UNIVERSITY OF ALBERTA

EFFECTS OF CAMBER ON PHYSIOLOGICAL RESPONSES DURING SIMULATED WHEELCHAIR EXERCISE: AGE AND GENDER COMPARISONS

by

SHELLEY MARIE BUCKLEY ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE**.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **EFFECTS OF CAMBER ON PHYSIOLOGICAL RESPONSES DURING SIMULATED WHEELCHAIR EXERCISE: AGE AND GENDER COMPARISONS** submitted by **SHELLEY MARIE BUCKLEY** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE**.

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Dated: 26 Sept., 1994.

To my husband Lance because he is the wind beneath my wings.

ABSTRACT

With the ever-increasing age of the Canadian population, the incidence of wheelchair dependent older adults is certain to increase. Therefore, it is essential that design parameters for wheelchairs be evaluated with the purpose of increasing the overall efficiency and function of wheelchair users, while minimizing the physiological requirements needed to utilize the equipment.

This study evaluated the effects of three different rear wheel camber angles (0, 4, and 8 degrees) on the physiological and perceptual responses during wheelchair propulsion in younger and older males and females. Physiological responses studied included: absolute oxygen consumption ($A\dot{V}O_2$), relative oxygen consumption ($R\dot{V}O_2$), heart rate (HR), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER), oxygen pulse (O_2 pulse), carbon dioxide production ($\dot{V}CO_2$), ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$), and the ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$). Perceptual responses included: the rating of perceived exertion for central factors (RPEC), and the rating of perceived exertion for local factors (RPEL). The gross energy cost (GEC), relative gross energy cost (RGEC), net energy cost (NEC), and relative net energy cost (RNEC) wer calculated from the values of $A\dot{V}O_2$ and RER.

Informed consent was obtained from 20 younger (7 males, 13 females) and 20 older subjects (12 males, 8 females). Each subject participated in a single testing session, which involved randomly assigned camber angles, interspersed with rest periods. Subjects were required to propel a wheelchair (Quickie GPS), mounted on a customized roller system, for a period of 8

minutes and 30 seconds for each of the three different camber angles, at a velocity of 2 kmh. A Sensormedics Metabolic Measurement Cart (MMC), Polar Wireless Heart Rate Monitors, and the Borg Scale for Ratings of Perceived Exertion (RPE), were used to measure responses. Data were analyzed using a three - way (age by gender by camber) repeated measures ANOVA. Significant 'F' ratios were analyzed using post - hoc Scheffe` tests to locate pairwise differences. The Statistical Package for the Social Sciences (SPSS) was used for the analysis.

Analysis of the results revealed no significant triple interactions for any of the variables examined, indicating that subjects in both age groups and genders responded to the differing camber angles in a similar fashion. Increasing wheelchair camber resulted in a significant increase in the $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC. Camber did not have a significant effect on the remaining variables. Age had a significant effect on $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, NEC and RNEC at some camber angles. There was a tendency for the values to be significantly higher in older subjects when compared to the younger ones. There was a significant difference between genders for $A\dot{V}O_2$, $\dot{V}_E$, $\dot{V}CO_2$, RPEC, RPEL, GEC and NEC. Females demonstrated lower responses than males for physiological and energy cost variables, but the trend was reversed for perceptual responses.

It was concluded that: (1) increased wheelchair camber elevates the physiological stress and energy costs of ambulation, but not the perceived stress in younger and older subjects of both genders, (2) physiological and perceptual stress during wheelchair propulsion is significantly higher in older than in younger subjects, regardless of gender, when maximal physiological capacity is taken into consideration, and (3) there is no significant gender difference in the energy cost of wheelchair propulsion in younger and older subjects.

ABREGE

En raison du viellissement de la population canadienne, il est certain que la proportion de personnes âgées qui devront avoir recours à un fauteuil roulant ira en augmentant. Il devient alors essentiel d'évaluer les données de dessin des fauteuils roulants afin d'en augmenter l'efficacité et d'en faciliter le fonctionnement chez ceux qui s'en servant, tout en réduisant le plus possible l'effort physiologique exigé pour s'en servir.

Cette étude évalue l'effet de trois différents angles de cambrure des roues arrières des fauteuils roulants (0, 4 et 8 degrés) sur les réactions physiologiques et les réactions perçues durant la propulsion d'un fauteuil roulant chez des hommes et des femmes, des jeunes et des gens plus âgés. Les réactions physiologiques étudiées comprennent: la consommation totale d'oxygène ($A\dot{V}O_2$), la consommation relative d'oxygène ($R\dot{V}O_2$), la rapidité du pouls (HR), le volume d'air respiré à la minute ($\dot{V}_E$), le taux d'éxchange à la respiration (RER), le montant d'oxygène transporté par pulsation (O_2 pulse), la production de gaz carbonique ($\dot{V}CO_2$), le rapport volume d'air respiré/consommation d'oxygène ($\dot{V}_E/\dot{V}O_2$), et le rapport volume d'air respiré/production de gaz carbonique ($\dot{V}_E/\dot{V}CO_2$). Les réactions perçues comprennent: l'évaluation de l'effort ressenti au niveau du torse (RPEC) et l'évaluation de l'effort ressenti au niveau des membres (RPEL). La dépense relative d'energie en vrac (RGEC), la dépense d'énergie nette (NEC) et la dépense relative d'énergie nette (RNEC) ont été calculées d'après les valeurs de $A\dot{V}O_2$ et de RER.

On a obtenu un consentement fondé sur la connaissance des faits de la part des 20 sujets plus jeunes (7 masculins et 13 féminins) et des 20 sujets plus âgés (12 masculins et 8 féminins). Chaque sujet a pris part à une seule session de tests; on a choisi l'angle de cambrure dans un ordre désigné au hasard et les tests on été entrecoupés de périodes de repos. On a demandé aux sujets de propulser au fauteuil roulant (Quickie GPS) monté sur un système de rouleaux fait sur mesure, durant une période de 8 minutes et 30 secondes pour chacun des trois différents angles de cambrure, à une vitesse de 2 kmh. Pour mesurer les réactions, on s'est servi d'un *Sensormedics Metabolic Measurement Cart (MMC),* de *Polar Wireless Heart Rate Monitors,* et d'une *Borg Scale of Perceived Exertion (RPE).* On a analysé les rapports révélateurs 'F' au moyen de tests post - hoc Scheffé afin de localiser les différences entre les paires. On a employé le *Statistical Package for the Social Sciences (SPSS)* pour effectuer les analyses.

L'analysé des résultats ne démontre aucune triple interaction d'importance pour aucune des variables examinées, ce qui suggère que les sujets des deux groupes d'âge et des deux genres ont réagi aux différents angles de cambrure de façon similaire. L'augmentation de la cambrure des roues des fauteuils a eu pour résultat une augmentation appréciable de $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC et RNEC. La cambrure n'a pas eu d'effets notables sue les autres variables. L'âges a démontré un effet appré sur $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_I/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, NEC et RNEC à certains angles de cambrure. Il y a eu tendance à ce que les valeurs soient haussées de façon appréciable chez les personnes âgées, comparativement aux personnes plus jeunes. Il y a eu une différence appréciable entre les genres pour $A\dot{V}O_2$, $\dot{V}_E$, $\dot{V}CO_2$, RPEC, RPEL, GEC et NEC. Les femmes ont démontré des réactions moins élevées que les hommes au plan physiologique et pour la dépense d'énergie, mais la tendance était renversée pour les réactions perçues.

On a conclu que: (1) chez les sujets plus jeunes et plus vieux des deux genres, l'augmentation de la cambrure des roues arrières d'un fauteuil roulant hausse la tension physiologique et la dépense d'énergie de la déambulation, mais non pas leur perception; (2) la tension physiologique et la tension perçue durant l'usage d'un fauteuil roulant sont nettement plus élevées chez lez sujets plus âgés que chez les sujets plus jeunes, indépendamment du genre, lorsqu'il s'agit de la capacité physiologique maximale; et (3) lorsque l'on considère la dépense d'énergie pour propulser un fauteuil roulant, il n'y a pas de différence appréciable de genre chez les sujets plus jeunes non plus que chez les sujets plus âgés.

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CHAPTER I
INTRODUCTION

THE EFFECTS OF WHEELCHAIR CAMBER ON PHYSIOLOGICAL PARAMETERS

One of the primary goals in rehabilitation engineering should be the design and development of wheelchairs which meet the needs of the individuals using them (Glaser, Simsen-Harold, & Petrofsky, 1983; Redford, 1993). In addition to meeting the functional needs of the individuals using these wheelchairs, it is also important to consider how design factors influence the individual from both physiological and ease of use aspects. It is likely that wheelchairs which require a minimum of physiological energy for propulsion are likely to be the most functional. While there is little information to support this assumption within the field of study, there is some support for this theory (Redford, 1993). This theory stresses that the higher the physiological cost to the individual, the more likely the user is to become reliant on a caregiver for locomotion. Moreover, it is a common tenet underlying occupational therapy, that in general, energy conservation promotes and facilitates optimal functioning. If this belief were to be applied to the concept of wheelchair design, then it seems reasonable to assume that a wheelchair design which conserves the maximal amount of energy while remaining easy to use, will lead to not only optimal functioning, but also increased independence for the individual.

Currently, wheelchair design is an issue which bears much consideration. According to Statistics Canada (1992), the population of individuals in the 65 years and older age group increased by 17.5% between the years of 1986 and

1991. As the population in general ages, more attention needs to be focused upon the design and development of equipment which facilitates the maximum independence of this group, in order to alleviate burgeoning health care costs. While no specific data exists on the exact number of elderly persons requiring the use of wheelchairs, a study by Redford (1993) estimates that approximately one third of all individuals over the age of 65 are wheelchair users. Although this study is American, it can be assumed that the proportion of users will be similar in Canada.

One area which is particularly lacking in previous studies is the design of wheelchairs for the elderly population. It is interesting to note that while wheelchairs have undergone substantial modification in recent years, the majority of these changes have been driven by the need for optimal sports wheelchairs for use in athletics for the disabled population (Hutzler, 1991; Redford, 1993; Sanderson & Sommer, 1985; van der Woude, de Groot, Hollander, van Ingen Schenau & Rozendal, 1986). While the information which has been generated from this research has been valuable, it is difficult to extrapolate it accurately to an older, more sedentary population. Moreover, it is questionable whether or not the older population would respond in the same manner to the variables under scrutiny as the recreational or highly trained, elite athletes who generally tend to be the subjects of these studies. Another aspect relates to the suitability of the recent modifications, and whether they are in fact, employable for the older population. Many of the modifications center on the design of wheelchairs which are smaller, lighter weight, and have a minimum of postural support to them. While this may be appropriate for the younger individual, these chairs may not be entirely appropriate for the older individual who may demonstrate increased and complex cognitive, postural, physical, and perceptual deficits (Cerquiglini, Figura & Marchetti 1981; Redford, 1993). Therefore, it is essential that more research be conducted which evaluates the effects of different wheelchair prototypes on different user groups, in particular, the elderly.

A final aspect relates to the issue of gender and the effect that this plays on the physiological response to wheelchair design features. Few studies could be found which evaluate the effects of gender on wheelchair performance. Studies that have examined males and females have tended to group the data together, without evaluating the independent effects of gender on performance (Glaser, Simsen-Harold & Petrofsky, 1983; van der Woude, Hendrich, Veeger, van Ingen Schenau, Rozendal, de Groot & Hollander, 1988). It is generally accepted that there are significant differences between males and females in the maximal physiological responses to exercise (Bishop, 1987; McKardle, Katch & Katch, 1991; Washburn & Seals, 1984). Reduced peak oxygen consumption has been attributed to: decreased oxygen transport capacity due to lower hemoglobin, blood volume, and lower muscle mass available for extracting oxygen from the blood (McArdle, et al., 1991). Gender differences have also been demonstrated for methods of ambulation such as walking and running. In a study by Bhambhani & Singh (1985), females did not significantly differ from males in the gross or net metabolic energy cost during walking, however, significantly higher costs were observed in females during running. Other studies, such as those by Blessey, Hislop, Walters & Antonelli (1976), Durnin & Namyslowski (1958), and Zarrugh, Todd & Ralston (1974) have revealed no significant differences between the two genders during walking. Thus, in light of the controversy generated by the literature, it is important that the effect of gender also be considered in the design phase of wheelchair manufacture and research.

STATEMENT OF THE PROBLEM

One variable which has received very little attention in the literature relates to wheelchair rear wheel camber. Camber has been defined as "tilted rear wheels" (Veeger, van der Woude & Rozendal, 1989), "the angle of the mainwheel to the vertical" (Higgs, 1983), and alignment of the rear wheels such that "the spacing between the top points of the wheels may be less than the spacing between the bottom points" (Frank & Abel, 1991). Camber should not be confused with "toe-in" or "toe-out", which is the condition where the spacing between the front of the wheels varies from the spacing between the rear of the wheels. A diagramatic illustration of wheel camber has been presented in Appendix A. A limited number of studies have been conducted on wheel camber, and to date none have addressed the effect that this variable has on <u>any</u> sedentary population. Since hand rim propulsion is the major type of wheelchair locomotion, and rear wheel camber occurs directly at the equipment-user interface, it seems reasonable to question the impact of this variable upon the user. It is well documented (Cerquiglini, Figura, Marchetti & Ricci, 1984; van der Woude, de Groot, Hollander, van Ingen Schenau & Rozendal, 1986; Veeger, 1991; Veicsteinas, Sarchi & Ronchi, 1991) that hand rim propulsion is associated with high physiological costs. Therefore, it is also reasonable to question whether differences exist between different rear wheel cambers and physiological costs.

The purpose of this study was to evaluate the effects of one wheelchair variable, namely, rear wheel camber, on the physiological costs in apparently healthy younger (19-44 years of age) sedentary individuals and older sedentary (45-74 years of age) individuals. Additionally, this study examined the effects of gender on physiological responses to camber changes. While it is difficult to define a "apparently healthy" sedentary population, in general, the concept would apply to individuals who demonstrate no documented injuries or disabilities. The following metabolic and cardiorespiratory variables were evaluated: absolute oxygen consumption ($A\dot{V}O_2$), relative oxygen consumption ($R\dot{V}O_2$), heart rate (HR), respiratory exchange ratio (R) , carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), oxygen pulse (O_2 pulse), ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$), and the ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$). As well, perceptual responses were monitored for central (RPEC) and local (RPEL) factors using the Borg scale for ratings of perceived exertion (RPE). Finally, energy cost was calculated from the information derived from the metabolic measurement cart. The variables which were of interest were gross energy cost (GEC), relative gross energy cost (RGEC), net energy cost (NEC), and relative net energy cost (RNEC). A summary of the abbreviations and the units of measurement used in this study can be found in Appendix B.

HYPOTHESES

The following null hypotheses were tested in this study. There would be no significant differences in the physiological and perceptual responses:

1. among the three wheelchair camber angles under investigation, namely 0 degrees, 4 degrees and 8 degrees,

2. between the younger and older subjects for each of the wheelchair camber angles in both genders, and

3. between the males and females in each age group for each of the wheelchair camber angles.

