. A reappraisal of caloric requirements in healthy women. Am.J.Clin.Nutr. 1986 Jul;44(1):1-19.

(56) Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, et al. A reappraisal of the caloric requirements of men. Am.J.Clin.Nutr. 1987 Dec;46(6):875-885.

(57) Molnar D, Jeges S, Erhardt E, Schutz Y. Measured and predicted resting metabolic rate in obese and nonobese adolescents. J.Pediatr. 1995 Oct;127(4):571-577.

(58) Kaplan AS, Zemel BS, Neiswender KM, Stallings VA. Resting energy expenditure in clinical pediatrics: measured versus prediction equations. J.Pediatr. 1995 Aug;127(2):200-205.

(59) Havalad S, Quaid MA, Sapiega V. Energy expenditure in children with severe head injury: lack of agreement between measured and estimated energy expenditure. Nutr.Clin.Pract. 2006 Apr;21(2):175-181.

(60) Patt PL, Agena SM, Vogel LC, Foley S, Anderson CJ. Estimation of resting energy expenditure in children with spinal cord injuries. J.Spinal Cord Med. 2007;30 Suppl 1:S83-7.

(61) Rodriguez DJ, Benzel EC, Clevenger FW. The metabolic response to spinal cord injury. Spinal Cord 1997 Sep;35(9):599-604.

(62) Long CL, Schaffel N, Geiger JW, Schiller WR, Blakemore WS. Metabolic response to injury and illness: estimation of energy and protein needs from indirect calorimetry and nitrogen balance. JPEN J.Parenter.Enteral Nutr. 1979 Nov-Dec;3(6):452-456.

(63) Schutz Y. The basis of direct and indirect calorimetry and their potentials. Diabetes Metab.Rev. 1995 Dec;11(4):383-408.

(64) Twaddle, B.J., Papadopoulos, C. Assessment of The Kb1-c Portable Metabolic Measurement System During Submaximal Cycle And Treadmill Exercise. Med. Sci. Sports Exer. 2005;37(5):S25-S26.

(65) Ekelund U, Yngve A, Westerterp K, Sjostrom M. Energy expenditure assessed by heart rate and doubly labeled water in young athletes. Med.Sci.Sports Exerc. 2002 Aug;34(8):1360-1366.

(66) Schoeller DA, Racette SB. A review of field techniques for the assessment of energy expenditure. J.Nutr. 1990 Nov;120 Suppl 11:1492-1495.

(67) Seale JL, Klein G, Friedmann J, Jensen GL, Mitchell DC, Smiciklas-Wright H. Energy expenditure measured by doubly labeled water, activity recall, and diet records in the rural elderly. Nutrition 2002 Jul-Aug;18(7-8):568-573.

(68) Rennie KL, Wareham NJ. The validation of physical activity instruments for measuring energy expenditure: problems and pitfalls. Public Health Nutr. 1998 Dec;1(4):265-271.

(69) Seale JL, Conway JM, Canary JJ. Seven-day validation of doubly labeled water method using indirect room calorimetry. J.Appl.Physiol. 1993 Jan;74(1):402-409.

(70) Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jequier E. Energy expenditure by doubly labeled water: validation in humans and proposed calculation. Am.J.Physiol. 1986 May;250(5 Pt 2):R823-30.

(71) Schutz Y, Weinsier RL, Hunter GR. Assessment of free-living physical activity in humans: an overview of currently available and proposed new measures. Obes.Res. 2001 Jun;9(6):368-379.

(72) Wareham NJ, Rennie KL. The assessment of physical activity in individuals and populations: why try to be more precise about how physical activity is assessed? Int.J.Obes.Relat.Metab.Disord. 1998 Aug;22 Suppl 2:S30-8.

(73) Baranowski T, Smith M, Thompson WO, Baranowski J, Hebert D, de Moor C. Intraindividual variability and reliability in a 7-day exercise record. Med.Sci.Sports Exerc. 1999 Nov;31(11):1619-1622.

(74) Rennie K, Rowsell T, Jebb SA, Holburn D, Wareham NJ. A combined heart rate and movement sensor: proof of concept and preliminary testing study. Eur.J.Clin.Nutr. 2000 May;54(5):409-414.

(75) Ades PA, Savage PD, Brochu M, Tischler MD, Lee NM, Poehlman ET. Resistance training increases total daily energy expenditure in disabled older women with coronary heart disease. J.Appl.Physiol. 2005 Apr;98(4):1280-1285.

(76) Delikanaki-Skaribas E, Trail M, Wong WW, Lai EC. Daily energy expenditure, physical activity, and weight loss in Parkinson's disease patients. Mov.Disord. 2009 Apr 15;24(5):667-671.

(77) Tanhoffer RA, Tanhoffer AIP, Raymond J, Hills AP, Davis GM. Estimation of Energy Expenditure in People with Spinal Cord Injury: A Pilot Study. Med.Sci.Sports Exerc. 2010;42(5):334.

(78) Spungen AM, Adkins RH, Stewart CA, Wang J, Pierson RN,Jr, Waters RL, et al. Factors influencing body composition in persons with spinal cord injury: a cross-sectional study. J.Appl.Physiol. 2003 Dec;95(6):2398-2407.

(79) Cole PJ, LeMura LM, Klinger TA, Strohecker K, McConnell TR. Measuring energy expenditure in cardiac patients using the Body Media Armband versus indirect calorimetry. A validation study. J.Sports Med.Phys.Fitness 2004 Sep;44(3):262-271.

(80) Dwyer TJ, Alison JA, McKeough ZJ, Elkins MR, Bye PT. Evaluation of the SenseWear activity monitor during exercise in cystic fibrosis and in health. Respir.Med. 2009 Oct;103(10):1511-1517.

(81) Fruin ML, Rankin JW. Validity of a multi-sensor armband in estimating rest and exercise energy expenditure. Med.Sci.Sports Exerc. 2004 Jun;36(6):1063-1069.

(82) Hiremath SV, Ding D. Evaluation of activity monitors to estimate energy expenditure in manual wheelchair users. Conf.Proc.IEEE Eng.Med.Biol.Soc. 2009;Pgs 721-1078:835-838.

(83) Jakicic JM, Marcus M, Gallagher KI, Randall C, Thomas E, Goss FL, et al. Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. Med.Sci.Sports Exerc. 2004 May;36(5):897-904.

(84) King GA, Torres N, Potter C, Brooks TJ, Coleman KJ. Comparison of activity monitors to estimate energy cost of treadmill exercise. Med.Sci.Sports Exerc. 2004 Jul;36(7):1244-1251.

(85) Patel SA, Benzo RP, Slivka WA, Sciurba FC. Activity monitoring and energy expenditure in COPD patients: a validation study. COPD 2007 Jun;4(2):107-112.

(86) St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. Am.J.Clin.Nutr. 2007 Mar;85(3):742-749.

(87) Hayes AM, Myers JN, Ho M, Lee MY, Perkash I, Kiratli BJ. Heart rate as a predictor of energy expenditure in people with spinal cord injury. J.Rehabil.Res.Dev. 2005 Sep-Oct;42(5):617-624.

(88) Haymes EM, Byrnes WC. Walking and running energy expenditure estimated by Caltrac and indirect calorimetry. Med.Sci.Sports Exerc. 1993 Dec;25(12):1365-1369.

(89) Haugen HA, Chan LN, Li F. Indirect calorimetry: a practical guide for clinicians. Nutr.Clin.Pract. 2007 Aug;22(4):377-388.

(90) Raurich JM, Ibanez J, Marse P. Validation of a new closed circuit indirect calorimetry method compared with the open Douglas bag method. Intensive Care Med. 1989;15(4):274-278.

(91) Booth M. Assessment of physical activity: an international perspective. Res.Q.Exerc.Sport 2000 Jun;71(2 Suppl):S114-20.

(92) Levine JA. Measurement of energy expenditure. Public Health Nutr. 2005 Oct;8(7A):1123-1132.

(93) van den Berg-Emons HJ, Saris WH, de Barbanson DC, Westerterp KR, Huson A, van Baak MA. Daily physical activity of schoolchildren with spastic diplegia and of healthy control subjects. J.Pediatr. 1995 Oct;127(4):578-584.

(94) Wideman L, Stoudemire NM, Pass KA, McGinnes CL, Gaesser GA, Weltman A. Assessment of the aerosport TEEM 100 portable metabolic measurement system. Med.Sci.Sports Exerc. 1996 Apr;28(4):509-515.

(95) Bassett DR,Jr, Ainsworth BE, Swartz AM, Strath SJ, O'Brien WL, King GA. Validity of four motion sensors in measuring moderate intensity physical activity. Med.Sci.Sports Exerc. 2000 Sep;32(9 Suppl):S471-80.

(96) Haskell WL, Leon AS, Caspersen CJ, Froelicher VF, Hagberg JM, Harlan W, et al. Cardiovascular benefits and assessment of physical activity and physical fitness in adults. Med.Sci.Sports Exerc. 1992 Jun;24(6 Suppl):S201-20.

(97) Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. Res.Q.Exerc.Sport 2000 Jun;71(2 Suppl):S21-9.

(98) Melanson EL,Jr, Freedson PS. Physical activity assessment: a review of methods. Crit.Rev.Food Sci.Nutr. 1996 May;36(5):385-396.

(99) Morrow JR, Jackson AW, Disch JG, Mood DP. Physical fitness and activity assessment inadults. In: Measurement and evaluation in human performance. Champaign IL: Human Kinetics; 2000.

(100) Gretebeck RJ, Montoye HJ. Variability of some objective measures of physical activity. Med.Sci.Sports Exerc. 1992 Oct;24(10):1167-1172.

(101) Li R, Deurenberg P, Hautvast JG. A critical evaluation of heart rate monitoring to assess energy expenditure in individuals. Am.J.Clin.Nutr. 1993 Nov;58(5):602-607.

(102) Livingstone MB. Heart-rate monitoring: the answer for assessing energy expenditure and physical activity in population studies? Br.J.Nutr. 1997 Dec;78(6):869-871.

(103) Brage S, Brage N, Franks PW, Ekelund U, Wong MY, Andersen LB, et al. Branched equation modeling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured physical activity energy expenditure. J.Appl.Physiol. 2004 Jan;96(1):343-351.

(104) Haskell WL, Yee MC, Evans A, Irby PJ. Simultaneous measurement of heart rate and body motion to quantitate physical activity. Med.Sci.Sports Exerc. 1993 Jan;25(1):109-115.