SIGNIFICANCE OF THE STUDY

Overall, the importance of evaluating wheelchair design features cannot be overstressed. Not only is it important that these be examined, but that design factors be investigated with members of the populations which use them. If it can be demonstrated that differences in response exist between various groups, then this will provide direction for the design of wheelchairs for elderly individuals. The need to promote seniors independence has been demonstrated. However, the effect of equipment and the environment that encourages dependence through poor design continues to be a problem. A poorly designed wheelchair, or one which requires considerable effort for propulsion, will result in the user waiting for a caregiver's assistance (Glaser, Simsen-Harold, Petrofsky, Kahn & Suryaprasad, 1983; Redford, 1993). The goal of good wheelchair design should be to minimize user dependence, and maximize user independence. Wheelchairs which minimize physiological demands for older users should increase their function, independence, and comfort in their environments, thereby decreasing associated costs to the health care system, and improving overall quality of life for the user.

CHAPTER II
RELATED LITERATURE

REVIEW OF THE LITERATURE

The literature review will provide an overview of research in wheelchair design, with specific concentration on studies pertaining to rear wheel camber, rolling resistance and biomechanics. In particular, attention will be paid to those studies which evaluate physiological parameters.

A limited number of studies exist which evaluate the effects of rear wheel camber on performance. Perhaps the research which is the most beneficial in determining whether or not rear wheel camber will have a bearing is the literature which exists on the effects of rolling resistance and biomechanics. Although the research in these areas cannot completely address the interactions that rear wheel camber will have, it does provide some insight into the manner in which camber may cause performance differences.

Rear wheel camber and rolling resistance

In a study by Veeger, van der Woude and Rozendal (1989), the researchers examined the effects of rear wheel camber on wheelchair locomotion. The variables evaluated were HR, $\dot{V}O_2$, mechanical efficiency, push time, push angle, shoulder abduction, and electromylogram (EMG) recordings. The study was conducted using eight non-wheelchair users between the ages of 21 and 29 years. The authors evaluated four different wheel cambers of 0, 3, 6, and 9 degrees. A questionable procedure which the researchers used, however, was to evaluate wheelchair drag(resistance to motion) prior to the commencement of the study. In doing so, they discovered that there were significant differences in the drag between differing wheel cambers, and as such, they compensated or "normalized' for this condition by manipulating the loads on the wheelchairs so that all wheelchairs demonstrated equal drag ratios. The authors noted that the differences in drag could be accounted for by significant differences in rolling resistance.

The differences found in the drag ratios, however, are to be expected according to existing research on rolling resistance (Cerquiglini, et al., 1984). In regard to rear wheel camber, rolling resistance remains a fact of life, and therefore, should be considered as a given in any evaluation. Changes in camber result in changes to rolling resistance, and in the reality of the clinical or environmental setting, "normalization" does not occur, and therefore, individual wheelchair users will be affected by this. Thus, it is questionable as to whether or not the researchers should have compensated for this in their study. In their results, Veeger et al. (1989) reported that no significant differences were found for HR, $A\dot{V}O_2$ and mechanical efficiency, however, there was a significant effect on the kinematics of wheel push, with the most significant change evident in shoulder abduction which increased with camber. This represents an inverse relationship to the width of wheel camber in that as the camber is increased, the width between the tops of the wheels decreases, but shoulder abduction increases. It has been speculated by Cerquiglini, et al. (1984), Bardsley (1991), and Traut and Schmauder (1991) that the increased shoulder abduction compensates for the angle of the wheelchair pushrim.

This study was interesting from several perspectives. Firstly, the issue of "normalizing" is of concern due to the fact that rolling resistance should and is expected to change, although the authors stated that the rolling resistance may have been altered due to minor changes in wheel alignment. However, research which has been conducted on pure rolling resistance, has not agreed on the effects of this issue. While some research substantiates the view that wheel alignment affected rolling resistance, it was in addition to the changes in rolling resistance which were expected from changes in wheel camber (Brubaker & McLaurin, 1984; Kauzlarich & Thacker, 1985; Lemaire, Lamontagne, Barclay, John & Martel, 1991). An explanation for the discrepancies may lie in the fact that the actual calculations used to determine rolling resistance are very complex and difficult in nature, verging into the quantum physics core, and therefore, it is extremely complicated to analyze rolling resistance.

A study by O'Reagan et al. (1981) noted that a camber of 10 degrees will probably add less than 5% to the rolling resistance. However, a later article by Kauzlarich & Thacker (1985) evaluated rolling friction, and found that variables such as tire properties, rolling and contact surface, design features and equipment or tire wear, could significantly affect wheel rolling resistance. A major implication of the study by Kauzlarich and Thacker is the reference to hysteresis loss which can affect the friction on the tires and is determined by the materials, shear forces, and material fatigue. While this information would lead one to speculate that there may be significant differences between tires made of different materials, it should also lead one to question whether a particular material responds quite differently to hysteresis loss with changing camber, and therefore, has significant impacts upon the amount of rolling resistance changes which can be expected. Therefore, although O'Reagan et al. (1981) did not believe that rolling resistance was strongly influenced by wheel camber, they have not evaluated differing materials, and therefore, cannot generalize the results to all wheelchair tires. It is interesting to note the impact the 5% rolling resistance changes have on physiological parameters, and whether this is significant, has not been evaluated. As one can see in the paper by Veeger et al. (1989), they have eliminated any effects this might have had by "normalizing" the wheelchairs for their study.

A further study which supported this view was that conducted by Brubaker and McLaurin (1984), who analyzed the ergonomics of wheelchair propulsion, and stated that there were three major areas to be considered in the dynamics of wheelchair locomotion. The areas that were identified were the forces acting upon the wheelchair, the power the user was able to provide, and the interface between the chair and its user. In this study, the authors stressed the importance of considering the effects of friction and gravity upon the wheelchair and its user. They stated that numerous sources of rolling resistance can be encountered at various levels of the chair, which occur whenever there are moving parts. This would include friction at the bearings, on the tires, on the surface, and finally air resistance. The authors also make reference to the importance of the dynamic response of the wheelchair, under varying conditions. This could include bending of the frame in different configurations, in response to changes which occur in variables such as wheel camber. The concept of frame variation was supported by Baldwin and Thacker (1993) who related the von Mises theory of stresses which can act upon the wheelchair cross-braces in order to affect wheelchair rolling resistance through this avenue. The authors also stressed the importance of wheel configuration ie. camber, in terms of its impact upon these von Mises stresses.

Another study by Brubaker, McLaurin and McClay (1986) concluded that the power output required to propel a wheelchair could be altered and diminished by moving the rear wheel forward, and increasing the wheel width at the base by increasing camber. If this was the case, then it would be logical to assume that the physiological parameters which are interrelated to power output, could therefore be affected by changes in wheel camber. The authors stated concisely that this change in power output was a direct result of changes in rolling resistance.

A study by Higgs (1983) evaluated racing wheelchairs used in the 1980 Olympic games suggested that wheel camber may have some effect on the performance of athletes during wheelchair racing. The dynamics of this effect were not identified, although the author alludes to the differences between wheels and their response to alterations in camber. Due to the wide variety of chairs which were employed during the games, it was difficult to come to general conclusions.

Gass and Camp (1987) also identified changes in rolling resistance as having the potential to significantly affect net physiological efficiency during prolonged exercise. In discussing the findings of their study, they noted that extreme variance in wheelchair design could alter rolling resistance, and that differences in rolling resistance may become increasingly important with increasing distance covered. This effect was demonstrated in the additional amount of power output required over time as a function of distance. This would mean that over time, an individual using a wheelchair with increased rolling resistance would have to generate a higher $A\dot{V}O_2$.

A further study by van der Woude et al. (1988) examined the effects of power output on physiology and technique of wheelchair propulsion. This study concentrated on the mechanical efficiency of wheelchair propulsion. The authors found that by increasing mechanical efficiency, the $A\dot{V}O_2$ and HR could be decreased. Although this study did not especially implicate wheel camber, it is interesting to note that many studies examining mechanical efficiency concentrate on the hand-rim/user interface. It is widely known that mechanical efficiency can be altered by changing the angle at which the hands contact the hand-rim during the kinematics of wheelchair propulsion. Therefore, it is reasonable to assume that by altering wheel camber, the hand-rim/user interface will be affected.

In summary, a limited number of studies have been conducted on rear wheel camber of wheelchairs. Although several research projects allude to the importance and the effects of wheel camber, only one study has thoroughly evaluated camber, and this study appears flawed due to the "normalization" which was implemented. Therefore, rear wheel camber has the potential to affect physiological parameters based upon the literature reviewed.

The relationship of upper extremity physiology to wheelchair propulsion

In recent years, there has been much attention focused on the differences between the physiological responses required for upper body versus lower body exercise. This attention has been driven primarily by the recognition that many dynamic tasks in industry, sports and daily living employ the use of only upper body muscle groups. There has been a need to evaluate upper body exercise and performance in the disabled population who must rely on upper body function to propel wheelchairs for locomotion (Sawka, 1986; Voigt & Bahn, 1969).

Many of the studies have been conducted utilizing arm-crank ergometry protocols, but more recently, researchers have begun to evaluate upper body performance during wheelchair propulsion. Although the research conducted on arm-crank ergometers may not exactly simulate wheelchair propulsion, the information derived from them has been very useful in interpreting and identifying the physiological changes associated with upper body work. Therefore, these studies will be incorporated into the following discussion.

In general, the research has demonstrated that manual wheelchair propulsion is physiologically inefficient when compared to modes of locomotion which employ the lower extremities (Sawka, 1986; Smith, Glaser & Petrofsky, 1983; van der Woude, et al., 1986; Veicsteinas, Sarchi & Ronchi, 1991). Among the reasons cited for the particularly high stresses on the muscular, cardiovascular and respiratory systems are the obvious physical limitations which are imposed by the smaller muscle mass of the upper body. In addition, it has been recognized that the method of hand-rim propulsion normally employed by wheelchair users, is considered to be mechanically inefficient (Masse, Lamontagne, O'Riain, 1992; Smith, et al., 1983; Veeger, van der Woude & Rozendal, 1992; Veicsteinas, et al., 1991) thereby contributing to the higher physiological costs. Masse et al. (1992) have also discussed the importance of the pre-existing status of the wheelchair user, in terms of existing muscular strength, the physical capacity of the individual, type of disability, and the nature of the wheelchair user interface. It is believed that all of these considerations will have an impact upon the physiological responses observed during wheelchair propulsion.

Another factor which cannot be neglected when considering upper body locomotion versus lower body locomotion is the nature of the task itself. Smith et al. (1983) discuss the more efficient rhythms of lower body locomotion in terms of the asynchronous nature of the task. That is, ambulation of the lower extremities utilizes an alternating rhythm in the nature of its pattern. This is contrasted to wheelchair propulsion, in that normal handrim propulsion employs a synchronous rhythm in order to propel the wheelchair. Smith et al. (1983), Glaser, Sawka, Young and Suryaprasad (1980), and Glaser (1989) stress the inherent tendency within the individual to perform more efficiently by way of "alternating" or asynchronous rhythm patterns. Although asynchronous wheelchair propulsion is not very widely utilized, and the mechanisms responsible for the increased advantages of asynchronous movements are unclear, it is thought that asynchronous movements may take advantage of neural pathways which innervate bilateral muscle groups in a reciprocal fashion (Glaser et al., 1980). The advantages of asynchronous propulsion were demonstrated by Glaser et al. (1980) who reported that asynchronous application of force to wheelchair handrims reduced metabolic and cardiopulmonary responses in comparison to synchronous propulsion. This is in congruence with the findings (Smith, Glaser, Petrofsky, Underwood, Smith & Richard, 1983; Traut & Schmauder, 1991; Veeger, 1991) that submaximal arm crank exercise has been found to be less strenuous, and also more efficient than manual hand rim propulsion.

Although numerous studies have proved the advantages of arm-crank wheelchair propulsion over basic hand-rim propulsion (Brubaker & McLaurin, 1984; Glaser et al., 1980; Smith et al., 1983), these types of wheelchairs continue to be a rarity in the real world, and the emphasis continues to be on the design of hand-rim propulsion wheelchairs. At the present time, the majority of wheelchair users tend to employ hand-rim propulsion mechanisms.

Cardiovascular, metabolic and respiratory effects of upper body exercise

It is recognized that the physiological responses to upper body exercise are more profound than those observed during lower body exercise (Glaser, et al, 1980; Miles, Cox & Bomze, 1989; Pendergast, 1989; Sawka, 1986; Washburn & Seals, 1984). Sawka (1986), Pendergast (1989), and McArdle, Katch and Katch (1991) summarized much of the research related to upper body exercise and found that power output, HR and $A\dot{V}O_2$ varied significantly for upper body exercise compared to lower body exercise. In untrained subjects, the maximal $A\dot{V}O_2$ achieved during arm work has been reported as 70-80% of the maximal $A\dot{V}O_2$ achieved during leg exercise (McArdle, et al, 1991; Pendergast, 1989). It appears that for a given submaximal workload, the $A\dot{V}O_2$ elicited is significantly higher during arm exercise compared to leg exercise at a comparable workload. This is interpreted to mean that the physiological stress of upper body exercise is greater than the physiological stress of lower body exercise, given the same load. As well, differences can also be observed in minute ventilation ($\dot{V}_E$). The differences noted relate to an increased breathing frequency with a subsequent lower tidal volume, resulting in increased $\dot{V}_E$ levels. Although the arterial oxygen content is maintained at resting levels for both forms of exercise, the respiratory exchange ratio (RER) is lower during submaximal arm work than during leg exercise (Pendergast, 1989). The author has explained that this could be the result of a reduced oxidative metabolism, which was generally the result of less upper body training. Further to the cardiovascular findings, differences in cardiac output were also noted between upper versus lower body exercise. Heart rate was found to be generally higher, with lower stroke volume for upper body exercise (Miles et al., 1989) as compared to leg work . However, the maximal HR achieved with upper body exercise was approximately 90-93% of the maximal rate which could be achieved for lower body work (Sawka, 1986).

Age, disability and cardiovascular responses

It is logical at this point to discuss briefly the effects of age and disability on cardiorespiratory performance, since it is the older population whose cardiorespiratory function is more likely to be compromised.

In a study by Sawka, Glaser, Laubach, Al-Samkari and Suryaprasad (1981) the authors examined wheelchair exercise performance of three different, disabled age groups; young, middle-aged and elderly. The researchers evaluated power output, peak $A\dot{V}O_2$ and maximal HR. The purpose of the study was to quantify the levels which could be achieved by each of the groups. This investigation demonstrated that to perform a specific wheelchair locomotive task, a specific power output must be attained by an individual. The authors were able to show that the closer the power output requirements of the task came to the individual's absolute power output, the more difficult that task became. The researchers were able to determine that the power output maximum which could be achieved was lower for the middle aged and the elderly groups, compared to the young group. The authors speculated that the power output maximum was related to peak $A\dot{V}O_2$, which decreased significantly with age.

Dehn and Bruce (1972) and Sawka et al. (1981) found decreases approximating 3.0-4.0 ml/kg/min per decade of life. McArdle et al. (1991) reported that following the age of 25 years, the $A\dot{V}O_2$ max declines by 1% per year such that by age 55, there was a 27% decrease in the $A\dot{V}O_2$ max seen for 20 year old individuals, based on treadmill tests. Sawka et al. (1981) additionally found that HR maximum values were also diminished for the older adults, although the authors were only able to compare their values with studies which had evaluated the HR(s) of differing age groups for lower body exercise only. In comparison to this, the authors found their HR decreases to be magnified. In regards to specific findings of Sawka et al.'s study for young, middle aged, and elderly adults, the HR maximum values obtained were 98%, 81%, and 82% respectively of their age predicted HR(s). This could then be interpreted in another manner, in relation to proportion of peak $A\dot{V}O_2$.

Interpreted in this fashion, it can be seen that as the person ages, a greater proportion (represented as a percentage) of their $A\dot{V}O_2$ max must be achieved in order to propel a wheelchair, due in part, to the decline in $A\dot{V}O_2$ max which occurs with age. Therefore, viewed as a proportionate relationship, the energy cost of wheelchair propulsion increases with age, and as such, it is essential that wheelchair design strive to minimize the effect on this proportionate increase in metabolic cost.

Thus, it can be seen that there are general decreases in cardiovascular functioning which can be expected with age. However, one area which has been not fully explored, relates to the changes which occur in an elderly, sedentary population whose health may or may not be complicated by a number of factors. It is interesting to note that much of the literature on the biomechanics of wheelchair design also mentions the absolute paucity of research on physiological changes associated with wheelchair propulsion in the elderly (Cerquiglini, Figura & Marchetti, 1981; Hutzler, 1991; Sanderson & Sommer, 1985; van der Woude et al, 1986; Veicsteinas et al., 1991).

If one accepts that there will automatically be some decline in the physiological parameters, as suggested by the literature (Dehn et al., 1972; McArdle, et al., 1991; Sawka et al., 1981), then it is reasonable to question what effect various other factors such as cardiovascular disease, will have on the ability of the individual to perform work of the nature that is required for wheelchair locomotion. However, it is exactly these factors which need to be considered in the design and application of modifications to wheelchairs that are designed for the elderly. A normal, or highly trained athlete is not representative of this population and, therefore, the effects or non-effects of various design changes cannot necessarily be assumed to be beneficial or non-beneficial to an older person.

Gender differences in cardiovascular responses

McArdle, et al (1991) noted that gender differences in cardiovascular responses between males and females occur primarily after the age of puberty. After that time, it has been demonstrated that peak $A\dot{V}O_2$ scores for females tended to be approximately 15 - 30% lower than the peak $A\dot{V}O_2$ attained by males. This view was also supported by Astrand & Rodahl (1986), who stated that women tended to achieve peak $A\dot{V}O_2$ scores of 65 - 75% that of their male counterparts. While the majority of this research has been conducted utilizing lower body leg exercise, it has been speculated that the gender differences which were evidenced during the research were primarily a result of differences between males and females in: (a) hemaglobin levels and blood volumes, which effect oxygen transport capacity, and (b) body composition (reduced muscle mass in females), which effects oxygen utilization (McArdle, et al., 1991).

A further study by Washburn and Seals (1984) also demonstrated peak $A\dot{V}O_2$ to be higher in males than in females. Additionally, these researchers also proved peak V_E to be higher, yet were unable to demonstrate significant differences in HR between the two sexes. The research by Washburn et al. (1984) was particularly important, as the study involved the use of an arm cranking exercise, which although not identical to the movement performed during wheelchair propulsion, could be compared to the type of upper body exercise required during a task such as wheelchair mobility.

However, it should be noted that in wheelchair design studies, such as those by Glaser (1983), and van der Woude, et al. (1988), no allowances were made for gender differences, and male and female subjects were simply grouped together. Perhaps this was related to the fact that these studies were conducted at a very low intensity of exercise, and therefore, the researchers did not expect any gender differences. However, since this factor was not considered separately, it remained to be seen whether or not gender can affect physiological responses during low intensity wheelchair propulsion activities.

The nature of daily living tasks during wheelchair propulsion

It has been speculated that most daily living tasks require brief bursts of dynamic activity, which involves the anaerobic as opposed to aerobic metabolism (Janssen, Oers, Hollander, van der Woude & Rozendal, 1992; Jochheim & Strokendl, 1973). In a study by Hjeltnes and Vokac (1979), the authors concluded that no particular training effect could be expected from normal wheelchair use, and that additional exercise prescription may be required, just to maintain the individual's ability to propel a wheelchair independently.

This concept is particularly important with regard to the approach which will be taken during the physiological testing of wheelchair design features. While studies on wheelchairs advocate both maximal and submaximal aerobic testing in approximately equal proportions, it would make sense to utilize a method which approximates the nature of the regular conditions under which wheelchairs are propelled. For example, maximal aerobic testing would be logical for wheelchair athletes competing in high performance, endurance activities, but submaximal testing is a more reasonable choice for testing wheelchairs which will be used by the sedentary population for daily activities.

The finding that daily activity tasks tend to utilize the anaerobic metabolism system makes sense in light of the fact that full aerobic capacity is rarely demanded or achieved during everyday tasks. In addition, in a sedentary population, one is not likely to find endurance trained athletes.

Rather, it is likely that these individuals will merely be striving to maintain independence by carrying out their daily routines. It is also likely that these tasks will be of a "dynamic burst" nature, in that a task will be done, and then a rest period will follow, such as propelling oneself to the bedroom, and then resting prior to transferring into the bed. Therefore, the testing of wheelchair design factors through the use of submaximal exercise protocols were seen as beneficial.

Biomechanics of wheelchair propulsion

It is prudent at this point to briefly discuss the effects of camber on the biomechanics of wheelchair propulsion. Although the kinematics were not be evaluated during this study, consideration of the biomechanics provided some insight into the reasons why camber could reasonably be expected to have an effect on the physiology if biomechanical changes were demonstrated.

In a study by Traut and Schmauder (1991), the authors examined the impact of design parameters such as handrim orientation, gear ratio, and hand side of handrim on energy cost, heart rate, and shearing forces on the hand. Their objective was to determine if wheelchair propulsion could be made easier. They concluded that the axial position of the wheel was imperative in reducing the strain on the user and the joints involved in propulsion. However, they stopped short of stating that wheel camber had any effect, although this was one of the underlying tenets of this study. The authors subsequently concluded that wheel configuration, in all its dimensions, had a bearing on the biomechanics of wheelchair propulsion.

In a more recent study by Ruggles, Cahalan & An (1994), the researchers evaluated the mechanical parameters of wheelchair propulsion. This study involved the use of three different wheelchairs, each at a different camber angle. While physiological responses were not measured, the researchers were able to demonstrate significant differences in the mechanical propulsion parameters associated with wheelchair propulsion. They concluded that rear wheel camber influenced the contact point of the hand-to-rim interface, and thus, affected angular displacement of the wheel and stroke duration. Whether or not this had any impact upon physiological energy cost remained unclear.

Veeger (1991) also discussed the biomechanics of wheelchair propulsion, and noted that "the most effective force applied on the rims is directed tangential to the handrims at each position of hand-to-rim contact". The author demonstrated that the forces applied by the user were affected by a "push arc", which was generated through the flexion of the elbow, shoulder and wrist joints, and the position of the trunk. These positions result in a torque created around each joint during various phases of locomotion. While many researchers have studied the forces present, and the dynamic angles achieved during wheelchair propulsion, the majority agree that each one of these variables can be affected by the contact, or rather the nature of contact to the hand-rim (Bardsley, 1991; Cerquiglini et al., 1984; Cooper, 1989; Masse et al., 1992; Sanderson & Sommer, 1985; Veeger, van der Woude & Rozendal, 1992). Other studies, such as Walsh (1986) have demonstrated that the actual kinematics of wheelchair propulsion were affected by the push frequency. The researcher noted that at a self-selected frequency, optimization of biomechanical forces occurred, in contrast to a pre-determined fixed push frequency rate, which tended to result in unnecessary movement, and therefore, wasted energy.

Hand-rim wheelchair propulsion has been identified as having a very low degree of mechanical efficiency (Masse et al., 1992; van der Woude et al., 1986;

Veeger, 1991; Veicsteinas et al., 1991). According to van der Woude et al. (1986), a "low mechanical efficiency is associated with a high internal waste of mechanical efficiency". This view was supported by Cerquiglini et al. (1984) who noted that although the external power requirement was quite small during wheelchair propulsion, it actually represented a significant burden for patients, in part because of the mechanical inefficiency, ergonomic deficiency, and poor physical fitness levels of the individuals using these wheelchairs.

Another aspect to be considered in the biomechanics of wheelchair propulsion, was the position of the user in the wheelchair. This related to where the rear axle was located in relation to the seat, and the seat height. Masse et al. (1992) evaluated a number of different seating positions on wheelchair propulsion. In their study, they assessed three different rear wheel positions, and two different seat heights. They concluded that a lower seat position, with a rearwardly placed wheel would be the most mechanically efficient position. The low position was determined by seating the subject in the wheelchair, and aligning the distal phalanges with the lowest portion of the handrim. This was in contrast to the 100-120 degree elbow angle normally employed in studies, which Masse et al. associate with a generally reduced mechanical efficiency. In a study by Traut and Schmauder (1991), the researchers studied the optimum ergonomic design for the hand machine interface occurring between the wheelchair and user. They determined that the optimum position for the seat height and hand rim position was such that when the user is seated in the wheelchair, the handrim vertex was 75mm in front of the shoulder joint, and 50 mm below the forearm when it is maintained in a position of 90 degrees of flexion. As the authors noted, when these handrim angles were observed, they can automatically set the wheel position in relation to the user. A cursory review of the literature related to seat height indicated that a range of seat heights have been employed, while no consensus has been drawn for optimal height due to the myriad of other factors which affected performance, and the differences between wheelchairs. Generally, seat height has been set at between 90 and 120 degrees of elbow flexion, when the hand was on the topmost portion of the handrim.

In summary, based on a review of the literature on biomechanics it was reasonable to conclude that since camber will change the angle of the hand to rim dimension, biomechanical differences are expected to exist between various cambers, and that these changes could have some impact upon physiological parameters. Since it was evident that seat height could have some effect upon the hand machine interface, it was recognized that a constant seat height was important within the parameters of this study.

Perceived exertion

Much has been written regarding perceived exertion, and its relationship to physiological responses. A common method of evaluating perceptual responses during exercise is through the use of the Borg scale, which measures ratings of perceived exertion (RPE). Developed in 1970 (Pandolph, 1983) this scale provides a subjective rating of a person's level of exertion on a 15 point, ordinal scale. Through intensive study, the ratings obtained through the use of this scale during various tasks have been found to be correlated with exercise levels. Although perception of exertion is a complex concept (Goslin & Rorke, 1986), it is believed to integrate both local or peripheral factors and central cardiovascular factors in to one general perception regarding the intensity of work, which then yields a rating for perceived exertion.

The Borg scale consists of a numerical rating system with values ranging from 6 to 20. The scale is presented in a vertical format, with the odd scale values accompanied by descriptions of the degree of intensity of the work, such as 7=very, very light, while 19 = very, very hard (Borg, 1970). Validity coefficients of 0.91 and 0.97 have been reported between the RPE on the Borg scale and HR and $A\dot{V}O_2$ respectively (Borg & Noble, 1974), during lower body exercise.

Goslin and Rorke (1986) evaluated the perception of exertion during load carriage. In their study, the authors evaluated cardiorespiratory conditions, stating that peripheral, as well as central factors played a part in the ratings of perceived exertion which can be expected. However, their study focused on lower body work, while carrying an upper body load. The correlations obtained during this study were lower, reportedly .47 for HR, and .75 for $A\dot{V}O_2$. This may or may not have implications in the case of wheelchair locomotion, sincr this study evaluated two different types of exercise at the same time, static versus dynamic exercise. Other than the findings of Goslin and Rorke, very little information was available which examined the validity of the Borg scale during upper body exercise, and therefore, the application of the Borg scale during this study was limited in its utility.

While the validity of this scale has not been extensively evaluated during upper body exercise, differences have been found in the RPE ratings for upper body work as opposed to lower body work at comparable metabolic rates. In studies which have compared upper versus lower body work, the RPE has generally been found to be higher for upper body exercise (Pandolph, 1983). However, despite these differences, when compared to lactate concentration, the values were similar (Gamberale, 1985). This could have been a logical explanation for the increased perception of RPE with arm exercise as opposed to leg exercise as it was representative of local fatigue factors, as opposed to central factors. Indeed, in a study by Astrand, Guharay and Wahren (1968), the researchers demonstrated that lactate concentration in relation to oxygen consumption for upper body work, increased at a higher rate. According to Goslin and Rorke (1986), the explanation of local factors influencing perceived exertion to a greater degree than central factors during upper body exercise might indeed be the case.

This finding was also supported by Pandolph, Burse and Goldman (1975), who studied both peripheral and central factors involved in fatigue. The researchers demonstrated that during lower body work, the type of exercise has an impact on differentiated ratings of perceived exertion. That is, some tasks such as cycling, may be more associated with peripheral or local fatigue, than for example, treadmill work, which were associated with central fatigue. This finding may also hold true for the type of exercise involved in wheelchair propulsion. According to Sawka (1986), peripheral factors may be an important consideration in the perception of fatigue during upper body work.

No significant gender differences have been reported in regards to percent $A\dot{V}O_2$ and RPE ratings (Borg, 1970; Noble, 1982). That is, for a given percentage of $A\dot{V}O_2$ achieved by either males or females, the RPE ratings were essentially the same. However, the absolute differences between RPE response were found to be related to the absolute differences in aerobic capacity which can be demonstrated between males and females.

In regards to age related changes in the RPE ratings, Borg (1970) noted that while physical working capacity declines with age, HR at a given work load does not, however, the RPE values have been demonstrated to increase with age for the same workload. Borg advised that this was a reflection of the changes in physical work capacity, and this therefore could be interpreted as the RPE value yielding a "better estimation of the change of the physical stress with age than the heart rates" (Borg, 1970, p. 93). This is an important concept in the evaluation of rear wheel camber, because the Borg scale could demonstrate perceived differences between younger and older populations in exertion for the same wheelchair design features. That is, a particular wheel camber may be perceived as requiring very low exertion for a younger person, but the same camber may be perceived by an older person as requiring a significantly higher amount of exertion, or vice versa. This could then be used as a guide to selection and design of wheelchairs for a particular population.