(105) Strath SJ, Bassett DR,Jr, Swartz AM, Thompson DL. Simultaneous heart rate-motion sensor technique to estimate energy expenditure. Med.Sci.Sports Exerc. 2001 Dec;33(12):2118-2123.

(106) Strath SJ, Brage S, Ekelund U. Integration of physiological and accelerometer data to improve physical activity assessment. Med.Sci.Sports Exerc. 2005 Nov;37(11 Suppl):S563-71.

(107) Strath SJ, Bassett DR,Jr, Thompson DL, Swartz AM. Validity of the simultaneous heart rate-motion sensor technique for measuring energy expenditure. Med.Sci.Sports Exerc. 2002 May;34(5):888-894.

(108) Luke A, Maki KC, Barkey N, Cooper R, McGee D. Simultaneous monitoring of heart rate and motion to assess energy expenditure. Med.Sci.Sports Exerc. 1997 Jan;29(1):144-148.

(109) Strath SJ, Swartz AM, Bassett DR,Jr, O'Brien WL, King GA, Ainsworth BE. Evaluation of heart rate as a method for assessing moderate intensity physical activity. Med.Sci.Sports Exerc. 2000 Sep;32(9 Suppl):S465-70.

(110) Livingstone MB, Coward WA, Prentice AM, Davies PS, Strain JJ, McKenna PG, et al. Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labeled water (2H2(18)O) method. Am.J.Clin.Nutr. 1992 Aug;56(2):343-352.

(111) Emons HJ, Groenenboom DC, Westerterp KR, Saris WH. Comparison of heart rate monitoring combined with indirect calorimetry and the doubly labelled water (2H2(18)O) method for the measurement of energy expenditure in children. Eur.J.Appl.Physiol.Occup.Physiol. 1992;65(2):99-103.

(112) Keefer DJ, Tseh W, Caputo JL, Apperson K, McGreal S, Morgan DW. Comparison of direct and indirect measures of walking energy expenditure in children with hemiplegic cerebral palsy. Dev.Med.Child Neurol. 2004 May;46(5):320-324.

(113) Sawatzky BJ, Miller WC, Denison I. Measuring energy expenditure using heart rate to assess the effects of wheelchair tyre pressure. Clin.Rehabil. 2005 Mar;19(2):182-187.

(114) Valent LJ, Dallmeijer AJ, Houdijk H, Slootman J, Janssen TW, Hollander AP, et al. The individual relationship between heart rate and oxygen uptake in people with a tetraplegia during exercise. Spinal Cord 2007 Jan;45(1):104-111.

(115) Mollinger LA, Spurr GB, el Ghatit AZ, Barboriak JJ, Rooney CB, Davidoff DD, et al. Daily energy expenditure and basal metabolic rates of patients with spinal cord injury. Arch.Phys.Med.Rehabil. 1985 Jul;66(7):420-426.

(116) Valanou, E.M., Bamia,C. Trichopoulou, A. Methodology of physical-activity and energy-expenditure assessment: a review. J Public Health. 2006:58-65.

(117) Bassett DR,Jr, Cureton AL, Ainsworth BE. Measurement of daily walking distance-questionnaire versus pedometer. Med.Sci.Sports Exerc. 2000 May;32(5):1018-1023.

(118) Motl RW, McAuley E, Snook EM, Scott JA. Accuracy of two electronic pedometers for measuring steps taken under controlled conditions among ambulatory individuals with multiple sclerosis. Mult.Scler. 2005 Jun;11(3):343-345.

(119) Bassett DR,Jr, Ainsworth BE, Leggett SR, Mathien CA, Main JA, Hunter DC, et al. Accuracy of five electronic pedometers for measuring distance walked. Med.Sci.Sports Exerc. 1996 Aug;28(8):1071-1077.

(120) Cyarto EV, Myers AM, Tudor-Locke C. Pedometer accuracy in nursing home and community-dwelling older adults. Med.Sci.Sports Exerc. 2004 Feb;36(2):205-209.

(121) Beets MW, Combs C, Pitetti KH, Morgan M, Bryan RR, Foley JT. Accuracy of pedometer steps and time for youth with disabilities. Adapt.Phys.Activ Q. 2007 Jul;24(3):228-244.

(122) Mudge S, Stott NS. Timed walking tests correlate with daily step activity in persons with stroke. Arch.Phys.Med.Rehabil. 2009 Feb;90(2):296-301.

(123) Elsworth C, Dawes H, Winward C, Howells K, Collett J, Dennis A, et al. Pedometer step counts in individuals with neurological conditions. Clin.Rehabil. 2009 Feb;23(2):171-175.

(124) Berlin JE, Storti KL, Brach JS. Using activity monitors to measure physical activity in free-living conditions. Phys.Ther. 2006 Aug;86(8):1137-1145.

(125) Chen KY, Sun M. Improving energy expenditure estimation by using a triaxial accelerometer. J.Appl.Physiol. 1997 Dec;83(6):2112-2122.

(126) Bouten CV, Verboeket-van de Venne WP, Westerterp KR, Verduin M, Janssen JD. Daily physical activity assessment: comparison between movement registration and doubly labeled water. J.Appl.Physiol. 1996 Aug;81(2):1019-1026.

(127) Rowlands AV, Thomas PW, Eston RG, Topping R. Validation of the RT3 triaxial accelerometer for the assessment of physical activity. Med.Sci.Sports Exerc. 2004 Mar;36(3):518-524.

(128) Levine JA, Baukol PA, Westerterp KR. Validation of the Tracmor triaxial accelerometer system for walking. Med.Sci.Sports Exerc. 2001 Sep;33(9):1593-1597.

(129) Pambianco G, Wing RR, Robertson R. Accuracy and reliability of the Caltrac accelerometer for estimating energy expenditure. Med.Sci.Sports Exerc. 1990 Dec;22(6):858-862.

(130) Welk GJ, Blair SN, Wood K, Jones S, Thompson RW. A comparative evaluation of three accelerometry-based physical activity monitors. Med.Sci.Sports Exerc. 2000 Sep;32(9 Suppl):S489-97.

(131) Hendelman D, Miller K, Baggett C, Debold E, Freedson P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. Med.Sci.Sports Exerc. 2000 Sep;32(9 Suppl):S442-9.

(132) Bray MS, Wong WW, Morrow JR,Jr, Butte NF, Pivarnik JM. Caltrac versus calorimeter determination of 24-h energy expenditure in female children and adolescents. Med.Sci.Sports Exerc. 1994 Dec;26(12):1524-1530.

(133) Welk GJ, Corbin CB. The validity of the Tritrac-R3D Activity Monitor for the assessment of physical activity in children. Res.Q.Exerc.Sport 1995 Sep;66(3):202-209.

(134) Postma K, van den Berg-Emons HJ, Bussmann JB, Sluis TA, Bergen MP, Stam HJ. Validity of the detection of wheelchair propulsion as measured with an Activity Monitor in patients with spinal cord injury. Spinal Cord 2005 Sep;43(9):550-557.

(135) Washburn, R.A., Copay, A.G. Assessing physical activity during wheelchair pushing: Validity of a portable accelerometer. Adapt Phys Act Q. 1999;16(3):290-299.

(136) Warms CA, Belza BL. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. Nurs.Res. 2004 Mar-Apr;53(2):136-143.

(137) Warms CA, Belza BL, Whitney JD, Mitchell PH, Stiens SA. Lifestyle physical activity for individuals with spinal cord injury: a pilot study. Am.J.Health Promot. 2004 Mar-Apr;18(4):288-291.

(138) Haeuber E, Shaughnessy M, Forrester LW, Coleman KL, Macko RF. Accelerometer monitoring of home- and community-based ambulatory activity after stroke. Arch.Phys.Med.Rehabil. 2004 Dec;85(12):1997-2001.

(139) Tweedy SM, Trost SG. Validity of accelerometry for measurement of activity in people with brain injury. Med.Sci.Sports Exerc. 2005 Sep;37(9):1474-1480.

(140) Hale LA, Pal J, Becker I. Measuring free-living physical activity in adults with and without neurologic dysfunction with a triaxial accelerometer. Arch.Phys.Med.Rehabil. 2008 Sep;89(9):1765-1771.

(141) Kumahara H, Tanaka H, Schutz Y. Daily physical activity assessment: what is the importance of upper limb movements vs whole body movements? Int.J.Obes.Relat.Metab.Disord. 2004 Sep;28(9):1105-1110.

(142) Craig, B., Liden, C.B., Wolowicz, M., Stivoric, J., Teller, A., Vishnubhatla, S., Pelletier, R., Farringdon, J., Boehmke, S. Benefits of the SenseWear ™ Armband Over OtherPhysical Activity and Energy Expenditure Measurement Techniques. Available at: http://www.integratedfitnesssystems.com/Benefits.pdf. Accessed Sept 24, 2010.

(143) Malavolti M, Pietrobelli A, Dugoni M, Poli M, Romagnoli E, De Cristofaro P, et al. A new device for measuring resting energy expenditure (REE) in healthy subjects. Nutr.Metab.Cardiovasc.Dis. 2007 Jun;17(5):338-343.

(144) Wadsworth, D.D., Howard, T., Hallam, J.S., Blunt, G.A. Validation Study of A Continuous Body-monitoring Device: Assessing Energy Expenditure At Rest And During Exercise. Medicine and Science in Sports and Exercise 2005;37 (5 Suppl):S 24.

(145) Cereda E, Turrini M, Ciapanna D, Marbello L, Pietrobelli A, Corradi E. Assessing energy expenditure in cancer patients: a pilot validation of a new wearable device. JPEN J.Parenter.Enteral Nutr. 2007 Nov-Dec;31(6):502-507.

(146) Charoensuk J, Haennel R, Manns PJ. Validation of the SenseWear Pro ArmbandTM for the assessment of energy expenditure (EE) in healthy subjects: a pilot study. Accepted for poster presentation at the Canadian Society of Exercise Physiology (CSEP) Annual Meeting. Oct 2008.

(147) Papazoglou D, Augello G, Tagliaferri M, Savia G, Marzullo P, Maltezos E, et al. Evaluation of a multisensor armband in estimating energy expenditure in obese individuals. Obesity (Silver Spring) 2006 Dec;14(12):2217-2223.

(148) Calabro MA, Welk GJ, Eisenmann JC. Validation of the SenseWear Pro Armband algorithms in children. Med.Sci.Sports Exerc. 2009 Sep;41(9):1714-1720.