Presently, the Borg scale is a widely used rating scale for perceived exertion during exercise tasks. Although its use has been limited in the study of wheelchair design features, its applicability lends itself to use for such a purpose. The RPE could be beneficial in providing a reliable rating of the work intensity required to propel wheelchairs of differing design, or design features such as wheel camber. Despite its rather low correlation with $\Delta\dot{V}O_2$ for work under load conditions, this scale continues to appear to be the most reliable in terms of rating perceived exertion during exercise, and therefore, will be employed for this study.

Summary

From the literature, it can be seen that careful evaluation of wheelchair design features was necessary. It was also apparent that physiologic differences exist between individuals at different ages, and between males and females. Therefore, it was essential that the evaluation of wheelchair design features was conducted with the populations that were intended to utilize them. With regard to rear wheel camber there was a paucity of research on this particular design feature, and a body of research which indicated that this particular factor affected performance. Traditionally, performance has been measured using the following physiological variables: $A\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RER, and HR, in addition to RPE on both central and local dimensions.

CHAPTER III
METHODS AND PROCEDURES

INTRODUCTION

A sample of forty individuals recruited from the University of Alberta, the Society for the Retired and Semi-retired, and a selection of senior's drop-in centres throughout the city of Edmonton were asked to participate in this study. Participants were asked to attend one testing session, during which (i) baseline physiological responses were monitored, (ii) a wheelchair familiarization session was completed, and (iii) three different wheelchair camber tests at a speed of 2 km/hr, interspersed with sufficient rest periods to ensure recovery, were performed. Throughout the testing session, physiological responses were monitored. The data were analyzed to determine the differences, if any, between the different wheelchair cambers, between the two different age groupings, and between males and females.

SAMPLE

The sample consisted of forty participants in total, divided into two sub-groups of twenty subjects each. Subjects were assigned to one of two groups based upon their ages. The younger group included subjects aged from 19-44 years and the older group included subjects aged from 45-74 years. The gender composition of the younger group consisted of 7 males and 13 females, while the older group consisted of 12 males and 8 females. One participant withdrew from the study prior to the commencement of testing, necessitating his replacement with another subject.

All participants were assured of confidentiality as raw data was only available to the researchers. An information letter was provided to subjects upon the initial contact (Refer to Appendix C).

Participants were eligible for inclusion in the sample pool if they:

- •-satisfactorily completed a modified Physical Activity Readiness Questionnaire (PAR- Q) (Appendix D) (British Columbia Ministry of Health and the Department of National Health & Welfare, 1978),
- •- completed an Activity Questionnaire (Appendix E),
- •-had no history of cardiovascular disease,
- •-were not currently involved in any physical fitness/strength training program or activities, and
- •-consented to participate in the study and completed the consent form (Appendix F).

Testing terms and procedures as well as all possible risks were outlined within the consent form, which had been previously approved by a duly constituted Ethics committee.

The PAR-Q, developed by the British Columbia Ministry of Health (1978) was designed to be used as a screening instrument for individuals entering a vigorous exercise testing program. A minor modification to the upper age limit was made to permit inclusion of subjects over the age of 65 years of age. It has been demonstrated to be valid, and therefore, was employed as a screening tool during this study.

An activity questionnaire, developed from a form designed by the British Columbia Ministry of Health and the Department of National Health & Welfare (1978), was introduced in order to screen and eliminate participants who considered themselves sedentary, but in fact, participated in regular aerobic or fitness training.

Additional general demographic data was also collected and recorded, and the form utilized is included in Appendix G.

INSTRUMENTATION

Four major instruments were employed:

1. Wheelchair mounted on a customized roller system,
2. Sensormedics Metabolic Measurement Cart (MMC) (Sensormedics 2900Z, Yorba Linda, California),
3. Polar wireless heart rate monitors (Polar Key, Model PE 3000, Kempele, Finland)
4. Borg Scale of Perceived Exertion (RPE)

Wheelchair specifications

A Quickie GPS wheelchair with standard dimensions manufactured by Sunrise Medical, California, USA was used for this study. This wheelchair weighed 20.5 lbs, and is considered to be a high performance, rigid wheelchair, with positioning versatility. It had the option of adjustable camber, with potential camber settings of 0, 4, and 8 degrees. This wheelchair was relatively new on the market, so to date, no studies had been undertaken on its design features.

The wheelchair was provided at no cost, by Eco Medical Equipment Ltd. in conjunction with Sunrise Medical. Additional information is presented in

Appendix H. The wheelchair was mounted on a customized roller system which is described below.

Customized roller system

In this study, the subjects propelled the wheelchair on a customized roller system, designed to provide velocity and distance feedback.

Description

The wheelchair roller was a specially constructed, low friction steel roller, with a circumference of 53 cm. An optical sensor mounted on the roller frame detected signals from the roller each time a strip of reflective tape crossed its path during rotation. This information was then transposed to a computer which interfaced with the wheelchair roller. The computer recorded the revolutions per minute (rpm), and then calculated distance travelled (rpm's multiplied by circumference) and velocity by way of a customized computer program. This information was then displayed visually in the form of a speedometer on the computer monitor. This enabled the subject to maintain a constant speed of 2 km/hr. At the end of the test, the velocity and distance travelled during each minute was printed out and placed in the subject's file.

The customized roller system was described by Bhambhani, Holland, Eriksson, & Steadward (1994). A schematic representation of this roller system set - up is presented in Appendix I.

Calibration of the Roller System

Prior to the commencement of the study, it was necessary to calibrate the wheelchair roller system to ensure accuracy in the maintenance of the speed of 2 kmh. In order to achieve this a bicycle (Cateye Co., Model cc ST300, Japan) odometer was attached to the rear wheel of the wheelchair while it was mounted on the roller system. The researcher then rotated the tire at a continuous speed of 2 to 3 kmh, as indicated by the visual monitor. During this time, tire revolutions were counted manually, after which, the rpm's were then multiplied by the wheelchair roller circumference, and compared to the computer printouts for rpms, velocity, and distance travelled, and the display on the Cateye odometer. While the Cateye demonstrated no difference in the aforementioned variables, it was noted that the rpm's, velocity and distance travelled printed out by the computer were exactly half of those manually recorded. Therefore, these values were multiplied by two, so as to ensure accuracy of the calibration. This procedure for calibration was repeated numerous times to ascertain reliability. A copy of the wheelchair roller calibration results is presented in Appendix J.

Metabolic measurement cart

The MMC required calibration prior to testing each subject. Calibration of the MMC was carried out according to the protocol recommended by the manufacturer. Calibration of the oxygen and carbon dioxide analyzers was completed using commercially available precision gases. Volume calibration of the mixing chamber was conducted prior to testing by injecting a known volume of air, in accordance with the manufacturer's recommended guidelines. A copy of the calibration results was inserted with each subject's file.

During the testing sessions (throughout differing camber sessions), the physiological responses of the subjects were monitored continuously. An open-circuit spirometry method was used, in which the participant inhaled ambient air with a known composition of oxygen, carbon dioxide and nitrogen, which was then compared to the exhaled air. Absolute $\dot{V}O_2$ readings were then calculated from the collected data using a Haldane transformation (McArdle, Katch & Katch, 1991), which was performed by the computerized software package installed in the MMC. The MMC then calculated the variables that were measured in this study: $A\dot{V}O_2$, $\dot{V}CO_2$, RER, $\dot{V}_I$, $\dot{V}_I/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$.

In a study by Wilmore and Norton (1976), the authors demonstrated that in contrast to other measurement methods, the MMC was a valid instrument for several exercise media, such as arm ergometry, treadmill exercise, and bicycle ergometry. In addition, evaluator abilities have been found to have an insignificant effect on test scores, leading to the conclusion that the MMC is a valid and reliable method of measuring physiological responses.

Polar wireless heart rate monitors

Heart rate (HR) was monitored using a wireless HR monitor and transmitter, rather than the ECG, due to the obstruction that ECG leads would cause during the propulsion phase. Polar wireless HR monitors (Model PE 3000, Polar Electro, Kempele, Finland) were chosen to record HR. A transmitter unit was applied to the subject in the CM_5 location, consistent with the recommendation for EMG electrode pads, following the application of conductivity gel. In order to ascertain consistency of transmission and reception of the receiver unit, two separate receiver units were employed for each subject. No differences in the recorded HRs were detected throughout the course of the study.

In a study by Léger (1988), the researcher demonstrated that wireless HR monitors, such as the one employed during this study, could be considered reliable and stable. The study demonstrated this particular type of HR monitor to be "excellent" for accurate monitoring of HR.

Borg scale of perceived exertion

The Borg scale is a 15 point ordinal scale, used to measure subjective ratings of perceived exertion (Borg, 1970). The scale is presented in a vertical format, with the odd scale values having verbal descriptors relating to the perceived intensity of the work. The scale numbering system begins at the numerical value of 6 and continues in one unit intervals up to 20. The verbal descriptors attached to the numbers begin at the numeric value of 7 and are as follows: 7 = very, very light, 9 = very light, 11 = fairly light, 13 = somewhat hard,15 = hard, 17 = very hard, and 19 = very, very hard (Borg, 1970). A copy of the Borg scale is presented in Appendix K.

The Borg scale was employed during this study to provide data on two variables: RPEC and RPEL. During the course of the study, subjects were asked to provide firstly; a rating of central, or cardiorespiratory stress (RPEC), and secondly; a rating of local, or muscular fatigue stress (RPEL).

PILOT STUDY

Prior to the commencement of the research study, extensive pilot testing was conducted on a sample of 15 participants, over a period of two weeks. The pilot testing allowed for the determination of the 2 kmh wheelchair propulsion speed, the length of the camber testing session (8 minutes 30 seconds), the interval for the recording of the Borg ratings (at the 8 minute point), the determination of the length of baseline ratings (4 minutes), the length of the rest periods (8 minutes), and the time required to complete the camber changes. Additionally, the pilot testing allowed for the development of stringent controls regarding wheelchair tire pressure, camber bar placement, placement of the wheelchair on the customized roller, and administration of the Borg scale. Finally, the pilot testing allowed for the evaluation of equipment limitations, such as the elimination of camber angles which could not be accommodated by the width of the wheelchair roller.

TEST PROCEDURES

Testing sessions for the older and younger groups were interspersed in a random manner. Once the participant had presented to the testing session, camber testing order was randomized by drawing lots from a box.

Before testing commenced, height and weight were measured and recorded in both the subject's file, and on the MMC. Approximately sixty to eighty older participants who responded to the advertisements were excluded from the study on the basis of medical unsuitability. If the participants met the eligibility criteria, and agreed to participate in the study, the researcher provided a detailed explanation of the procedures and what was expected of the participant.

Following an explanation and demonstration of the testing procedure, the randomly chosen camber angle for each participant was implemented and the wheelchair was mounted on the customized roller.

The subject was then seated in the wheelchair and the initial seat height measurement was taken. Seat height remained constant, among camber angles relative to the dimensions of each individual subject's trunk, such that elbow flexion was consistent for each subject throughout the entire testing procedure. To ascertain the constancy of seat height, the axis of the shoulder was considered to be the centre of the acromion process, and the distance between this point and the centre of the wheelchair axle was taken prior to each different camber session. In order to ascertain reliability, the researcher was the only individual taking these measurements. This procedure ensured that the biomechanical aspects of seat height and hand wheel interface remained constant among the camber angles for each individual. This distance was recorded for comparison with subsequent camber tests for that individual.

Participants were then oriented to the MMC, and the accompanying mouthpieces and head supports. Throughout the testing session, the MMC was out of view from the participants, in order to alleviate any potential bias. The participant was then fitted with the headgear, mouthpiece and nose clip, and baseline physiological responses were monitored for four minutes while the individual remained seated in the wheelchair. At the end of this period, participants were given a brief familiarization session on the wheelchair, consisting of 5 minutes of free-wheeling, at a velocity of 2 kmh, in order to minimize difficulties with propulsion encountered due to non-familiarity with the wheelchair.

According to Veeger, Lute, Roelveld and van der Woude (1991), in a study evaluating the need for familiarization, no significant differences in physiological and biomechanical variables could be detected between able bodied groups which had received training in wheelchair propulsion versus those who did not. However, the use of a familiarization period has been identified as useful in controlling for unseen variables (Glaser, Simsen-Harold, Petrofsky, Kahn & Suryaprasad, 1983; Masse, Lamontagne & O'Riain, 1992), such as learning effect between trials. Following the familiarization session, the participant was allowed to rest for eight minutes, with the headgear and mouthpiece removed. At the end of the rest period, the first camber testing session commenced. In total, there were three camber sessions which were randomly assigned. Following each camber testing session there was an 8 minute rest period, at which point the participant was allowed to rest in a chair and the mouthpiece and headgear were removed. During this period, the researcher changed the rear wheel camber, and remounted the wheelchair on the customized roller, according to the procedures established during the pilot testing. A flow diagram for the study session and the data collection procedures is presented in Appendix L.

The commencement of a wheelchair camber testing session entailed the replacement of the headgear, mouthpiece and nose clip, a remeasurement of the distance from the wheelchair axle, and the commencement of wheeling at a rate of 2 kmh. Each camber session required that the participant continue wheeling the wheelchair at a rate of 2 kmh for a period of 8 minutes 30 seconds, during which physiological variables were continuously monitored. At 8 minutes exactly, the participant was asked to give two Borg ratings, the first being a RPEC, and the second being a RPEL. These ratings were then entered into the MMC, so that they could be recorded in the real time report.

Upon the completion of the wheelchair camber testing, the HR monitor and the headgear and mouthpiece were removed, and the participant was requested to rest in the presence of the researcher for 10 minutes, after which the subject was allowed to leave.

DATA COLLECTION

Timetable

Data collection took approximately two weeks. A total of two to six participants per day were evaluated. Data for each subject was collected during one complete session.

Administration times and conditions

The entire testing session lasted approximately one and one half to two hours, with the physiological data collection encompassing one hour and fifteen minutes. The balance of the time was spent in the collection of demographic data and the completion of questionnaires. There was a minimum of fifteen minutes between each subject session, to allow for the recalibration of the metabolic measurement cart, and for the adjustment of camber angles.

CALCULATION OF OTHER VARIABLES

Calculation of relative oxygen consumption and oxygen pulse

In addition to the data collected by the MMC and the Polar HR monitor, which consisted of: $A\dot{V}O_2$, $\dot{V}CO_2$, RER, $\dot{V}_E$, $\dot{V}_E/VO_2$, $\dot{V}_E/\dot{V}CO_2$, and HR, two additional variables were calculated. Relative oxygen consumption ($R\dot{V}O_2$) was obtained by dividing absolute oxygen consumption ($A\dot{V}O_2$) by body weight (in kg.), and expressing this value as ml/kg/min. Additionally, oxygen pulse (O_2 pulse) was calculated by dividing absolute oxygen consumption ($A\dot{V}O_2$) by heart rate (HR), and expressing this value in ml/beat.