(149) Dorminy CA, Choi L, Akohoue SA, Chen KY, Buchowski MS. Validity of a multisensor armband in estimating 24-h energy expenditure in children. Med.Sci.Sports Exerc. 2008 Apr;40(4):699-706.

(150) Arvidsson D, Slinde F, Larsson S, Hulthen L. Energy cost of physical activities in children: validation of SenseWear Armband. Med.Sci.Sports Exerc. 2007 Nov;39(11):2076-2084.

CHAPTER THREE

WHEELCHAIR ERGOMETRY EXERCISE AND SENSEWEAR PRO ARMBAND (SWA): A PRELIMINARY STUDY WITH HEALTHY CONTROLS

3.1 INTRODUCTION

Obesity affects all subgroups of the population but is more prevalent among people with disabilities (PWD), especially those with lower extremity impairments (1-5). Obesity is a health-related concern because it is linked with an increased risk for developing many kinds of chronic diseases, such as coronary heart disease, hypertension, and diabetes (6-8). It occurs when there is an imbalance between energy intake and energy expenditure (EE), which suggests that knowledge of EE may be crucial to achieving energy balance and body weight control. However, measurement of EE is challenging in PWD (9). The amount of active muscle mass may be limited and locomotor activity may be performed differently, using different muscles (i.e., arms vs. legs), than in people without disabilities. Hand-rim-propelled manual wheelchairs are the most common type of assistive device to enhance mobility for PWD, especially for those with lower extremity disabilities (10). As such, studies that test the validity of field devices to measure EE during upper extremity (UE) movement are needed (11).

Several previous studies have tested field devices such as pedometers and accelerometers to measure physical activity (PA) specifically in PWD (11-15) .

Hale et al. (16) reported that a triaxial accelerometer (TriTrac RT3), worn on the waist, distinguished levels of activity better than a 7-day recall questionnaire in ambulatory adults with stroke, Parkinson's disease, and multiple sclerosis. In people with stroke, the Step Watch Activity Monitor (SAM) (worn on the ankle) had high test-retest reliability across monitoring periods (r=0.96, $p<.001$), whereas for the Caltrac accelerometer (worn on the waist) reliability was poor (r=0.04) (17). In people who use wheelchairs, Washburn and Copay (13) reported significant associations between the Computer Science and Application accelerometers (CSA) (worn on both wrists) and EE as measured using indirect calorimetry (IC) at three wheelchair pushing speeds. Warms et al.(14) reported significant associations between the accelerometer counts (wrist-worn Actiwatch) and Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) data. Moreover, Actiwatch showed strong inter-unit reliability and concurrent validity with a self-report measure of activity (11). However, the same study revealed that the Actiwatch accelerometer registered spasticity as activity counts, which may be a problem with the use of this device for populations in which spasticity is common (11).

In these previous studies, accelerometers were used to measure PA or activity counts, which may be used as surrogates for EE (11,13-18). However, none of the studies directly measured EE. The SWA is a newer device that incorporates a 2-axis accelerometer as well as heat flux sensors, skin temperature sensors, a near-body temperature sensor, and galvanic skin response sensors to provide a measure of EE (19). The accelerator in the SWA utilizes a micro-electro-

mechanical sensor (NEMS) device to detect motion in two planes (longitudinal and transverse). Wheelchair related activities have a large degree of movement in these planes (20), therefore incorporating a 2-axis accelerometer with other heat-related sensors in the SWA may improve EE estimates during wheelchair-related activities compared to traditional accelerometers. The sensitivity of the SWA's accelerometer was set by the manufacturer. When a person moves, the motion can be mapped to forces exerted on the body or can be mapped to energy expended by the muscles that generate these forces. This physical energy can be then used as parts of the EE calculations by using the Body Media software(21-23). The SWA can provide information about EE (calories burned), duration and level of physical activity, sleep/wake states, and number of steps taken(21-23). The SWA is worn on the UE and for PWD who use wheelchairs, this positioning may provide a more accurate estimate of PAEE.

Most SWA studies with healthy populations report moderate to good agreement between EE as estimated by the SWA in comparison with IC or doubly-labeled water (DLW) (24-33). To date, three studies have examined the validity of the SWA for measuring EE during arm exercise (30,34,35), though only one used wheelchair ergometry (34). When the general proprietary algorithm was used, the SWA provided an accurate estimate of EE compared to IC during arm ergometry exercise in healthy subjects (35) and in cardiac rehabilitation patients (30).

The only one study assessing validity of the SWA using wheelchair ergometry exercise in 6 manual wheelchair users (34) reported strong agreement (ICC=0.79).

However, the SWA overestimated EE for this mode of exercise (34). Further validity studies with larger sample sizes are needed to confirm the validity of SWA for the measurement of EE during wheelchair-related activities.

The primary purpose of this investigation was to examine the criterion validity of the SWA (version 6.1) to estimate the EE during wheelchair ergometry exercise in healthy non-disabled participants. The secondary purpose of this study was to examine the validity of SWA to estimate the number of pushes compared to manual counting. The use of healthy participants in this initial study with wheelchair ergometry reduces potential confounding of EE measurement that may result from pathology (e.g., autonomic dysfunction). If our findings reveal that the SWA is a valid measure of EE during wheelchair ergometry exercise in healthy subjects, future studies may test its validity with disabled populations.

3.2 MOTHODS

3.2.1 Study design and participants

This study used an observational design and involved 20 healthy community-dwelling volunteers, aged 18-42, recruited from several sites. The sample size was determined using Intraclass Correlation Coefficient (ICC) information from a previous SWA study (34). With a desired statistical power of 0.80, and a significance level of $p < 0.05$, it was determined that a sample size of 15 participants was adequate (36,37)

3.2.2 Instrumentation and measurement tools

3.2.2.1 Wheelchair ergometer

A customized wheelchair ergometer was used in this study. It consisted of two steel tubular rollers, one for each wheel. Total rolling resistance of the wheelchair ergometer without external resistance was 32.4 N. Rear wheels of a standard wheelchair (Quickie GP, Motion Design Corporation, Fresno, CA) were attached to the rollers of wheelchair ergometer. Two tachometers attached to the rollers measured rolling speed and visual feedback regarding speed was provided with a television screen in front of the participant.

3.2.2.2 Manual step counter

The manual step counter was utilized as the criterion method to measure number of pushes to compare the result from the number of step acquired from the SWA. A research assistant who helped in data collection was trained about using of the manual step counter before helping in data collection.

3.2.2.3 SenseWear Pro Armband™

The SWA (Body Media, Pittsburgh, PA) version 6.1 was used as the experimental method for estimating EE. Utilizing proprietary equations developed by the manufacturer, EE is estimated by integrating acquired sensor data with participant's demographic characteristics including gender, age, smoking habit, handedness, height, and body weight. The SWA purports to

measure steps, not to measure pushes. However, the SWA is designed to be worn on the right upper arm; therefore it may be an appropriate device to quantify the number of pushes during wheelchair ergometry exercise. We wanted to test if the variable derived as steps would be comparable to pushes; therefore the number of steps estimated by the SWA was equated to the number of pushes for data analyses.

3.2.2.4 Indirect calorimetry or metabolic cart

The TrueOne® 2400 Metabolic Measurement System(Parvomedics Inc., Salt Lake City, UT) was utilized for measuring EE during wheelchair ergometry exercise. The TrueOne® 2400 Metabolic Measurement System is a mixing chamber system that has been validated against the criterion Douglas bag system (38). The participant's respiratory rate, minute-by-minute oxygen uptake, carbon dioxide production, and respiratory exchange ratio (RER) were monitored continuously. Because one MET equates to one kcal per kg of body weight per hour, the EE in kilocalories per minute (kcal/min) was computed by multiplying the MET value (ml/kg/min) by participants' body weight (kg) and dividing by 60(39).

3.2.3 Data collection

Participants were asked to come to the laboratory for one 90-minute session. They refrained from strenuous exercise for 24 hours prior to testing and arrived in the laboratory at least 2 hours after eating. Upon entering the

laboratory, all participants completed a physical activity readiness questionnaire (PAR-Q) (40) and medical history. Participants were excluded if they were PAR-Q positive or if they identified a medical condition on the medical history questionnaire that contraindicated moderate to vigorous exercise. All participants provided written informed consent approved by the University of Alberta health research ethics board.

After obtaining consent and demographic information, the participants' body weight, height, resting heart rate, and blood pressure were measured. Participants were then trained to propel the wheelchair on the wheelchair ergometer by using a semicircular stroke pattern. They were also trained to control 3 different speeds of wheeling: self-selected speed, moderate speed, and fast speed. The target speeds for moderate and fast speed were 0.9 m/s and 1.5 m/s, respectively. The training session took approximately 15 minutes.

After participants became familiar with the wheelchair and wheeling, electrodes were placed to collect electrocardiograph (ECG) data throughout the test period. Heart rate was measured continuously, utilizing the standard 5-lead ECG. The SWA armband was strapped on each subject's right arm over the triceps muscle at the midpoint between the acromion and olecranon processes. After SWA application, we waited 15 minutes to allow for acclimation of skin temperature before data collection.

Prior to each testing session the TrueOne® 2400 Metabolic Measurement System was calibrated according to the manufacturer's recommendations. This consisted of two-point calibration including a room air auto-calibration routine

(20.94% O_2, 0.03% CO_2) and a standard gas calibration with a single gas tank (16.11% O_2, 4.05% CO_2). In addition, the flow meter was calibrated using a 3.0 liters Hans Rudolf 5530 series syringe involved a five stroke calibration using different flow rates for each stroke. After the TrueOne 2400 was calibrated, participants were fitted with a mouthpiece while sitting in the customized wheelchair.

The testing was composed of three continuous speed wheeling stages including 5 minutes each at self-selected and moderate speed and 3 minutes at fast speed. Participants were allowed to rest at least 2 minutes between stages. Blood pressure was measured by sphynomanometer before and after each wheeling speed. During each wheeling speed, a research assistant who was trained and competent in using the manual step counter, manually counted participant's pushes every push.

3.2.4 Statistical analyses

All statistical analyses were performed using SPSS software (version 16.0; SPSS Inc, Chicago, IL). EE data from IC and the SWA were imported into Microsoft Excel® and synchronized for further analysis. All EE data from the metabolic cart and the SWA were computed at one minute intervals. Data were analyzed separately for each wheeling speed. The average of all minute EE data and the total number of pushes for each wheeling speed trial were utilized in the statistical analyses. Agreement between the EE measurements using IC versus the SWA estimate and agreement between the total number of pushes measured

by manual step counter versus the number of steps estimated by the SWA were assessed using intraclass correlation (ICC) analyses for single measures, using the two-way mixed effects model. Bland Altman plots were constructed to diagram the level of agreement between measurements of EE by IC versus SWA (41). This plot is useful when a new method (e.g., SWA) is compared with an established one (IC) (41). Data are presented as mean and standard deviation and significance was set at the $p<0.05$ level.

3.3 RESULTS

Twenty volunteers participated in the study. Participants were predominantly men, non-smokers, and right-handed. Based on BMI, 25% of the participants were overweight and 5% were characterized as obese. Baseline characteristics of the study participants are shown in Table 3-1. Participants had normal blood pressure. The mean (SD) of systolic blood pressure (SBP), and diastolic blood pressure (DBP) measured while sitting at rest was 119.9(13.5) mmHg and 81.7(9.2) mmHg, respectively. Heart rate, oxygen consumption, carbon dioxide production, and respiratory exchange ratio for each wheeling speed are shown in Table 3-2.

Table 3-1 Baseline characteristics of study participants

Demographic variables	
Gender (Male/Female)	17/3
Smoking habit (Non Smokers/Smokers)	18/2
Handedness (Right/Left)	18/2
Age (years)	34.0 (5.8)
Body weight (kg)	64.8 (10.5)
Height(cm)	167.3 (6.8)
BMI (kg/m^2)	23.6 (3.8)

Values for age, body weight, height, and BMI are means (SD).

Table 3-2 Heart rate, oxygen consumption, carbon dioxide production, and respiratory exchange ratio for each wheeling speed

	Variables			
Speed	**HR (bpm)**	**VO_2 (ml/min)**	**VCO_2 (ml/min)**	**RER**
Self-selected	99.6(12.0)	572.5(101.1)	528.5(99.6)	0.92(0.08)
Moderate	111.5(13.2)	648.0(107.8)	645.0(111.4)	1.00(0.05)
Fast	143.6(18.7)	833.5(197.3)	902.0(246.3)	1.07(0.06)

HR, Heart rate; VO_2, Oxygen consumption; VCO_2, Carbon dioxide production; RER, Respiratory exchange ratio.
Values are means (SD) of last minute HR and means (SD) of all minutes VO_2, VCO_2, and RER.

The mean actual speeds achieved during the 3 different pushing protocols were 0.81(Range 0. 57-1.16) m/s, 1.11 (Range 0.94-1.41) m/s, and 1.73 (Range 1.25- 1.99) m/s for self-selected speed, moderate speed, and fast speed, respectively.

The measured EE by IC and estimated SWA EE for each wheeling speed are shown in Table 3-3. For both measurement techniques EE increased as the speed of wheeling increased, indicating that both methods were able to detect the change of exercise intensity. The ICCs, assessing agreement between EE as measured from IC and estimated from the SWA, were 0.50 (p=0.010), 0.59 (p=0.003), and 0.68 (p=0.000) for self-selected, moderate, and fast speeds, respectively (Table 3-3, Figure 3- 1). The relationship between the IC EE measures and the SWA estimates is presented in Figure 3-1. The SWA EE overestimated the measured IC EE by 57.8%, 57.4 %, and 63.7 % for self-selected speed, moderate speed, and fast speed, respectively.

Table 3-3 Comparison of EE between indirect calorimetry and SWA for each wheeling speed

	Energy expenditure (kcal/min)			
			Agreement	
Speed	**Measured (IC)**	**Estimated (SWA)**	**ICC**	**p-value**
Self-selected	2.71(0.48)	4.28 (1.22)	0.50	0.010*
Moderate	3.05 (0.51)	4.80 (1.19)	0.59	0.003*
Fast	3.9 (0.86)	6.46 (1.80)	0.68	0.000*

IC, indirect calorimetry; SWA, SenseWear Pro Armband™; ICC, intraclass correlation coefficient. Values are means (SD).

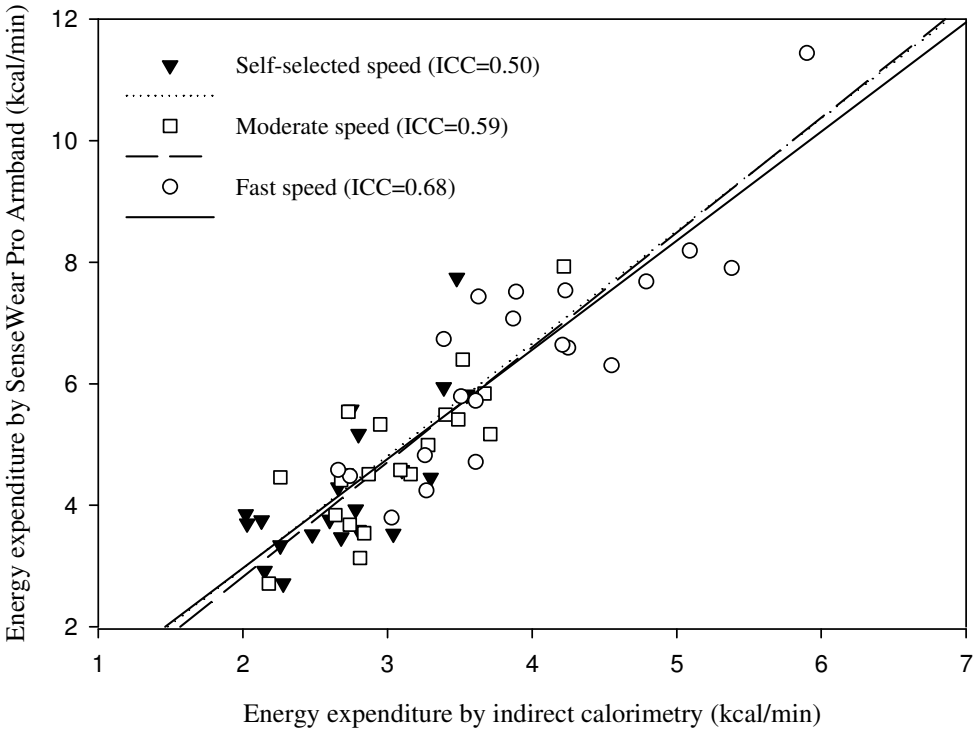


Figure 3-1 Scatter plots of energy expenditure between indirect calorimetry and SenseWear Pro Armband

Bland Altman plots (Figure 3- 2A-C) were constructed to diagram the level of agreement between measurements of EE by IC versus the SWA estimates. These results demonstrate that 95% of participants (19 of 20 participants) were within two standard deviations of the difference between the IC measured EE and the SWA estimated EE for each wheeling speed. The mean difference between the two methods of assessing EE (IC and SWA) increased as the speed of wheeling increased. As can be seen in Figure 3- 2A-C, the greatest dispersion of the data was during the fast wheeling speed, indicating that the greatest degree of

overestimation of EE was for this wheeling speed compared to self-selected speed and moderate speed (Figure 3-2A-C).

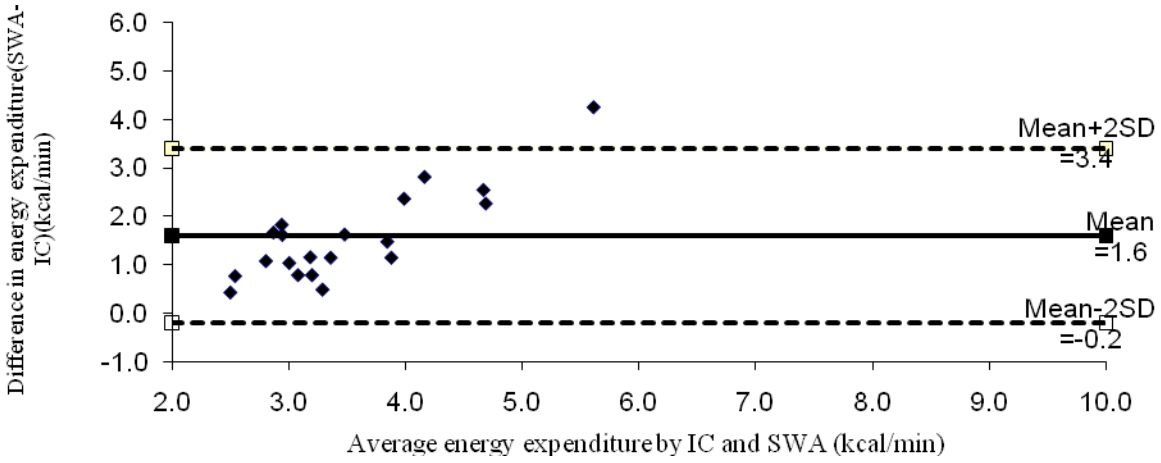


Figure 3-2A Bland-Altman plot between indirect calorimetry (IC) and SenseWear Pro Armband (SWA) energy expenditure for self- selected speed

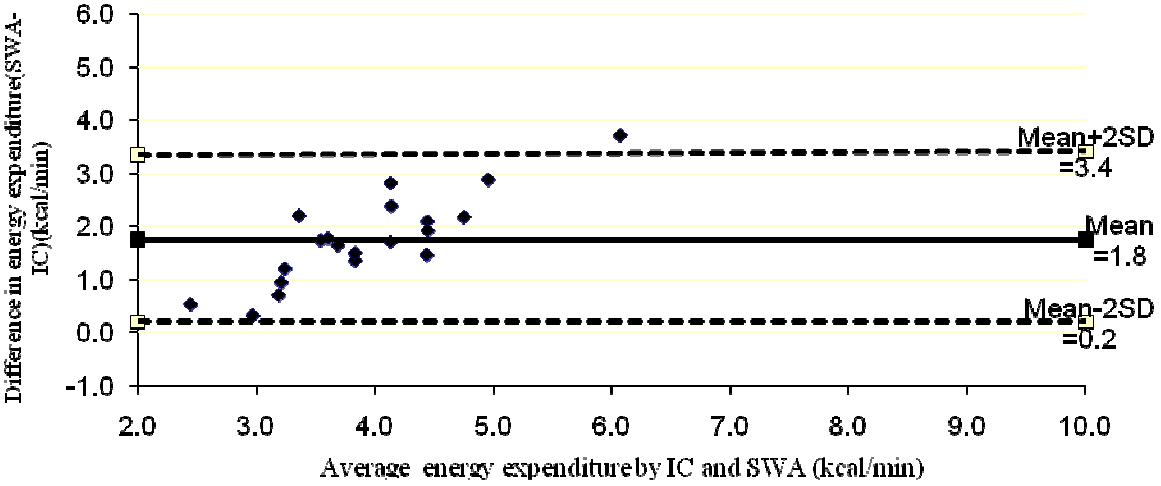


Figure 3-2B Bland-Altman plot between indirect calorimetry (IC) and SenseWear Pro Armband (SWA) energy expenditure for moderate speed