Calculation of energy cost

From the MMC data collected, further information was calculated on the energy cost during the task, such as gross energy cost (GEC), net energy cost (NEC), relative gross energy cost (RGEC), and relative net energy cost (RNEC). The kilocaloric (KCal) equivalent for a litre of oxygen consumed was derived from the table contained in Appendix M. Values employed for these calculations were derived from averaged values obtained over the last 2 minutes of the test. The values used were taken from the data obtained from minute six to minute eight.

The GEC of wheelchair propulsion at the three different camber angles was calculated as a product of AVO_2 (L/min) and the kilocaloric equivalent at the non-protein RQ suggested by McArdle et al. (1991). The resultant value was then expressed in Kcal/min. Relative gross energy (RGEC) cost was obtained by dividing the above value by body weight (in kg.), then multiplying the resultant value by 1000 to convert Kcals/kg/min to Cals/kg/min.

The NEC was calculated by subtracting the baseline gross energy cost from the GEC obtained at each camber angle. The resultant value was expressed as Kcals/min. Relative net energy cost (RNEC) was obtained by dividing the derived NEC by body weight (in kg.), multiplying the resultant value by 1000, and then expressing this value as Cals/kg/min.

Calculation of predicted maximum heart rate

Finally, predicted maximum HR was calculated by utilizing Karvonen's equation which subtracts the subject's age from 220 (McArdle et al., 1991, pp.436). Percentage of predicted maximum HR achieved during the testing was derived by dividing the test HR by maximum HR and multiplying the value by 100.

STATISTICAL ANALYSIS

Missing data

During testing, the data set for one female subject in the older group was incomplete due to the fact that at the 8 degree camber setting, the participant was unable to fit in the wheelchair, in part due to equipment limitations. However, the data obtained at the 0 degree and 4 degree camber angles for this subject were complete, and therefore, were included in the statistical analysis.

Experimental design

The study corresponded to three factorial design: Factor A, namely age, had two levels (younger versus older adults), Factor B, namely gender, had two levels (males versus females), and Factor C, namely camber, had three levels (0, 4 and 8 degrees camber).

Statistical procedures

Subject demographics, namely age, height, weight and body surface area (BSA) were analyzed using a two - by - two ANOVA with factor A having two levels (younger versus older adults), and factor B having two levels (males versus females).

For each physiological, perceptual and energy cost variable under consideration, the data were analyzed utilizing a three-way repeated measures analysis of variance (ANOVA). Each factor was evaluated separately for $A\dot{V}O_2$, $R\dot{V}O_2$, HR, V_E, RER, O_2 pulse, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, GEC, NEC, RGEC, and RNEC. A Bonferroni process was applied to correct for the repeated measurements and to minimize the possibility of a Type I error occurring. Additionally, the Greenhouse - Geisser correction factor was applied prior to the interpretation of data. Post hoc Scheffe` tests were employed to evaluate pairwise comparisons. Results were considered to be significant at the .05 level of confidence.

In consultation with the statistician at the University of Alberta, it was decided that although the Borg scale for RPE was an ordinal scale, it closely approximated an interval scale, with a relatively normal distribution. For this reason, it was recommended that the data obtained from the Borg scale be analyzed utilizing a three - way repeated measures ANOVA, in the same fashion as the other data.

All statistical analyses were completed using the Statistical Package for the Social Sciences (SPSS) program.

ETHICAL CONSIDERATIONS

During this study, some ethical considerations arose. There was some concern that the testing being performed may have caused some discomfort, in terms of soreness around the mouth region from the MMC headgear and mouthpiece. In addition, performing unaccustomed activity such as propelling a wheelchair for approximately 30 minutes might have induced some localized muscle soreness. As well, there could have been symptoms of general fatigue resulting from the exercise protocol, and this might have been more pronounced in the older subjects. In accordance with general ethical principles for testing human subjects, the subjects were informed clearly of any possible risks and possible side effects. All participants were advised to contact the researcher should they experience any adverse effects from the testing. However, none did so. Some participants stated that they found the mouthpiece to be uncomfortable, and in some cases, found the wheelchair propulsion to be fatiguing during the course of the testing session. Despite these concerns, none of these subjects terminated the test due to discomfort. In addition, it was believed that concerns could have arisen regarding the safety of the testing during the actual session. The researcher reassured the participants that the test would have been terminated if any unexpected events occurred. In addition, the participants were advised that they could terminate the test at any given time, for any reason, without repercussions. Someone with cardiopulmonary resuscitation (CPR) training was always available.

Subjects were reassured regarding the intent of the study, and its importance in terms of benefitting wheelchair users. A large number of the participants, particularly the older individuals, expressed a desire to learn the outcome of the study. Therefore, arrangements were made to mail out a summary of the study findings.

LIMITATIONS OF THE STUDY

Many of the limitations for this study have been discussed in the context of the previous section, however, the major limitations will be reiterated here.

Firstly, the study was performed on a sample of apparently healthy individuals, who were not normally wheelchair users, and therefore, are not medically compromised in any way. It is important to keep this in mind when designing wheelchairs for the disabled population, as persons with disabilities may respond quite differently. Additionally, different results may be found with the recreational and elite wheelchair athletes who are propelling their wheelchairs at high speeds, and are regular, high intensity users.

A second limitation relates to the fact that only three different camber angles were studied, and therefore, it is still possible that with higher camber angles, physiological responses could be different. Additionally, the speed employed during the tests was of low intensity, which may not have been high enough to generate larger physiological responses. It is also possible that had the speed been self-selected, the energy cost values could have been lower, since this value is reportedly optimized (minimized) for other modes of ambulation such as walking and running (Bhambhani, et al., 1985).

A third limitation presented by this study was the lack of peak exercise testing, which could not be conducted upon this sample, due to possible unforeseen medical complications of the older group. This prevented absolute comparison of proportionate increases and energy costs, as they relate to the maximal attainable peak physiological costs. This would be of particular importance with respect to age and gender differences, since both these factors have been reported to influence the peak physiological responses during exercise. Thus, the activity performed during this study would likely have represented a greater proportionate energy cost for the older subjects and females, because of their significantly lower peak oxygen uptake (Sawka, et al., 1981).

Finally, no provision was possible during this study for biomechanical factors. Every participant was evaluated in the same wheelchair, regardless of fit, and although each subject served as his or her own control, it is possible that an optimally prescribed fit could impact upon the responses which were observed.

CHAPTER IV
RESULTS

This chapter is divided into three sections. Firstly, participant demographics are reported. Secondly, a summary of the results for the ANOVA procedures and an overview of the post - hoc Scheffe` tests have been presented. Finally, results for each variable studied have been presented in the form of means and standard deviation tables, with indicators for significance.

PARTICIPANT DEMOGRAPHIC CHARACTERISTICS

Subject demographics and other relevant characteristics are listed in Table 1. It was found that height, weight, and body surface area (BSA) were all significantly higher in males as compared to females, in both age groups. However, as necessitated by the study design, significant differences between the younger and older groups were observed for age, irrespective of gender.

Table 1: Comparison of Demographics of Subject Groups

Variable	Group	# of Subjects (n)	Males (mean)	Males (S.D.)	Females (mean)	Females (S.D.)
Total n	young	20	n = 7		n = 13	
	old	20	n = 12		n = 8	
Age† (yr.)	young	20	25.4	7.0	24.5	4.7
	old	20	59.1	8.6	56.3	9.2
Height§ (cm.)	young	20	166.8	11.0	161.2	8.5
	old	20	174.2	5.9	160.0	5.7
Weight§ (kg.)	young	20	70.6	18.7	59.0	7.7
	old	20	80.8	6.2	62.6	14.2
B.S.A.§ (sq.m.)	young	20	1.80	.30	1.64	.14
	old	20	1.98	.09	1.66	.20

† - denotes significant differences between younger and older subjects (irrespective of gender)
§ - denotes significant differences between males and females (irrespective of age)

SUMMARY OF RESULTS OF ANOVA PROCEDURES AND POST - HOC SCHEFFE` TESTS

General trends

In this study, the recommendations of Keppel (1973) were followed for the interpretation of the results of the three-way ANOVA. The first stage was to examine the triple interaction in the summary table. If the 'F'-ratio proved to be significant, the author then recommended proceeding to examine the simpler two-way interaction at each level (ie. at each camber angle in this case). However, if the three-way interaction was not significant, Keppel then recommended examining the two-way interactions. If the two-way interactions were not statistically significant, the author then recommended an examination of the main effects of each factor.

In this study, examination of the four different interaction terms ABC, AB, AC, and BC, demonstrated that no significant 'F' -ratios occurred for any of the variables studied, as shown in Table 2. This indicated that regardless of age or gender, the trend in the physiological responses of the subjects were similar for each of the camber angles tested. Since none of the interaction terms for any of these variables were significant, an examination of the main effects was undertaken. A complete presentation of the individual summaries of the analyses of variance for the variables examined in this study can be found in Tables 23 to 37, Appendix N.

Main effects of ANOVA

Camber:

In analyzing the main effect of camber, it was noted (Table 2) that there were significant differences among camber angles for $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC. However, no significant effects were seen for the RER, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC and RPEL. These are described more fully in conjunction with the variable summary tables.

In analyzing the post - hoc tests for the main effect of camber, it was noted that significant differences occurred between the camber angles of 4 and 8 degrees, and 0 and 8 degrees for most variables. A summary of the post - hoc Scheffe` test results are presented in Table 3.

Age:

In evaluating the main effect of age (group) on the variables studied, significant differences were observed between the younger and older subjects for $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, NEC and RNEC. A closer examination of the post - hoc analyses revealed significant differences between the two age groups primarily on the camber angles of 0 degrees and 4 degrees, while only three of the seven variables identified above demonstrated significant differences at 8 degrees of camber. It was noted that all of the aforementioned variables demonstrated significant differences between the age groups at the 0 degree camber angle. At the 4 degree camber angle, once again, all of the above variables indicated significant differences, with the exception of RNEC, which did not demonstrate significant differences between the age groups. However, at 8 degrees of camber, only the $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$ presented significant differences between age groups, while $\dot{V}CO_2$,

Table 2: **Summary of Results for Three - Way Repeated Measures ANOVA**

Physiological Responses

VARIABLE	Interactions†	Effect of Camber	Effect of Age(group)	Effect of Gender
$A\dot{V}O_2$	NS	**	NS	**
$R\dot{V}O_2$	NS	**	NS	NS
HR	NS	**	NS	NS
$\dot{V}_E$	NS	**	**	**
RER	NS	NS	NS	NS
O_2 Pulse	NS	**	NS	**
$\dot{V}CO_2$	NS	**	**	**
$\dot{V}_E/\dot{V}O_2$	NS	NS	**	NS
$\dot{V}_E/\dot{V}CO_2$	NS	NS	**	NS

Perceptual Responses

VARIABLE	Interactions	Effect of Camber	Effect of Age(group)	Effect of Gender
RPEC	NS	NS	**	**
RPEL	NS	NS	NS	**

Energy Expenditure

VARIABLE	Interactions	Effect of Camber	Effect of Age(group)	Effect of Gender
GEC	NS	**	NS	**
RGEC	NS	**	NS	NS
NEC	NS	**	**	**
RNEC	NS	**	**	NS

Note: *†"Interactions: ABC, AB, AC, BC - none of these interactions were significant*

NS - denotes "F" ratio was not significant

** - denotes significant "F" ratio for that Factor

Table 3: Summary of Results for Post - Hoc Scheffe` Tests (tests involving camber)

Physiological Responses

VARIABLE	Camber 0 vs.4	Camber 0 vs. 8	Camber 4 vs. 8
A$\dot{V}O_2$	NS	**	**
R$\dot{V}O_2$	**	**	**
HR	NS	**	**
$\dot{V}_E$	NS	**	**
RER	/////////////// ///////////////	/////////////// ///////////////	/////////////// ///////////////
O_2 Pulse	NS	**	**
$\dot{V}CO_2$	NS	**	**
$\dot{V}_E/\dot{V}O_2$	/////////////// ///////////////	/////////////// ///////////////	/////////////// ///////////////
$\dot{V}_E/\dot{V}CO_2$	/////////////// ///////////////	/////////////// ///////////////	/////////////// ///////////////

Perceptual Responses

VARIABLE	Camber 0 vs.4	Camber 0 vs. 8	Camber 4 vs. 8
RPEC	/////////////// ///////////////	/////////////// ///////////////	/////////////// ///////////////
RPEL	/////////////// ///////////////	/////////////// ///////////////	/////////////// ///////////////

Energy Expenditure

VARIABLE	Camber 0 vs.4	Camber 0 vs. 8	Camber 4 vs. 8
GEC	NS	**	**
RGEC	**	**	**
NEC	NS	**	**
RNEC	**	**	**

NS - denotes Scheffe` test was not significant
** - denotes significant Scheffe` test
///////////Scheffe` not performed due to non-significance of ANOVA

RPEC, NEC and RNEC did not. A complete summary of the post - hoc tests for the main effect of age can be found in Table 4.

In examining the main effect of gender, significant differences were demonstrated between males and females for $\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, RPEC, RPEL, GEC and NEC. However, no significant differences were observed for $R\dot{V}O_2$, HR, RER, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RGEC and RNEC.

Gender:

In analyzing the post - hoc Scheffe` tests for the main effect of gender, it was observed that for the aforementioned variables, significant differences between males and females occurred primarily at the camber angles of 0 degrees and 8 degrees, with few significant differences occurring at 4 degrees of camber. In summary, significant differences between males and females occurred for the following variables at 0 degrees of camber: $A\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, RPEC, RPEL, GEC and NEC. At 4 degrees of camber, only $A\dot{V}O_2$, O_2 pulse, and GEC demonstrated significant differences between males and females, while the remaining variables did not exhibit significant differences. Finally, at 8 degrees of camber, all of these variables demonstrated significant differences between males and females, with the exception of RPEL. A complete summary of the post - hoc tests for the main effect of gender can be found in Table 5.