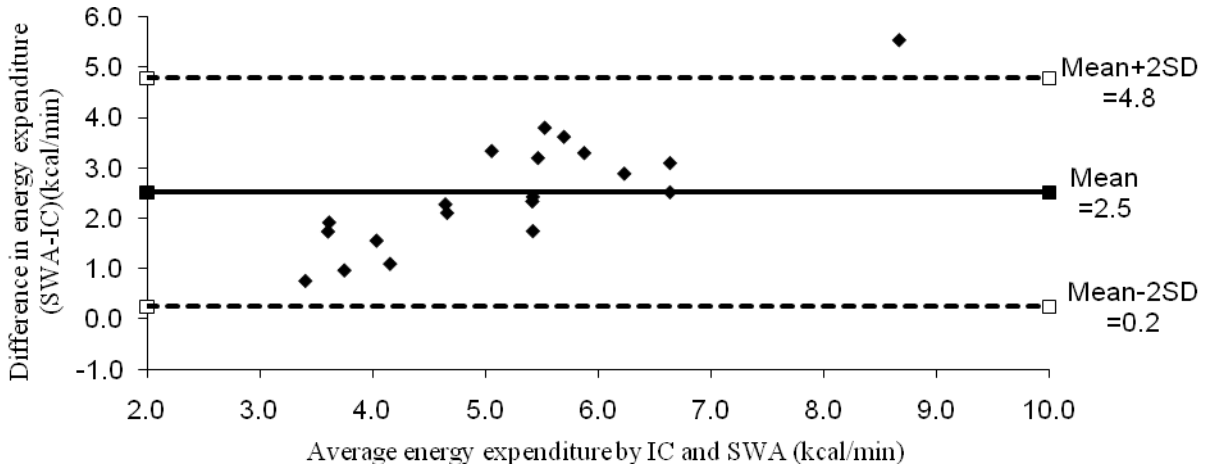


Figure 3-2C Bland-Altman plot between indirect calorimetry (IC) and SenseWear Pro Armband (SWA) energy expenditure for fast speed

Figure 3-2A-C Bland-Altman plot between indirect calorimetry (IC) and SenseWear Pro Armband (SWA) energy expenditure for self- selected speed (Figure 3-2A), moderate speed (Figure 3-2 B), and fast speed (Figure 3-2C). The middle horizontal line corresponds to the mean difference between both EE measurement methods, and the upper and lower dotted horizontal lines represents the 95% limits of agreement given by the mean difference plus or minus 2 x standard deviation of difference.

The mean total number of pushes as measured by manual counter and the mean total number of steps as estimated by the SWA is shown in Table 3-4. The ICCs, assessing agreement between the number of pushes as measured by manual counts and estimated from the SWA, were 0.38 (p=0.066), 0.42 (p=0.049), and 0.19 (p=0.231) for self-selected, moderate, and fast speeds, respectively (Table 3-

4). Compared to simultaneous manual counts using step counter, the SWA overestimated the number of pushes by 8.2 %, 37.2 %, and 38.4 % for self-selected speed, moderate speed, and fast speed, respectively.

Table 3-4 Comparison of number of pushes as measured by manual counts and step counts by SWA for each wheeling speed

	Number of pushes		Agreement	
Speed	**Manual counts**	**SWA step counts**	**ICC**	**p-value**
Self-selected	213.38(45.03)	230.81(120.72)	0.38	0.066
Moderate	227.06 (47.69)	311.50(150.07)	0.42	0.049*
Fast	183.81 (41.99)	254.44(98.72)	0.19	0.231

SWA, SenseWear Pro Armband™; ICC, intraclass correlation coefficient. Values are means (SD).

3.4 DISCUSSION

3.4.1 Validity of the SenseWear Pro Armband for measuring energy expenditure

To our knowledge, this is the first study to investigate the validity of the SWA to estimate EE during wheelchair ergometry exercise in healthy subjects by using open-circuit IC as the criterion measure. This study provides preliminary evidence that the SWA failed to provide an accurate measure of EE for this exercise modality. The SWA overestimated EE for all exercise intensities in the current study. Results from the present study are contrary to the findings of Jakicic et al. (35) who reported higher degree of agreement (ICC =0.74) for arm

ergometry exercise in healthy subjects. Similarly, Hiremath et al. (34) reported strong agreement (ICC=0.79) between EE measured by IC versus SWA estimated EE in manual wheelchair users using wheelchair ergometry and arm ergometry as an exercise modality. Cole et al. (30) reported an even higher correlation coefficient (r=0.9) between EE measured by IC and EE estimated by SWA for arm ergometry exercise in cardiac rehabilitation patients. However, Cole et al. applied different statistical analyses for their study.

The ICC differences among various studies may be partly due to the differences in the nature of samples, mode of exercise, and SWA version. Hiremath et al. studied individuals with SCI who used manual wheelchairs in their daily activities, Cole et al. (30) studied cardiac rehabilitation patients, whereas the present study and Jakicic's study (35) used healthy controls. Participants in Hiremath's study were individuals with SCI who may experience numerous changes in body composition as a result of injury. Those changes likely included a reduction in lean tissue mass and bone mineral density and an increase in fat mass and may result in a reduction of PA and EE (42,43). Previous studies have reported that individuals with SCI had lower levels of PA and EE compared to able-bodied controls (42,44-46). The difference of ICC between the present study and Hiremath's study may be partly due to the difference in the characteristics of the samples.

The ICC differences between the current study, Jakicic's study, and Cole's study may be partly due to the difference in mode of exercise (21). Although all three studies evaluated validity of the SWA during arm exercise, the current study

used wheelchair ergometry as an exercise modality, whereas Jakicic's study and Cole's study used arm ergometry as an exercise modality. These two modes of exercise used different movement patterns and biomechanical parameters. These may result in the difference in research findings among these studies.

Over time, the SWA manufacturer has tried to improve the SWA's algorithms to provide more accurate and reliable estimations of EE encompassing all activity contexts for various populations (21). Previous studies have reported that the accuracy of the SWA EE estimates were dependent on SWA version (25-28,31-35,47-49) and the percent overestimation of the SWA newer version was lowered than the SWA previous version for the same activity context(50). Hiremath used software version 4.2, Jakicic used version 3.2, Cole used version 2.2 and 4.0, and the present study used version 6.1. The difference of ICC among these studies may partly reflect differences in the SWA software version.

We also found that the SWA significantly overestimated EE for all wheeling speeds. This result is consistent with the findings of Hiremath et al. Hiremath (29) reported overestimation of SWA by 88.2 % for 0.89 m/s wheeling speed and 46.2% for 1.34 m/s wheeling speed during wheelchair ergometry exercise, whereas Jakicic reported overestimation of SWA by 29.3 % during arm ergometry exercise in healthy subjects. However, these findings were in contrast to the finding of Cole et al. (30) who reported underestimation of SWA by 2.3% during 8-minute steady state arm ergometry exercise in cardiac patients. Unfortunately, Cole et al. haven't reported exercise intensity in detail.

The overestimation of EE by SWA in the current study may have been due to an ability of the SWA sensors to detect wheelchair ergometry exercise context. The SWA incorporates data from a 2-axis accelerometer into the proprietary algorithm to estimate EE (19,21,22). A 2-axis accelerometer of the SWA purports to track the movement of upper arm and provides information about body position. This accelerometer can measure arm movements in two different planes; longitudinal and transverse planes. Wheelchair ergometry exercise has a large degree of movement in these planes (20). The overestimation of SWA in Hiremath's study and in the current study may have been attributed to the error of a 2-axis accelerometer to detect the movement of upper arm.

The SWA has been designed to measure steps. Evidences from our pilot study (27) indicated that ability of the SWA to count the steps was dependent on magnitude of arm movement. From the raw data in our pilot study, the SWA failed to count steps during cycling exercise but had ability to count the steps during stair stepping exercise (27). Result from the current study indicated that the SWA overestimated number of pushes compared to manual counts for all wheeling speeds. It is possible that an overestimation of the SWA for measuring EE in wheelchair ergometry exercise in the current study may be partly due to an overestimation of SWA in counting number of pushes.

3.4.2 Improve accuracy of the SenseWear Pro Armband for measuring energy expenditure

Because results from the present study revealed that the SWA is not an interchangeable method of indirect calorimetry to accurately measure EE during wheelchair ergometry exercise, exercise-specific algorithms may need to be developed to improve the estimate of EE in wheelchair-related activities (34,35). Previous study by Hiremath et al. (34) reported that when an exercise -specific software was used, excellent agreement (ICC=0.94) was found between the EE measured by IC and estimated by the SWA. Jakicic et al. (35) also reported that when exercise-specific algorithms were used, the SWA improved its accuracy in measuring EE during exercise periods examined in their study. The ICCs improved from 0.77 to 0.87, 0.28 to 0.89, and 0.63 to 0.82 for treadmill walking, cycling exercise, and stepping, respectively, compared to using the general algorithm. Surprisingly, the ICC decreased from 0.74 to 0.66 for arm ergometry exercise. In a cardiac patient group, Cole et al. (30) reported that when the preliminary cardiac software was used, all correlation coefficients were improved. Because there were only few studies developing exercise-specific algorithm to improve the accuracy of SWA for measuring EE in arm exercise, further validity studies need to be done to confirm the ability of SWA's exercise-specific algorithms to calculate EE for this mode of exercise.

This investigation has limitations. We evaluated the criterion validity of the SWA in laboratory setting that may not reflect every day activities of wheelchair users. Future studies need to be done in community settings to assess

validity of the SWA during wheelchair related activities. An additional limitation of this study is that the validity of the SWA was examined during specific wheelchair-related activity (wheelchair ergometry exercise) and specific intensities. The results from the current study can only be generalized to this specific mode of activity and exercise intensities. Moreover, this study used stationary IC as the criterion measure of EE. Future studies should consider using DLW or portable IC as the gold standard measures of EE in free-living conditions.

3.5 CONCLUSION

This study indicated that the SWA failed to provide an accurate measure of EE for wheelchair ergometry exercise. The SWA overestimated EE for all exercise intensities. Exercise-specific algorithms need to be developed to improve the estimate of EE in wheelchair-related activities. Future studies should consider examining EE during other modes of activities in wheelchair users.

REFERENCES

(1) Weil E, Wachterman M, McCarthy EP, Davis RB, O'Day B, Iezzoni LI, et al. Obesity among adults with disabling conditions. JAMA 2002 Sep 11;288(10):1265-1268.

(2) Gater DR,Jr. Obesity after spinal cord injury. Phys.Med.Rehabil.Clin.N.Am. 2007 May;18(2):333-51, vii.

(3) Ferraro KF, Su YP, Gretebeck RJ, Black DR, Badylak SF. Body mass index and disability in adulthood: a 20-year panel study. Am.J.Public Health 2002 May;92(5):834-840.

(4) Must A, Spadano J, Coakley EH, Field AE, Colditz G, Dietz WH. The disease burden associated with overweight and obesity. JAMA 1999 Oct 27;282(16):1523-1529.

(5) Launer LJ, Harris T, Rumpel C, Madans J. Body mass index, weight change, and risk of mobility disability in middle-aged and older women. The epidemiologic follow-up study of NHANES I. JAMA 1994 Apr 13;271(14):1093-1098.

(6) Bauman WA, Spungen AM. Carbohydrate and lipid metabolism in chronic spinal cord injury. J.Spinal Cord Med. 2001 Winter;24(4):266-277.

(7) Imai K, Kadowaki T, Aizawa Y, Fukutomi K. Morbidity rates of complications in persons with spinal cord injury according to the site of injury and with special reference to hypertension. Paraplegia 1994 Apr;32(4):246-252.

(8) Yekutiel M, Brooks ME, Ohry A, Yarom J, Carel R. The prevalence of hypertension, ischaemic heart disease and diabetes in traumatic spinal cord injured patients and amputees. Paraplegia 1989 Feb;27(1):58-62.

(9) Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. Fam.Community Health 2006 Jan-Mar;29(1 Suppl):78S-88S.

(10) Spaepen, A., Vanlandewijck, Y., Lysens, R. Relationship between energy expenditure and muscular activity patterns in handrim wheelchair propulsion. International Journal of Industrial Ergonomics. 1996;17:163-173.

(11) Warms CA, Belza BL. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. Nurs.Res. 2004 Mar-Apr;53(2):136-143.

(12) Postma K, van den Berg-Emons HJ, Bussmann JB, Sluis TA, Bergen MP, Stam HJ. Validity of the detection of wheelchair propulsion as measured with an Activity Monitor in patients with spinal cord injury. Spinal Cord 2005 Sep;43(9):550-557.

(13) Washburn, R.A., Copay, A.G. Assessing physical activity during wheelchair pushing: Validity of a portable accelerometer. Adapt Phys Act Q. 1999;16(3):290-299.

(14) Warms CA, Belza BL, Whitney JD. Correlates of physical activity in adults with mobility limitations. Fam.Community Health 2007 Apr-Jun;30(2 Suppl):S5-16.

(15) Warms CA, Belza BL, Whitney JD, Mitchell PH, Stiens SA. Lifestyle physical activity for individuals with spinal cord injury: a pilot study. Am.J.Health Promot. 2004 Mar-Apr;18(4):288-291.

(16) Hale LA, Pal J, Becker I. Measuring free-living physical activity in adults with and without neurologic dysfunction with a triaxial accelerometer. Arch.Phys.Med.Rehabil. 2008 Sep;89(9):1765-1771.

(17) Haeuber E, Shaughnessy M, Forrester LW, Coleman KL, Macko RF. Accelerometer monitoring of home- and community-based ambulatory activity after stroke. Arch.Phys.Med.Rehabil. 2004 Dec;85(12):1997-2001.

(18) Warms, C.A., Whitney, J.D., Belza, B. \Measurement and description of physical activity in adult manual wheelchair users. Disabil and Health J. 2008;1:236-244.

(19) Liden, C.B., Wolowicz, M., Stivoric, J., Teller, A., Kasabach, C., Vishnubhatla, S., Pelletier, R., Farringdon, J.,Boehmke, S. Characterization and Implications of the Sensors Incorporated into the SenseWear armband for Energy Expenditure and Activity Detection. Available at: http://www.bodymedia.com/Learn-More/Whitepapers/Characterization-and-Implications-of-the-Sensors-Incorporated-into-the-SenseWear. Accessed Sept 24, 2010.

(20) Newsam CJ, Rao SS, Mulroy SJ, Gronley JK, Bontrager EL, Perry J. Three dimensional upper extremity motion during manual wheelchair propulsion in men with different levels of spinal cord injury. Gait Posture 1999 Dec;10(3):223-232.

(21) Andre, D., Pelletier, R., Farringdon, J., Safier, S., Talbott, W., Stone, R., Vyas, N., Trimble, J., Wolf, D., Vishnubhatla, S., Boehmke, S., Stivoric, J., Teller, A. The Development of the SenseWear® armband, a Revolutionary Energy Assessment Device to Assess Physical Activity and Lifestyle. 2006; Available at: http://www.bodybugg.com/pdf/wp_accuracy_ee.pdf. Accessed Sept 24, 2010.

(22) Craig, B., Liden, C.B., Wolowicz, M., Stivoric, J., Teller, A., Vishnubhatla, S., Pelletier, R., Farringdon, J., Boehmke, S. Benefits of the SenseWear ™ Armband Over OtherPhysical Activity and Energy Expenditure Measurement Techniques. Available at: http://www.integratedfitnesssystems.com/Benefits.pdf. Accessed Sept 24, 2010.

(23) Liden, C.B., Wolowicz, M., Stivoric, J., Teller, A., Kasabach, C., Vishnubhatla, S., Pelletier, R., Farringdon, J., Boehmke, S. Characterization and Implications of the Sensors Incorporated into the SenseWear armband for Energy Expenditure and Activity Detection. Available at: http://www.bodymedia.com/Learn-More/Whitepapers/Characterization-and-Implications-of-the-Sensors-Incorporated-into-the-SenseWear. Accessed Sept 24, 2010.

(24) Malavolti M, Pietrobelli A, Dugoni M, Poli M, Romagnoli E, De Cristofaro P, et al. A new device for measuring resting energy expenditure (REE) in healthy subjects. Nutr.Metab.Cardiovasc.Dis. 2007 Jun;17(5):338-343.

(25) Fruin ML, Rankin JW. Validity of a multi-sensor armband in estimating rest and exercise energy expenditure. Med.Sci.Sports Exerc. 2004 Jun;36(6):1063-1069.

(26) Wadsworth, D.D., Howard, T., Hallam, J.S., Blunt, G.A. Validation Study of A Continuous Body-monitoring Device: Assessing Energy Expenditure At Rest And During Exercise. Medicine and Science in Sports and Exercise 2005;37 (5 Suppl):S 24.

(27) Charoensuk J, Haennel R, Manns PJ. Validation of the SenseWear Pro ArmbandTM for the assessment of energy expenditure (EE) in healthy subjects: a pilot study. Accepted for poster presentation at the Canadian Society of Exercise Physiology (CSEP) Annual Meeting. Oct 2008.

(28) St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. Am.J.Clin.Nutr. 2007 Mar;85(3):742-749.

(29) Patel SA, Benzo RP, Slivka WA, Sciurba FC. Activity monitoring and energy expenditure in COPD patients: a validation study. COPD 2007 Jun;4(2):107-112.

(30) Cole PJ, LeMura LM, Klinger TA, Strohecker K, McConnell TR. Measuring energy expenditure in cardiac patients using the Body Media Armband versus indirect calorimetry. A validation study. J.Sports Med.Phys.Fitness 2004 Sep;44(3):262-271.

(31) Cereda E, Turrini M, Ciapanna D, Marbello L, Pietrobelli A, Corradi E. Assessing energy expenditure in cancer patients: a pilot validation of a new wearable device. JPEN J.Parenter.Enteral Nutr. 2007 Nov-Dec;31(6):502-507.

(32) King GA, Torres N, Potter C, Brooks TJ, Coleman KJ. Comparison of activity monitors to estimate energy cost of treadmill exercise. Med.Sci.Sports Exerc. 2004 Jul;36(7):1244-1251.

(33) Mignault D, St-Onge M, Karelis AD, Allison DB, Rabasa-Lhoret R. Evaluation of the Portable HealthWear Armband: a device to measure total daily energy expenditure in free-living type 2 diabetic individuals. Diabetes Care 2005 Jan;28(1):225-227.

(34) Hiremath SV, Ding D. Evaluation of activity monitors to estimate energy expenditure in manual wheelchair users. Conf.Proc.IEEE Eng.Med.Biol.Soc. 2009;Pgs 721-1078:835-838.

(35) Jakicic JM, Marcus M, Gallagher KI, Randall C, Thomas E, Goss FL, et al. Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. Med.Sci.Sports Exerc. 2004 May;36(5):897-904.

(36) Donner A, Eliasziw M. Sample size requirements for reliability studies. Stat.Med. 1987 Jun;6(4):441-448.

(37) Walter SD, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. Stat.Med. 1998 Jan 15;17(1):101-110.

(38) Bassett DR,Jr, Howley ET, Thompson DL, King GA, Strath SJ, McLaughlin JE, et al. Validity of inspiratory and expiratory methods of measuring gas exchange with a computerized system. J.Appl.Physiol. 2001 Jul;91(1):218-224.

(39) Sharon AP, Denise LS. Exercise Physiology for Health, Fitness, and Performance. 2nd ed. Baltimore, MD: Lippincott Williams & Wilkins; 2008.

(40) Thomas S, Reading J, Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Can.J.Sport Sci. 1992 Dec;17(4):338-345.

(41) Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986 Feb 8;1(8476):307-310.

(42) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(43) Wilmet E, Ismail AA, Heilporn A, Welraeds D, Bergmann P. Longitudinal study of the bone mineral content and of soft tissue composition after spinal cord section. Paraplegia 1995 Nov;33(11):674-677.