Table 4: Summary of Results for Post - Hoc Scheffe` Tests for Age Differences During Differing Camber Angles

Physiological Responses

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
$A\dot{V}O_2$	////////////// //////////////	////////////// //////////////	////////////// //////////////
$R\dot{V}O_2$	////////////// //////////////	////////////// //////////////	////////////// //////////////
HR	////////////// //////////////	////////////// //////////////	////////////// //////////////
$\dot{V}_E$	**	**	**
RER	////////////// //////////////	////////////// //////////////	////////////// //////////////
O_2 Pulse	////////////// //////////////	////////////// //////////////	////////////// //////////////
$\dot{V}CO_2$	**	**	NS
$\dot{V}_E/\dot{V}O_2$	**	**	**
$\dot{V}_E/\dot{V}CO_2$	**	**	**

Perceptual Responses

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
RPEC	**	**	NS
RPEL	////////////// //////////////	////////////// //////////////	////////////// //////////////

Energy Expenditure

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
GEC	////////////// //////////////	////////////// //////////////	////////////// //////////////
RGEC	////////////// //////////////	////////////// //////////////	////////////// //////////////
NEC	**	**	NS
RNEC	**	NS	NS

///////////Scheffe` not performed due to non-significance of ANOVA

** - denotes significant Scheffe` test

NS - denotes Scheffe` test was not significant

Table 5: Summary of Results for Post - Hoc Scheffe` Tests for Gender Differences During Differing Camber Angles

Physiological Responses

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
A$\dot{V}O_2$	**	**	**
R$\dot{V}O_2$	////////////// //////////////	////////////// //////////////	////////////// //////////////
HR	////////////// //////////////	////////////// //////////////	////////////// //////////////
$\dot{V}_E$	**	NS	**
RER	////////////// //////////////	////////////// //////////////	////////////// //////////////
O_2 Pulse	**	**	**
$\dot{V}CO_2$	**	NS	**
$\dot{V}_E/\dot{V}O_2$	////////////// //////////////	////////////// //////////////	////////////// //////////////
$\dot{V}_E/\dot{V}CO_2$	////////////// //////////////	////////////// //////////////	////////////// //////////////

Perceptual Responses

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
RPEC	**	NS	**
RPEL	**	NS	NS

Energy Expenditure

VARIABLE	CAMBER 0	CAMBER 4	CAMBER 8
GEC	**	**	**
RGEC	////////////// //////////////	////////////// //////////////	////////////// //////////////
NEC	**	NS	**
RNEC	////////////// //////////////	////////////// //////////////	////////////// //////////////

** - denotes significant Scheffe` test

//////////Scheffe` not performed due to non-significance of ANOVA

NS - denotes Scheffe` test was not significant

VARIABLE RESULTS DURING CAMBER SESSIONS

The results for each of the variables studied, $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, RER, O_2 pulse, $\dot{V}CO_2$, $\dot{V}_I/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, RPEL, GEC, RGEC, NEC, and RNEC are presented in Tables 6 to 20.

Physiological responses during the three different camber angles

Tables 6 through 22 outline the means and standard deviations (S.D.'s) for the physiological responses and energy costs during each of the three different camber angles (0, 4, and 8 degrees), and baseline resting state.

When comparing each of the different camber angles, there was a significant difference between camber angles for the $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC, but not for the RER, $\dot{V}_I/\dot{V}O_2$, $\dot{V}_I/\dot{V}CO_2$, RPEC, and RPEL, for both age groups and genders. When the results were analyzed using post - hoc Scheffe` tests, it was apparent that the physiological responses at 8 degrees of camber were significantly higher than those observed at 0 and 4 degrees of camber each of these variables. While the majority of variables at 4 degrees of camber were not significantly higher than 0 degrees of camber, the RVO_2, RGEC and RNEC proved to be significantly higher at 4 degrees as compared to 0 degrees. While the differences in the physiological responses between 0 degrees and 4 degrees of camber were not significant for the remaining variables, it can be seen that the physiological responses for these variables were higher at the 4 degree camber angle than the 0 degree camber angle.

Age comparison of physiological responses during the three different camber sessions

In evaluating the effect that age had on the physiological changes observed during the tests with the three different camber angles, there were significant differences between age groups only for $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, NEC and RNEC. When the post - hoc Scheffe` tests were analyzed, it was noted that for the 0 degree camber angle, each of these variables demonstrated significant differences. For the 4 degree camber angle, all of the variables demonstrated significant differences between age groups, with the exception of RNEC. Lastly, at the 8 degree camber angle, only $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$ demonstrated significant differences between age groups.

However overall, subjects in the older group demonstrated higher responses on most of the variables, specifically: $A\dot{V}O_2$, $\dot{V}_E$, RER, O_2 pulse, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, RPEL, GEC, NEC and RNEC. While the differences between the age groups remained slight for $A\dot{V}O_2$, RER, O_2 pulse, RPEC, RPEL, GEC, NEC and RNEC, and did not achieve statistical significance, a more careful analysis of the data revealed a 27% to 67% difference in the RNEC between the two groups at the different camber angles, with the RNEC being higher in the older group.

Gender comparison of physiological responses during the three different camber sessions

When comparing the responses between gender for each camber angle, significant differences were found for $A\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, RPEC, RPEL, GEC and NEC. However, based upon post - hoc Scheffe` tests (Table 4), it was noted that males and females demonstrated significant differences on each of these variables for the camber angle of 0 degrees. However, at the camber angle of 4 degrees, males and females demonstrated significant differences only for the $A\dot{V}O_2$, O_2 pulse, and GEC, but not for $\dot{V}_E$, $\dot{V}CO_2$, RPEC, RPEL, and NEC. Finally, at the 8 degree camber angles, males and females demonstrated significant differences, once again, on all of these variables, with the exception of RPEL.

It should be noted that there was no consistent trend in the gender differences observed in this study. The females demonstrated lower values for $A\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC, while the males demonstrated lower values for the variables of HR, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC and RPEL. While no significant differences between males and females were demonstrated for HR, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RGEC, and RNEC it should be noted that some slight differences were observed, which may not be of clinical importance due to their small magnitude.

Table 6: **Comparison of Absolute Oxygen Consumption ($\dot{V}O_2$) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees‡	4 degrees‡	8 degrees‡
Young	**Males (n = 7)**	265 (70)	496 (126)	525 (154)*	621(274)§
	Females (n = 13)	226 (47)	383 (46)	398 (59)*	440 (59)§
Old	**Males (n = 12)**	277 (41)	568 (61)	570 (90)*	657 (80)§
	Females (n = 8)	210 (28)	434 (86)	509 (138)*	492 (127)§

S.D.'s - in parentheses
$\dot{V}O_2$ reported as ml/min, STPD.
† - denotes no significant differences between younger and older subjects for each gender
‡ - denotes significant differences between males and females for camber angles indicated
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 7: **Comparison of Relative Oxygen Consumption ($R\dot{V}O_2$) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees	4 degrees	8 degrees
Young	**Males (n = 7)**	3.8 (.5)	7.1 (.6)‡	7.4 (.5)*	8.6 (1.7)§
	Females (n = 13)	3.8 (.6)	6.5 (.6)‡	6.8 (.9)*	7.5 (.7)§
Old	**Males (n = 12)**	3.5 (.6)	7.1 (.8)‡	7.1 (.7)*	8.1 (.9)§
	Females (n = 8)	3.5 (.7)	7.3 (1.1)‡	8.0 (1.2)*	8.7 (1.8)§

S.D.'s - in parentheses
$R\dot{V}O_2$ reported as ml/kg/min
† - denotes no significant differences between younger and older subjects for each gender
↕ - denotes no significant differences between males and females in each age group
‡ - denotes significant differences between 0 and 4 degrees of camber
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 8: **Comparison of Heart Rate (HR) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	**Gender**‡	**Baseline**	**0 degrees**	**4 degrees**	**8 degrees**
Young	**Males (n = 7)**	73 (20)	87 (16)	88 (16)*	92 (15)§
	Females (n = 13)	79 (11)	91 (10)	90 (8)*	93 (9)§
Old	**Males (n = 12)**	69 (8)	86 (9)	87 (8)*	91 (10)§
	Females (n = 8)	76 (9)	95 (6)	97 (5)*	100 (5)§

S.D.'s - in parentheses
HR reported as beats/min
† - denotes no significant differences between younger and older subjects for each gender
‡ - denotes no significant differences between males and females in each age group
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 9: **Comparison of Minute Ventilation ($\dot{V}_E$) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees†‡	4 degrees†	8 degrees†‡
Young	**Males (n = 7)**	8.3 (2.5)	15.4 (2.5)	16.2 (3.7)*	18.8 (6.0)§
	Females (n = 13)	8.1 (2.1)	12.9 (2.5)	13.3 (2.8)*	14.5 (4.2)§
Old	**Males (n = 12)**	10.3 (2.2)	20.7 (3.0)	20.3 (3.8)*	24.2 (5.3)§
	Females (n = 8)	8.6 (1.0)	16.8 (4.6)	20.1 (6.6)*	18.9 (5.9)§

S.D.'s - in parentheses
$\dot{V}_E$ reported in L/min, BTPS.
† - denotes significant differences between younger and older subjects for camber angles indicated
‡ - denotes significant differences between males and females for camber angles indicated
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 10: **Comparison of Respiratory Exchange Ratio (RER) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees	4 degrees	8 degrees
Young	**Males (n = 7)**	.82 (.06)	.88 (.05)	.88 (.03)	.91 (.05)
	Females (n = 13)	.88 (.07)	.88 (.05)	.89 (.05)	.89 (.10)
Old	**Males (n = 12)**	.85 (.07)	.89 (.05)	.90 (.03)	.91 (.05)
	Females (n = 8)	.89 (.10)	.89 (.03)	.92 (.05)	.91 (.03)

S.D.'s - in parentheses
† - denotes no significant differences between younger and older subjects for each gender
‡ - denotes no significant differences between males and females in each age group

Table 11: **Comparison of Oxygen Pulse (O_2 pulse) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees‡	4 degrees‡	8 degrees‡
Young	**Males (n = 7)**	3.9 (1.6)	6.0 (2.3)	6.3 (2.5)*	7.0 (3.4)§
Young	**Females (n = 13)**	2.9 (.8)	4.3 (.6)	4.4 (.7)*	4.8 (.8)§
Old	**Males (n = 12)**	4.0 (.6)	6.6 (.6)	6.5 (1.2)*	7.3 (.9)§
Old	**Females (n = 8)**	2.8 (.5)	4.6 (1.0)	5.2 (1.5)*	5.0 (1.3)§

S.D.'s - in parentheses
O_2 pulse reported as ml/beat
† - denotes no significant differences between younger and older subjects for each gender
‡ - denotes significant differences between males and females for the camber angles indicated
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 12: **Comparison of Carbon Dioxide ($\dot{V}CO_2$) Production during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees†‡	4 degrees†	8 degrees‡
Young	**Males (n = 7)**	218 (64)	428 (97)	460 (130)*	556 (225)§
	Females (n = 13)	200 (51)	336 (47)	354 (59)*	390 (55)§
Old	**Males (n = 12)**	237 (51)	511 (70)	512 (86)*	599 (97)§
	Females (n = 8)	186 (25)	388 (80)	472 (152)*	446 (121)§

S.D.'s - in parentheses
$\dot{V}CO_2$ reported as ml/min
† - denotes significant differences between younger and older subjects for camber angles indicated
‡ - denotes significant differences between males and females for camber angles indicated
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 13: **Comparison of Ventilatory Equivalent for Oxygen ($\dot{V}_E/\dot{V}O_2$) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees†	4 degrees†	8 degrees†
Young	**Males (n = 7)**	31.2 (2.9)	31.7 (4.1)	31.6 (4.7)	31.4 (4.7)
	Females (n = 13)	35.9 (6.5)	33.5 (4.5)	33.4 (5.4)	32.9 (4.2)
Old	**Males (n = 12)**	37.4 (6.2)	36.8 (7.1)	36.5 (6.9)	37.0 (7.8)
	Females (n = 8)	41.5 (5.8)	38.6 (5.4)	39.4 (5.0)	38.2 (4.2)

S.D.'s - in parentheses
($\dot{V}_E/\dot{V}O_2$) reported as a ratio
† - denotes significant differences between younger and older subjects for camber angles indicated
‡ - denotes no significant differences between males and females in each age group

Table 14: Comparison of the Ventilatory Equivalent for Carbon Dioxide ($\dot{V}_E/\dot{V}CO_2$) during Simulated Wheelchair Exerercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)

Group†	**Gender‡**	**Baseline**	**0 degrees†**	**4 degrees†**	**8 degrees†**
Young	**Males (n = 7)**	38.6 (5.0)	36.6 (4.1)	35.9 (4.4)	34.7 (4.0)
	Females (n = 13)	40.8 (7.4)	38.4 (6.6)	37.5 (5.1)	37.1 (4.1)
Old	**Males (n = 12)**	44.0(7.0)	40.9 (7.7)	40.8 (7.7)	40.7 (8.1)
	Females (n = 8)	46.8 (3.9)	43.3 (6.1)	42.8 (5.4)	42.1 (4.4)

S.D.'s - in parentheses
($\dot{V}_E/\dot{V}CO_2$) reported as a ratio
† - denotes significant differences between younger and older subjects for camber angles indicated
‡ - denotes no significant differences between males and females in each age group

Table 15: **Comparison of Borg Ratings of Perceived Exertion for Central Factors (RPEC) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender	0 degrees*	4 degrees	8 degrees*
Young	**Males (n = 7)**	7.6 (1.0)	8.0 (1.5)	8.4 (1.9)
	Females (n = 13)	9.1 (1.4)	8.8 (1.6)	10.0 (1.8)
Old	**Males (n = 12)**	9.3 (1.2)	10.1 (1.8)	9.7 (1.5)
	Females (n = 8)	10.8 (1.4)	10.0 (1.7)	10.4 (2.0)

S.D.'s - in parentheses
† - denotes significant differences between younger and older subjects for respective genders
* - denotes significant differences between males and females (irrespective of age group) for indicated camber

Table 16: **Comparison of Borg Ratings of Perceived Exertion for Local Factors (RPEL) during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	0 degrees‡	4 degrees	8 degrees
Young	**Males (n = 7)**	8.9 (1.2)	9.3 (1.3)	10.3 (1.3)
	Females (n = 13)	10.8 (1.7)	10.5 (1.7)	11.4 (1.9)
Old	**Males (n = 12)**	10.0 (2.0)	10.5 (2.3)	10.3 (2.4)
	Females (n = 8)	11.6 (1.6)	11.0 (1.7)	11.4 (1.4)

S.D.'s - in parentheses
† - denotes no significant differences between younger and older subjects for respective gender
‡ - denotes significant differences between males and females for camber angle indicated

Table 17: **Comparison of Gross Energy Cost During Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees‡	4 degrees‡	8 degrees‡
Young	**Males (n = 7)**	1.3 (.3)	2.4 (.6)	2.6 (.7)*	3.1 (1.3)§
	Females (n = 13)	1.1 (.2)	1.9 (.2)	2.0 (.3)*	2.2 (.3)§
Old	**Males (n = 12)**	1.4 (.2)	2.8 (.3)	2.8 (.5)*	3.2 (.4)§
	Females (n = 8)	1.0 (.1)	2.1 (.4)	2.5 (.7)*	2.4 (.6)§

S.D.'s - in parentheses
Gross Energy Cost reported i : KCals/min.
† - denotes no significant differences between younger and older subjects for respective gender
‡ - denotes significant differences between males and females for camber angles indicated
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant di'ferences between 0 and 8 degrees of camber

Table 18: **Comparison of Relative Gross Energy Cost During Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	Baseline	0 degrees	4 degrees	8 degrees
Young	**Males (n = 7)**	18.3 (2.6)	34.7 (3.0)‡	36.4 (2.4)*	42.5 (7.8)§
	Females (n = 13)	18.8 (3.1)	31.9 (3.1)‡	33.2 (4.1)*	36.8 (3.7)§
Old	**Males (n = 12)**	16.8 (2.8)	34.7 (4.2)‡	34.4 (6.3)*	40.2 (4.52)§
	Females (n = 8)	17.0 (3.4)	34.4 (2.9)‡	43.4 (22.4)*	40.8 (5.2)§