(44) Buchholz AC, McGillivray CF, Pencharz PB. Physical activity levels are low in free-living adults with chronic paraplegia. Obes.Res. 2003 Apr;11(4):563-570.

(45) Buchholz AC, McGillivray CF, Pencharz PB. Differences in resting metabolic rate between paraplegic and able-bodied subjects are explained by differences in body composition. Am.J.Clin.Nutr. 2003 Feb;77(2):371-378.

(46) Buchholz AC, Pencharz PB. Energy expenditure in chronic spinal cord injury. Curr.Opin.Clin.Nutr.Metab.Care 2004 Nov;7(6):635-639.

(47) Arvidsson D, Slinde F, Larsson S, Hulthen L. Energy cost of physical activities in children: validation of SenseWear Armband. Med.Sci.Sports Exerc. 2007 Nov;39(11):2076-2084.

(48) Bertoli S, Posata A, Battezzati A, Spadafranca A, Testolin G, Bedogni G. Poor agreement between a portable armband and indirect calorimetry in the assessment of resting energy expenditure. Clin.Nutr. 2008 Apr;27(2):307-310.

(49) Dorminy CA, Choi L, Akohoue SA, Chen KY, Buchowski MS. Validity of a multisensor armband in estimating 24-h energy expenditure in children. Med.Sci.Sports Exerc. 2008 Apr;40(4):699-706.

(50) Calabro MA, Welk GJ, Eisenmann JC. Validation of the SenseWear Pro Armband algorithms in children. Med.Sci.Sports Exerc. 2009 Sep;41(9):1714-1720.

CHAPTER FOUR

GENERAL DISCUSSION AND CONCLUSION

4.1 GENERAL DISCUSSION

The prevalence of overweight and obesity is increasing at alarming rates and reaching epidemic proportions in Canada. Approximately 36.1 % of Canadian adult ages 18 years and over were categorized as overweight, and an additional 23.1 %were categorized as obesity (1). Obesity affects almost all subgroups of the population and is more prevalent among PWD compared to general population (2). Successful management of obesity involves both accurate assessment and effective treatment (3).

Overweight and obesity occur when there is positive energy balance, i.e., more calories consumed than calories expended. Because EE is a crucial component for achieving energy balance and body weight control, the measurement of EE in real life has become increasingly important for health care. However, the accurate measurement of PAEE has been and still remains a challenge to researchers. Measuring PAEE in PWD may be more complicate and difficult than measuring PAEE in able-bodied population (4). PWD may experience numerous changes in body composition (5), sympathetic nervous system function (6), locomotion activity, and physical activity level as a result of pathology. As manual wheelchair is a primary mode of locomotion for people with mobility impairments, EE studies during upper extremity movement is necessary for this population (4). Wheelchair ergometry exercise mimics the

daily locomotor tasks of wheelchair users closely; therefore measurement of EE during this mode of exercise is very important (4).

There are numerous techniques available to quantify PA and EE. Unfortunately, each technique has limitations that affect its ability to accurately measure PAEE, so that the valid, reliable and cost efficient ways of EE measurement are needed for able-bodied and for people with disability populations. The SWA is a portable device designed to be worn on the right upper arm to estimate EE. It is more likely to accurately measure EE during upper extremity exercise (7). The SWA may be an appropriate device to quantify EE during wheelchair ergometry exercise.

Results from the current study indicated that the SWA failed to provide an accurate estimate of EE during this mode of exercise with intraclass correlation coefficients (ICC) between 0.50-0.68. These correlation coefficients appear to be weaker than what have reported in previous studies (8-10). The difference of correlation coefficients among these studies could have been a result of the differences in mode and intensity of PA, sample characteristics, and SWA version.

Consistent with previous study (9), we have found that the SWA overestimated EE during wheelchair ergometry exercise. The overestimation of EE by SWA for wheelchair ergometry exercise may be attributed to the sensitivity of the sensors, or the accuracy of the algorithm used to estimate EE during arm exercise (11). The SWA incorporates the use of a 2-axis accelerometer to measure movement in the transverse and longitudinal planes in combination with

other heat- related sensors to estimate EE. The 2-axis accelerometer incorporated in SWA may be hypersensitive in detecting arm movement in wheelchair-related activities. At the beginning, we hypothesized that the use of a 2-axis accelerometer in combination with data derived from other heat-related sensors would improve the ability of SWA to predict EE in wheelchair ergometry exercise. Contrary to our hypothesis, the result from the present study indicated that the SWA failed to provide an accurate measure of EE. The SWA overestimated EE for all wheeling speeds. We attribute this finding to the fact that wheelchair ergometry exercise has a large degree of arm movement in the planes represented by the SWA (8,12); therefore the 2-axis accelerometer may lack of ability to accurately detect arm movement.

4.2 CONCLUSION AND FUTURE STUDIES

The present study indicated that the SWA did not accurately assess the energy cost of wheelchair ergometry exercise. The SWA overestimated EE for all exercise intensities. According to the manufacturer, there is no specific algorithm for wheelchair ergometry exercise. We strongly suggest that the SWA manufacturer develop predictive equations or exercise-specific algorithms to improve the estimate of EE in this mode of exercise. Previous studies reported that when predictive equations were developed or specific exercise algorithms were used, the SWA improved its ability to provide a more accurate estimate of EE (8-10,13). We suggest that further validity studies need to be done to confirm the validity of SWA general and exercise-specific algorithms in various modes of

activities, especially for wheelchair-related activities to clarify the sources of errors of the SWA.

REFERENCES

(1) Statistics Canada. Canadian Community Health Survey. 2004; Available at: http://www.statcan.gc.ca/pub/82-620-m/2005001/t/4053594-eng.htm. Accessed Sept 24, 2010.

(2) Weil E, Wachterman M, McCarthy EP, Davis RB, O'Day B, Iezzoni LI, et al. Obesity among adults with disabling conditions. JAMA 2002 Sep 11;288(10):1265-1268.

(3) Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report. National Institutes of Health. Obes.Res. 1998 Sep;6 Suppl 2:51S-209S.

(4) Warms C. Physical activity measurement in persons with chronic and disabling conditions: methods, strategies, and issues. Fam.Community Health 2006 Jan-Mar;29(1 Suppl):78S-88S.

(5) Monroe MB, Tataranni PA, Pratley R, Manore MM, Skinner JS, Ravussin E. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. Am.J.Clin.Nutr. 1998 Dec;68(6):1223-1227.

(6) Warms, C.A., Whitney, J.D., Belza, B. \Measurement and description of physical activity in adult manual wheelchair users. Disabil and Health J. 2008;1:236-244.

(7) Craig, B., Liden, C.B., Wolowicz, M., Stivoric, J., Teller, A., Vishnubhatla, S., Pelletier, R., Farringdon, J., Boehmke, S. Benefits of the SenseWear ™ Armband Over OtherPhysical Activity and Energy Expenditure Measurement Techniques. Available at: http://www.integratedfitnesssystems.com/Benefits.pdf. Accessed Sept 24, 2010.

(8) Cole PJ, LeMura LM, Klinger TA, Strohecker K, McConnell TR. Measuring energy expenditure in cardiac patients using the Body Media Armband versus indirect calorimetry. A validation study. J.Sports Med.Phys.Fitness 2004 Sep;44(3):262-271.

(9) Hiremath SV, Ding D. Evaluation of activity monitors to estimate energy expenditure in manual wheelchair users. Conf.Proc.IEEE Eng.Med.Biol.Soc. 2009;Pgs 721-1078:835-838.

(10) Jakicic JM, Marcus M, Gallagher KI, Randall C, Thomas E, Goss FL, et al. Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. Med.Sci.Sports Exerc. 2004 May;36(5):897-904.

(11) Andre, D., Pelletier, R., Farringdon, J., Safier, S., Talbott, W., Stone, R., Vyas, N., Trimble, J., Wolf, D., Vishnubhatla, S., Boehmke, S., Stivoric, J., Teller, A. The Development of the SenseWear® armband, a Revolutionary Energy Assessment Device to Assess Physical Activity and Lifestyle. 2006; Available at: http://www.bodybugg.com/pdf/wp_accuracy_ee.pdf. Accessed Sept 24, 2010.

(12) Newsam CJ, Rao SS, Mulroy SJ, Gronley JK, Bontrager EL, Perry J. Three dimensional upper extremity motion during manual wheelchair propulsion in men with different levels of spinal cord injury. Gait Posture 1999 Dec;10(3):223-232.

(13) Dorminy CA, Choi L, Akohoue SA, Chen KY, Buchowski MS. Validity of a multisensor armband in estimating 24-h energy expenditure in children. Med.Sci.Sports Exerc. 2008 Apr;40(4):699-706.

APPENDIX A ETHICS APPROVAL

APPROVAL FORM

Date:	November 9, 2009
Principal Investigator:	Patricia Manns
Study ID:	Pro00009212
Study Title:	Wheelchair Ergometry Exercise and the SenseWear Pro Armband (SWA): A preliminary study with healthy controls
Approval Expiry Date:	November 8, 2010

Thank you for submitting the above study to the Health Research Ethics Board (Health Panel). Your application, along with revisions submitted October 20th and November 6th, 2009, has been reviewed and approved on behalf of the committee.

A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date, you will have to re-submit an ethics application.

Approval by the Health Research Ethics Board does not encompass authorization to access the patients, staff or resources of Capital Health or other local health care institutions for the purposes of the research. Enquiries regarding Capital Health administrative approval, and operational approval for areas impacted by the research, should be directed to the Capital Health Regional Research Administration office, #1800 College Plaza, phone (780) 407-1372.

Sincerely,

Glenn Grisner, Ph.D.
Chair, Health Research Ethics Board (Health Panel)

Note: This correspondence includes an electronic signature (validation and approval via an online system).

APPENDIX B INFORMATION LETTER

UNIVERSITY OF ALBERTA

Information letter

Title of Study: Wheelchair Ergometry Exercise and the SenseWear Pro Armband (SWA): A preliminary study with healthy controls

Principal Investigator and Contact Information:
Trish Manns Ph.D. Telephone 780-492-7274 or Email: trish.manns@ualberta.ca

You are being asked to take part in a research study. This letter provides information about the study. Please read the information below and ask questions about anything you don't understand. Participation is entirely voluntary.

What is the purpose of this study?

This study will compare two methods of measuring energy expenditure (EE) during rest and wheelchair exercise. The SenseWear device (pictured below) measures energy expenditure and is worn as an armband. Results from SenseWear will be compared with laboratory measurements of EE.