S.D.'s - in parentheses
relative gross energy cost expressed as Cals/kg/min.
† - denotes no significant differences between younger and older subjects for each gender
‡ - denotes no significant differences between males and females in each age group
‡ - denotes significance between 0 and 4 degrees of camber
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

Table 19: **Comparison of Net Energy Cost During Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D's)**

Group†	Gender↕	0 degrees†↕	4 degrees†	8 degrees↕
Young	**Males (n = 7)**	1.2 (.3)	1.3 (.5)*	1.8 (1.0)§
	Females (n = 13)	.8 (.2)	.9 (.2)*	1.1 (.1)§
Old	**Males (n = 12)**	1.4 (.3)	1.4 (.4)*	1.9 (.5)§
	Females (n = 8)	1.1 (.4)	1.5 (.7)*	1.4 (.6)§

S.D.'s - in parentheses
Net energy cost reported as KCals/min

† - denotes significant differences between younger and older subjects for camber angles indicated
↕ - denotes significant differences between males and females for camber angles indicated
§ - denotes significance between 0 and 3 degrees of camber
* - denotes significance between 4 and 8 degrees of camber

Table 20: **Comparison of Relative Net Energy Cost During Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	0 degrees†	4 degrees	8 degrees
Young	**Males (n = 7)**	16.4 (2.0)ⁱ	18.1 (2.9)*	24.2 (8.1)§
	Females (n = 13)	13.2 (2.8)ⁱ	14.5 (3.7)*	18.0 (2.0)§
Old	**Males (n = 12)**	17.9 (5.7)ⁱ	17.6 (5.7)*	23.4 (5.2)§
	Females (n = 8)	17.4 (3.0)ⁱ	26.4 (20.5)*	23.1 (7.0)§

S.D.'s - in parentheses
relative net energy consumption expressed as Cals/kg/min
† - denotes significant differences between younger and older subjects for camber angles indicated
‡ - denotes no significant differences between males and females in each age group
ⁱ - denotes significanct differences between 0 and 4 degrees of camber
* - denotes significanct differences between 4 and 8 degrees of camber
§ - denotes significant differences between 0 and 8 degrees of camber

CHAPTER V
DISCUSSION

This study has evaluated the effect of one wheelchair design feature, rear wheel camber, on physiological and perceptual responses in younger and older males and females.

COMPARISON OF RESULTS TO THE LITERATURE

The results of this study were generally consistent with previous findings. During the present study, mean $A\dot{V}O_2$ ranged from .38 L/min (± .05) in the young females to .66 L/min (± .08) in the older males. These values are similar to that of Glaser, et al. (1983) who obtained .53 L/min in a similar wheelchair ergometer exercise with a combined sample of males and females, some of whom were wheelchair users and some who were not, and Veeger, et al. (1989) who demonstrated $A\dot{V}O_2$ to be approximately .70 L/min. for wheelchair exercise performed at a rate of 2 kmh using male, non-wheelchair user subjects. More importantly, the results of Veeger, et al. (1989) were derived during testing of wheel camber. Although these are slightly higher, it must be noted that additional weight was added to the wheelchair during the trials, and therefore, total power output would have been greater, thereby accounting for the increased oxygen cost. Finally, the $A\dot{V}O_2$(s) obtained during the present study also compared favourably with those of the wheelchair bound male subjects of van der Woude, et al. (1988), who reported a value of .5 L/min range for a similar exercise.

The results obtained for HR (86 beats/min ± 9 to 100 beats/min ±5) and $\dot{V}_E$ (12.9 L/min ± 2.5 to 24.2 L/min ± 5.3), are consistent with those obtained by van der Woude, et al. (1988) who reported values of 80 to 100 beats/min for

HR and approximately 12 to 22 L/min for $\dot{V}_E$. The results obtained in the present study were also similar to those obtained by Glaser, et al. (1983) who reported values of 94.6 beats/min for HR, and 19.6 L/min for $\dot{V}_E$, and those of Veeger, et al. (1989) who reported HR(s) of 90 to 95 beats/min for similar a exercise.

Therefore, based upon the literature available, the results derived from this study were consistent with those obtained by other researchers who have performed similar exercise tests.

THE EFFECTS OF CAMBER

From the data presented in the previous chapter, it can be seen that rear wheel camber did in fact, have a significant effect on $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC. Camber did not appear to have a significant effect, however, on RER, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC and RPEL.

Physiological responses and energy costs

It was demonstrated that camber has a significant effect on $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC. Interestingly enough, the NEC for propelling a wheelchair at 8 degrees of camber was significantly higher than that of propelling the same wheelchair at either 0 or 4 degrees of camber. Specifically, the cost of propelling a wheelchair at 8 degrees of camber ranged from 27.3% to 50.0% higher than propelling the same wheelchair at 0 degrees of camber, and the cost of propelling a wheelchair at 8 degrees of camber was anywhere from 6.7% less to 38.5% higher than 4 degrees of camber, with the majority of subjects expending a

Table 21: **Proportionate Mean Change (%) in Net Energy Consumption during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group	Gender	0 to 4 degrees	4 to 8 degrees*	0 to 8 degrees*
Young	**Males (n = 7)**	8.3%	38.5%	50.0%
	Females (n = 13)	12.5%	22.2%	37.5%
Old	**Males (n = 12)**	0.0%	35.7%	35.7%
	Females (n = 8)	36.4%	-6.7%	27.3%

S.D.'s - in parentheses
* - denotes significant increases for the cambers indicated

greater amount of energy (Table 21). While only a few significant differences were demonstrated between 0 degrees and 4 degrees of camber, it is worthwhile to note that overall increases occurred across all variables during the propulsion of the wheelchair at 4 degrees of camber, when compared to 0 degrees of camber. These values represented anywhere from a 0% change at 4 degrees of camber to as much as 36.4% more NEC to propel the wheelchair at 4 degrees of camber, with increased NEC being the norm. Only RGEC, RNEC and $R\dot{V}O_2$ demonstrated significant differences between the cambers of 0 and 4 degrees.

It is evident that camber significantly affects the physiological cost of wheelchair propulsion. Despite the fact that numerous significant differences were not demonstrated between the camber angles of 0 and 4 degrees, it should be remembered that the exercise was performed at a low velocity of 2 kmh. This velocity may not have been sufficient to induce large differences among the camber angles tested. The fact that there were very significant differences between the levels of 0 and 8 degrees, and 4 and 8 degrees at such a low exercise intensity leads one to question the effect that a higher level of exercise intensity would have in generating larger proportionate increases in physiological demand. Additionally, the low intensity of exercise might also explain why the RER and RPE did not demonstrate significant differences among camber angles.

Although non-significant results were also demonstrated for $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, it should be noted that the $\dot{V}_E/\dot{V}O_2$ ratio is considered to representation of the economy of ventilation during an exercise (Bhambhani, et al., 1994). Therefore, a significant change in these variables would not necessarily be demonstrated during a low intensity exercise such as the one employed during this study, particularly since the velocity at which the exercise was performed remained constant. Since these variables are simply expressed as a ratio between $\dot{V}_E$ and $A\dot{V}O_2$ and $\dot{V}CO_2$, little change in the economy of ventilation ($\dot{V}_E/\dot{V}O_2$) and the $\dot{V}_E/\dot{V}CO_2$ ratio would have been expected among different camber angles. Since the $\dot{V}_E$, $A\dot{V}O_2$ and $\dot{V}CO_2$ all demonstrated significant, but consistent increases with increasing camber, it is not surprising to conclude that these two ratios were unchanged under these conditions. Thus, based upon the present study, it is reasonable to conclude that the economy of ventilation is not affected by a change in the camber angle during wheelchair exercise at a low velocity.

These results clearly indicate that physiological cost increases with increasing camber. It is important to remember that while the majority of variables did not demonstrate statistical significance between 0 and 4 degrees of camber, the increases which were observed might be clinically significant during periods of extended wheelchair use, or higher velocities.

Perceptual responses

It has been noted that significant differences were not demonstrated for RPEC or RPEL. In relation to the Borg RPE(s), in general, slight increases were noted with increasing camber. However, some of the groups (older males and females) did indicate a downward trend as camber increased. This would lead the author to conclude that there were no consistent changes with regard to camber when all groups were considered together.

These results are particularly interesting from a number of perspectives. Firstly, it has been hypothesized that increased camber leads to a greater mechanical advantage (Brubaker et al., 1984; Cerquiglini et al., 1984). However, despite what appears to be a greater mechanical advantage in terms of hand-rim interface, and an increased angle of shoulder abduction, it would appear from the results of this study that this does not translate into reduced physiological cost. In fact, the energy cost is actually increased.

Secondly, while it may appear that the mechanical advantage is actually compromised, it is important to consider the effect or the counter effect that a change in the rolling resistance has on the mechanical advantage. That is, it is possible that the effects of changing the rolling resistance by increasing the rear wheel camber actually negates and possibly, supersedes any mechanical advantage that is gained through the introduction or alteration of rear wheel camber angle. Thus, from the results of this study, it would seem that the 5% increase that occurs in rolling resistance when camber is changed by 10 degrees (O'Reagan et al., 1981) is, in fact, significant enough to cause changes in the physiological demands of the task. However, it is possible that at higher exercise intensities or self-selected velocities, the mechanical advantage may indeed outweigh the effects of rolling resistance, thereby increasing the efficiency of wheelchair propulsion.

Thirdly, the results of this study lead the author to question just what exactly causes elite wheelchair athletes to choose increased camber angles for participatory sports and activities of daily living, if there is no demonstrable benefit. Although it can be seen from the RPE that no significant differences occur among camber angles, it is possible that at a higher exercise intensity, the introduction of increased camber angles may be perceived as easier to propel, and therefore, leads wheelchair athletes to select increased camber angles. Additionally, it should be noted that although the changes in RPE were not significant, a large majority of the participants indicated that the higher the camber angle, the easier the wheelchair was to propel, in terms of local muscle fatigue. This was in spite of the fact that they rated the cardiorespiratory stress as higher.

Fourthly, this subjective impression from the participants brings the Borg ratings themselves under scrutiny, particularly when used for rating local factors as Pandolph (1983) has suggested. Based upon the results obtained in this study, it would seem that during upper body work, such as that required to propel a wheelchair, it is not that easy to separate the local factors from the central factors which affect the perceptual responses.

In summary, the perceptual responses observed during this study did not demonstrate any significant differences among camber angles. However, some slight increases were noted with increasing camber, which might be of clinical importance during periods of extended use, or under differing wheeling conditions.

THE EFFECTS OF AGE

Physiological responses and energy cost

Age had a significant effect on the following physiological responses at the different camber angles: $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, NEC and RNEC. Interestingly, every one of the aforementioned variables displayed significant differences between the younger and older age groups at the camber angle of 0 degrees camber. At 4 degrees of camber, significant differences were once again displayed for each variable, with the exception of RNEC, which was not significant. Finally, at 8 degrees of camber, only $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$ demonstrated significant differences, while $\dot{V}CO_2$, NEC, and RNEC did not. This indicated that while there are significant differences between the younger and older groups in their physiological responses to changing camber angles, these differences tend to disappear as the camber angle increases. Thus, at the lower camber angles, the differences between the groups were more evident than at the higher camber angles, where the differences tended to even themselves out.

A more careful consideration of the differences in the variables indicated that differences existed between the two age groups particularly in regards to the $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$ ratios. Since $\dot{V}_E/\dot{V}O_2$ is indicative of the economy of ventilation (Bhambhani, et al., 1994), it appeared that the older group displayed a reduced economy of ventilation during the propulsion of the wheelchair, regardless of the camber angle introduced, and that the economy of ventilation did not balance out between the two groups as the camber angles increased.

However, the remaining variables, namely, $A\dot{V}O_2$, $R\dot{V}O_2$, HR, RER, O_2 pulse, GEC, and RGEC, while displaying some effect on the physiological responses, did not demonstrate any statistically significant differences between the younger and the older age groups. While the increases were not statistically significant, they may be of clinical importance. A cursory review of the data revealed that overall, the older group demonstrated slightly higher, but not statistically significant, responses for $A\dot{V}O_2$, RER, O_2 pulse, $\dot{V}CO_2$, and GEC, irrespective of gender. The differences between the age groups were minimal, and most likely present from the very outset of this study.

It is also possible that $A\dot{V}O_2$, $R\dot{V}O_2$, HR, RER, O_2 pulse, GEC and RGEC did not achieve statistical significance during this study as a result of extremely low testing speeds. However, it is likely that similar trends in the physiological responses would occur regardless of a change in speed. Therefore, any idea that it may not always be necessary to evaluate wheelchair design factors for different age groups should be examined with caution.

This was a particularly interesting aspect of this study, in terms of its importance to the development and design of wheelchairs for the elderly. Very few studies existed which evaluated the effect of different wheelchair design features on the elderly because this particular population is difficult to study, find homogeneity, and avoid taking unnecessary risks with respect to existing medical conditions.

In examining the data further, however, it can be noted that NEC and RNEC (Tables 19 & 20) for the older group, when compared to the younger group seems to be more notable than the other variables. This may have particular clinical significance which should be considered when evaluating and designing wheelchairs for the elderly population. From this data, at least it can be concluded that the energy cost of propelling the same wheelchair at different camber angles, is indeed higher for the older population, for whatever reason.

Additionally, it was noted that the older group attained a higher proportion of their predicted maximum HR than did the younger group (Table 22). While there were known to be significant differences in the age between the two groups, a significant difference in the proportionate HR maximum achieved was not unexpected, and it should be noted that absolute HR(s) in general, did not differ significantly between the two groups. Although the total energy cost of propelling a wheelchair were the same for both younger subjects as compared to older subjects, it must be remembered that the maximum $A\dot{V}O_2$ attainable declines with age (McArdle et al., 1991). Therefore, as the maximum $A\dot{V}O_2$ declines, the amount of energy required to complete a task, while unchanged, represents a greater proportion of the energy available for that task. What is important, is that the older group was using <u>more</u> of their maximum available energy than the younger group.

Table 22: **Percentage of Predicted Heart Rate Maximum Achieved during Simulated Wheelchair Exercise at Three Different Camber Angles in Younger and Older Males and Females (means & S.D.'s)**

Group†	Gender‡	0 degrees†‡	4 degrees†‡	8 degrees†
Young	**Males (n = 7)**	44.6 (7.0)	45.2(7.1)*	47.4 (6.4)✢
	Females (n = 13)	46.4 (4.9)	46.2 (4.1)*	47.6 (4.5)✢
Old	**Males (n = 12)**	53.8 (6.5)	54.1 (5.0)*	56.5 (7.0)✢
	Females (n = 8)	57.9 (5.0)	59.6 (4.7)*	60.8 (5.8)✢

S.D.'s - in parentheses
† - denotes significant difference between younger and older subjects for each gender
‡ - denotes no significant difference between males and females in each age group
✢ - denotes significance between 0 and 8 degrees of camber
* - denotes significance between 4 and 8 degrees of camber

Therefore, these observations suggest that the relative cardiorespiratory and metabolic stress was higher in the older group as compared to the younger one. This may have implications when considering the endurance of older subjects.