What will happen if you take part in this research study?

You will be asked to come to the Wheelchair Biomechanics Laboratory one time, for a session of approximately 90 minutes in length. You will be asked to refrain from strenuous exercise for 24 hours prior to testing and to arrive in the laboratory at least 2 hours after eating the meal. Upon arriving at the Wheelchair Biomechanics Laboratory of the Faculty of Rehabilitation Medicine, the University of Alberta, your basic physical and background demographic information (height, weight, blood pressure, heart rate, age, gender, smoking habits, and handedness will be recorded. Five ECG electrodes will be placed on your chest wall to continuously measure your heart rate.

The testing session will consist of 2 conditions including EE during rest and EE during wheelchair exercise. For each testing condition, you will wear the SenseWear Pro Armband™ and be monitored by the metabolic cart. To measure energy expenditure using the metabolic cart, you will be fitted with a mouthpiece and a nose clip so that expired gases can be measured to calculate energy expenditure. Blood pressure will be measured before and after each testing session. If we notice anything abnormal in your heart rate or your blood pressure, we'll ask you to stop exercising. For example if your blood pressure is higher than the accepted standard (220/105) we will stop.

Energy expenditure during rest (REE): The test will be carried out while you are awake, resting, and sitting quietly on a standard wheelchair. You will be instructed to sit as still and as relaxed as possible for 5 minutes.

Wheelchair exercise energy expenditure (WEE): After completion of the resting session, you will rest for 5 minutes. After that you will be asked to perform an exercise test on a wheelchair ergometer for 30 minutes in the upright seated position. The test will consist of three separate continuous speed wheeling stages of 5-minute self-selected speed, 5-minute 0.9 m/s speed, and 3-minute 1.5 m/s speed for men or 3-minute 1.3 m/s speed for women. Participants will be monitored for a 5 minute resting period following highest speed wheeling. Participants will rest for at least 2 minutes between stages.

What are the possible discomforts and risks of participation?

This is a low-risk study using well-documented research procedures. There are no adverse effects to be expected from participation. You may experience arm muscle soreness from wheeling wheelchair on wheelchair ergometry.

What are the possible benefits to you or to others?

The benefit for you is the opportunity to receive information about energy expenditure during rest and exercise.

How will your privacy and the confidentiality of your research records be protected?

Personal records relating to this study will be kept confidentially by the study coordinator in a locked cabinet at the Physical Activity & Disability Laboratory at Corbett Hall, the University of Alberta. Only the researchers will have access to the confidential data. All data collected about you will not identify your name, only initials and a coded number. Your name will not be disclosed outside the research office. Any report published as a result of this study will not identify your name. Study data will be retained for at least 5 years.

Can you withdraw from this study?

If you decide to take part in the research project, you may discontinue participation at any time without penalty or the need to provide an explanation, in which case any information pertaining to you will be deleted from the analysis.

What if you do not want to answer a particular question?

You do not have to answer every question asked of you.

Whom may you contact if you have concerns about this research study?

If you have questions about your rights as a research participant, please contact the Health Research Ethics Board (HREB) at 780- 492-0302.

IF YOU ARE INTERESTED IN PARTICIPATING, PLEASE CONTACT THE STUDY COORDINATOR, Jutikarn Charoensuk at 780-492-7885, or e-mail at jutikarn@ualberta.ca

APPENDIX C CONSENT FORM

UNIVERSITY OF ALBERTA

Consent form

Wheelchair Ergometry Exercise and the SenseWear Pro Armband (SWA): A preliminary study with healthy controls

Name of Principal Investigator: Dr. Trish Manns
Contact Information: Phone: 780-492-7274, Email: trish.manns@ualberta.ca
Name of **Study Coordinator**: Jutikarn Charoensuk
Contact Information: Phone: 780-492-7889, Email: jutikarn@ualberta.ca

	Yes	No
Do you understand that you have been asked to participate in a research study?		
Have you received and read a copy of the attached Information Sheet?		
Do you understand the benefits and risks involved in taking part in this research study?		
Have you had an opportunity to ask questions and discuss this study?		
Do you understand that you are free to refuse to participate or withdraw from the study at any time, without having to give reason, and that your information will be withdrawn at your request?		
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records information?		

This study was explained to me by: _____

I agree to take part in this study. Yes No

_____ _____ _____
Signature of Research Participant Date Witness

_____ _____
Printed Name Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

_____ _____
Signature of Investigator or Designee Date

APPENDIX D DEMOGRAPHIC INFORMATION

UNIVERSITY OF ALBERTA

Demographic Information

Date of Birth:_____

Year/Mo/Day

Age:_____years

Height:_____inches or _____centimeters
Weight:_____ pounds or_____ kilograms

Gender:	Male	☐	Female	☐
Handedness:	Right Handed	☐	Left Handed	☐
Smoker:	Smoker	☐	Non Smoker	☐

Resting blood pressure:_____mmHg
Resting heart rate: _____(beats/min)

APPENDIX E PHYSICAL ACTIVITY READINESS QUESTIONAIRE ((PAR-Q)

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

We won't collect your Signature on the PAR-Q.
No Need to Sign Your Name in this Part.

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

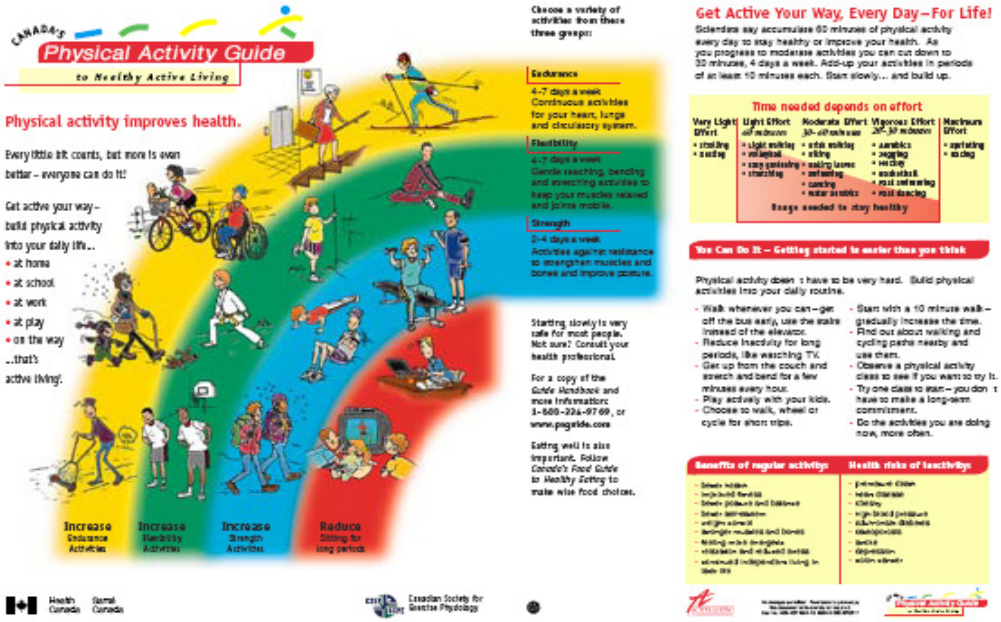
Supported by: Health Canada Santé Canada

continued on other side...

...continued from other side

PAR-Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)



Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy. In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

Supported by: Health Canada Santé Canada

APPENDIX F MEDICAL HISTORY QUESTIONAIRE

Particpant #:_____

UNIVERSITY OF ALBERTA

Medical history Questionnaire

Do you have any of these medical conditions?	**Yes**	**No**
Pregnancy		
Eating disorders		
Asthma		
Chronic or acute bronchitis		
Diabetes		
Exercise-induced wheezing		
Pulmonary diseases (pnuemonia, COPD, etc.)		
Seizure disorders		
Major surgery within the past year		

APPENDIX G RECRUITMENT LETTER

UNIVERSITY OF ALBERTA

Recruitment letter

Dear Volunteer:

We wish to invite you to participate in a research project titled

Wheelchair Ergometry Exercise and the SenseWear Pro Armband (SWA): A preliminary study with healthy controls

This study is being conducted by Dr. Trish Manns at the Department of Physical Therapy, the University of Alberta.

The primary purpose of this investigation is to examine the validity of the SenseWear Pro Armband ™ to estimate the energy expenditure (EE) during rest and wheelchair exercise in healthy subjects.

Participants SHOULD be healthy, and 18 years of ages and older.

Participants with ANY of the following are NOT eligible: high blood pressure, heart disease, pregnancy, eating disorders, asthma, diabetes, lung disease, seizure disorders, major surgery within past year.

Participants will be asked to come to the Wheelchair Biomechanics Laboratory only once, for a session of approximately 90 minutes. Participants will participate in 2 testing conditions including rest and wheelchair exercise. An information letter describing the study is attached.

If you would like additional information or you are interested in participating, please contact the Study Coordinator, Jutikarn Charoensuk at 780-492-7885, or e-mail at jutikarn@ualberta.ca

Thank you for your consideration. Your participation is greatly appreciated.

Jutikarn Charoensuk,

Study Coordinator

APPENDIX G RECRUITMENT POSTER

UNIVERSITY OF ALBERTA

Recruitment poster

SEEKING HEATHY VOLUNTEERS FOR ENERGY EXPENDITURE MEASUREMENT STUDY

University of Alberta researchers are seeking healthy volunteers for a study on research project:

Wheelchair Ergometry Exercise and the SenseWear Pro Armband (SWA): A preliminary study with healthy controls

The primary purpose of this investigation is to examine the validity of the SenseWear Pro Armband ™ to estimate the energy expenditure (EE) during rest and wheelchair exercise in healthy subjects.

Participants SHOULD be healthy, and18 years of ages and older. Participants with ANY of the following are NOT eligible: high blood pressure, heart disease, pregnancy, eating disorders, asthma, diabetes, lung disease, seizure disorders, major surgery within past year.

Participants will be asked to come to the Wheelchair Biomechanics Laboratory only once, for a session of approximately 90 minutes. Participants will participate in 2 testing conditions including rest and wheelchair exercise.

If you would like additional information or you are interested in participating, please contact the Study Coordinator, Jutikarn Charoensuk at 780-492-7885, or e-mail at jutikarn@ualberta.ca

Thank you for your consideration. Your participation is greatly appreciated.

Jutikarn Charoensuk,

Study Coordinator