Despite the findings of this study with regard to age groups, cautious interpretation is necessary. It should be remembered that the older participants involved in this study were all relatively healthy, and while they considered themselves to be sedentary, they were still involved in active daily living tasks. This is not necessarily the population that will generally be utilizing wheelchairs. For the most part, it is individuals who are infirm and suffering from a variety of health problems that are wheelchair dependent. It is likely that the reduced fitness levels of these subjects could compromise their ability to use a wheelchair.

Additionally, none of the participants in this study, from either group were actually wheelchair users, and therefore, the generalization of these results to all possible populations is not possible.

Perceptual responses

During this study, significant differences between the younger and older subjects were noted for RPEC, but not for RPEL. A cursory review of the data indicated that the older subjects demonstrated higher responses for both RPEC and RPEL, although the latter did not achieve statistical significance. Closer examination of RPEC revealed that these values were significantly different between the younger and older groups at the camber angles of 0 and 4 degrees, but not at 8 degrees of camber.

The results obtained for RPEC are consistent with the physiological differences noted above, in that the higher RPEC ratings reflect the increased energy cost and relative stress discussed earlier. It is interesting to note, however, that at the camber angle of 8 degrees, it appeared that the differences between the two age groups tended to become less apparent. This would appear to indicate that as the task of wheelchair propulsion became more difficult, both groups perceived the task as similar in terms of central fatigue.

EFFECTS OF GENDER

Physiological responses and energy cost

Based on the findings of this study, it can be seen that gender had a significant effect upon the $A\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, GEC, and NEC for the camber angles evaluated during this study. In analyzing the post - hoc tests, it was seen that males and females differed significantly on each of these variables for the camber angle of 0 degrees. However, at the camber angle of 4 degrees, males and females differed significantly only for $A\dot{V}O_2$, O_2 pulse, and GEC, while $\dot{V}_E$, and NEC did not demonstrate significant differences between males and females. Interestingly, at 8 degrees of camber, males and females once again differed significantly on all of the aforementioned variables. It was noted that while males and females responded differently at the different camber angles, they responded in the same manner regardless of the group they were in. In regards to the all of the physiological variables mentioned, it was noted that females tended to demonstrate lower values, while males tended to display higher values.

It should also be noted that there were differences overall between the genders which were <u>not</u> statistically significant, which should be addressed herein because they may be of clinical importance. For the $A\dot{V}O_2$, $\dot{V}_E$, O_2

pulse, $\dot{V}CO_2$, GEC, RGEC, NEC, and RNEC, women in general demonstrated lower responses than did males. This is particularly of concern due to the fact that in numerous research studies, males have been consistently demonstrated to perform better than women, particularly in maximal exercise tasks. However, it should be remembered that these studies often employ maximal performance tasks, rather than tasks of such low intensity as was utilized in this study. The results obtained during this study might imply that at a given submaximal exercise level, females may be more efficient better than males. Additionally, the task of wheelchair propulsion employed in this study represented submaximal exercise, and therefore, the higher values for males might have been more indicative of their larger body size than their female counterparts. Males, however, demonstrated lower responses for HR, $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$. The lower results for women observed during this study may be representative of the fact that women tend to use their upper bodies on a more regular basis for daily living tasks, such as mopping, cleaning, secretarial work, etc., which may have some carry over effects for lower intensity levels of work, such as that required for propulsion of a slow moving wheelchair. While proof of this would be difficult to find, it should be noted here that studies by Glaser et al. (1983), Hilbers (1987), and Hildebrandt et al. (1970) used mixed samples within their research, and did not note differences related to gender on low intensity wheelchair propulsion tasks.

In regard to the variables on which males performed at a significantly lower rate than females, such as HR, $\dot{V}_E/\dot{V}O_2$, and $\dot{V}_E/\dot{V}CO_2$ it is possible to somewhat explain these results. For example, men in general, may demonstrate an improved level of cardiorespiratory fitness as a result of the nature of vocational selection. That is to say, men may be involved in heavier tasks by nature of their work, or the type of daily living tasks which they are required to perform, thus having accounted for the lower HR levels.

In summary, this study demonstrated statistically significant differences between genders on some, but not all, physiological variables during wheelchair propulsion. Additionally, some differences which were not significant, while small, were found between males and females on the remaining variables, and may represent some undefined clinical significance.

Perceptual responses

In evaluating RPEC and RPEL, it was noted that females tended to report significantly higher values than did their male counterparts.

It is somewhat difficult to interpret why this difference might be evidenced. However, when the variable of RPEL is considered, it is possible that men tend to rate local factors somewhat lower than women, due to their greater muscle strength, which could enable them to perceive the work as being lighter. This view is supported by the study of Bishop et al. (1987) who analyzed strength differences between males and females, and concluded that there were differences between strength in equally trained men and women, and that those strength differences could be almost entirely attributed to the difference in muscle size. It is likely that given the smaller muscle mass available in the female, and the apparent inability to totally isolate central factors from the local factors (Pandolph, 1983), caused the females to rate their exertion level as higher than that of their male counterparts.

A further concern relates to RPEC. It is of particular note that the physiological differences found between males and females for the other variables seemed to indicate that the task of propelling the wheelchair was easier for the females than the males, as females tended to display lower responses, yet RPEC tended to be higher for the females. Perhaps an explanation for these results lies in the research of Shephard, Vandewalle, Gil, Bouhlel, & Monod (1992) who suggested that if the active muscle mass being employed is small, the dominant component of the perception of exertion becomes principally peripheral and muscular. Interpreted, this would mean that peripheral or local factors play a more active role in the overall RPE. If this were extrapolated to the results obtained during this study, it is likely that the smaller muscle mass exhibited by the females had an impact upon the RPEC as well as RPEL.

IMPLICATIONS FOR REHABILITATION

This study has raised some interesting concerns, particularly for rehabilitation professionals who are not only designing wheelchairs for the disabled population, but also for those who are involved in the prescription, provision and purchase of wheelchairs for this population.

From the information which has been generated in this study, it can be seen that increased wheelchair camber also increases the physiological cost, and therefore, the provision and design of wheelchairs for the medically compromised individual should be considered carefully and cautiously, so as not to put undue stress on the cardiorespiratory system. While in some cases increasing the demand on the cardiorespiratory system might be advisable to facilitate increased fitness and reduce the risk of ailments related to inactivity, for others, this could almost represent a traumatic, unnecessary physical demand leading to further medical complications.

The current observations may also be important from the perspective of the elite disabled athlete. For quite some time, it has been believed that increased wheelchair camber diminishes the physiological cost of propulsion, while at the same time providing more stability. However, the results of this study have not substantiated this claim. Rather, this study has demonstrated that increased camber results in a greater physiological cost, and therefore, the only possible advantage to be gained is increased stability. However, it is important for athletes, coaches and the rehabilitation professionals involved with these sports to consider which is paramount for the actual execution of the task. Perhaps for wheelchair sprinting, it may not be necessary to have extra stability, but rather, to have maximal physiological resources available in order to achieve the end goal. While this study did not come close to approximating the speeds at which a disabled athlete would propel a wheelchair during competition, it would be interesting to evaluate whether or not the same results would hold true.

From the results of this study, it can also be noted that while subjects believed that it was easier to push the wheelchair with increased camber angles, this did not, in fact, prove to be the case. Therefore, it is important for rehabilitation professionals and athletic advisors to be familiar with the true nature of the task demands, so that they may advise both patients and athletes accordingly in regards to the selection of an optimal piece of equipment. Accordingly, judging from the extremely high numbers of athletes who employ wheelchairs with acute camber angles, and subsequently report these wheelchairs as being easier to use, it is apparent that Pandolph's theory (1983) that local factors play a larger role than was previously believed, has some validity.

Finally, this study calls into question the validity of using the Borg scale for upper body exercise, and the differentiation between central and local factors when using the scale to rate perceived exertion. In particular, it was interesting to note that while RPEC increased with increasing camber, as did RPEL, subjects reported after testing that the increased cambers "felt" easier to propel, but the statistical analysis did not bear this out. Therefore, this would call into question either the validity of the scale, or the validity of using the scale to differentiate between central and local factors, as Pandolph has suggested (1983). Additionally, this would also cause speculation as to whether or not the effects of local factors have either a moderating or cancelling out effect upon the overall or the cardiorespiratory perception of exertion, as has been suggested by Shephard, et al. (1992). This should have implications for researchers attempting to use this scale for ongoing research, or in the design of wheelchairs. It is extremely interesting to note that while the clinical ratings did not differentiate between camber angles, verbal reports of the patients indicated that there was a difference, and yet this was not captured in the data collected. Additionally, it can be seen that at low levels of exercise intensity, it does not have superior ability to detect differences in the physiological costs, and therefore, may only be useful for activities which have the potential to generate large and dramatic effects. Therefore, it is important that researchers continue to search for a tool which has the ability to adequately and reliably measure perceived exertion for tasks which are part of the everyday repertoire, and for which equipment has been specifically designed for.

CHAPTER VI
SUMMARY AND CONCLUSIONS

This study evaluated the effects of three different rear wheel cambers on the physiological responses of males and females in two different age groups. Instruments which were employed during this study consisted of a Quickie GPS wheelchair, custom designed roller system, Metabolic Measurement Cart (MMC), Polar wireless heart rate monitors, and the Borg scale for ratings of perceived exertion (RPE). Following a careful subject screening procedure, 20 younger subjects (7 males, 13 females) and 20 older (12 males, 8 females) who were apparently healthy, sedentary non-wheelchair users were required to propel a wheelchair on the customized roller system at a constant rate of 2 kmh, for three different camber angles (0, 4, and 8 degrees). Camber testing sessions were interspersed with rest periods, and wheel camber angles were randomly assigned. During the study, $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, RER, O_2 pulse, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}O_2$, RPEC, RPEL, GEC, RGEC, NEC, and RNEC were monitored.

In this study, it was demonstrated that rear wheel camber had a significant effect on the physiological cost of wheelchair propulsion. In general, it was demonstrated that as camber angle increased, the physiological energy cost also increased. Specifically, variables such as $A\dot{V}O_2$, $R\dot{V}O_2$, HR, $\dot{V}_E$, RER, O_2 pulse, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, RPEL, GEC, RGEC, NEC, and RNEC all demonstrated increases with increasing camber angles. The changes were statistically significant at 8 degrees of camber as compared to 0 degrees, and as compared to 4 degrees of camber. However, only $R\dot{V}O_2$, RGEC, and RNEC were significantly different at 4 degrees of camber as compared to 0 degrees of camber. Other factors such as age and gender did have a significant effect upon some, but not all of the physiological and perceptual responses to increased camber angle. Increased age demonstrated a significant effect on $\dot{V}_E$, $\dot{V}CO_2$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$, RPEC, NEC and RNEC, while gender had a significant effect on the $A\dot{V}O_2$, $\dot{V}_E$, O_2 pulse, $\dot{V}CO_2$, RPEC, RPEL, GEC, and NEC, with females demonstrating lower physiological responses and males demonstrating lower perceptual responses. In summary, the conclusions which were drawn from this study were: (1) increased wheelchair camber elevates the physiological stress and energy costs of ambulation, but not the perceived stress in younger and older subjects of both genders, (2) physiological and perceptual stress during wheelchair propulsion is significantly higher in older than in younger subjects, regardless of gender, when maximal physiological capacity is taken into consideration, and (3) there is no significant gender differences in the energy cost of wheelchair propulsion in younger and older subjects.

Thus being the case, it is important that rear wheel camber angle be considered when prescribing wheelchairs for the disabled population. Although it is commonly believed that increased rear wheel camber requires less energy to propel, this study has demonstrated the opposite, and therefore, these results should be taken into consideration during the provision of wheelchairs for a population who can least afford to increase their energy demand. Additionally, this study lends support to the idea that the higher the camber angle, the greater the physiological demands, and therefore, there is more risk of the disabled user being unable to propel the wheelchair or to fatigue prematurely due to the increased energy requirements. This could lead to increased health care costs through causing disabled wheelchair users to be unable to independently wheel their own wheelchairs. Additionally, it is also important that the wheelchair user's age and gender be considered in the prescription process. While certain wheelchairs may prove to be more fitting for the younger population, these same wheelchairs may be unsuitable for the older individual, and detrimental to their health. Although wheelchair design studies have not typically compared the responses or effects of use on younger subjects as opposed to older subjects, this is an area which requires further study. So too, should the research focus on more specific differences in response to wheelchair design between males and females, as it remains to be seen how this might affect the choice of one wheelchair over another.

In closing, it is recommended that wheelchair design features be evaluated carefully, and more frequently using non - disabled individuals, rather than disabled athletes. While the results of this study have shown differences in physiological and energy costs between age groups, it should be noted that these results cannot easily be extrapolated to special populations, or those with varying degrees of physical impairment or handicap. Thus, it is essential that similar studies be conducted using different populations, so that a thorough understanding of the effects of wheelchair design on the energy costs of ambulation can be reliably determined.

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APPENDICES

APPENDIX A
Wheelchair Rear Wheel Camber

Copyright permission to reproduce diagram could not be obtained prior to publication. Therefore, the source for this reference is listed below:

- rear wheel camber expressed as Wa: the angle of the wheelchair tire in relation to perpendicular.

Excerpted From: Higgs, C. (1983). An analysis of racing wheelchairs used at the 1980 Olympic games for the disabled. Research Quarterly for Exercise and Sport, 54, p. 230

APPENDIX B
LIST OF ABBREVIATIONS USED IN THIS STUDY

$A\dot{V}O_2$ - Absolute oxygen consumption (ml/min)

$R\dot{V}O_2$ - Relative oxygen consumption (ml/kg/min)

HR - heart rate (beats/min)

$\dot{V}_E$ - minute ventilation (L/min)

RER - respiratory exchange ratio

O_2 pulse - oxygen pulse (ml/beat)

$\dot{V}CO_2$ - carbon dioxide production (ml/min)

$\dot{V}_E/\dot{V}O_2$ - ventilatory equivalent for oxygen

$\dot{V}_E/\dot{V}CO_2$ - ventilatory equivalent for carbon dioxide

RPEC - rating of perceived exertion (central factors)

RPEL - rating of perceived exertion (local factors)

GEC - gross energy cost (KCals/min)

RGEC - relative gross energy cost (Cals/kg/min)

NEC - net energy cost (KCals/min)

RNEC - relative net energy cost (Cals/kg/min)

APPENDIX C
INTRODUCTORY INFORMATION FOR PARTICIPANTS

During the months of May and June 1994, I will be conducting a research study on the effects of wheelchair design features on younger and older persons. Specifically this study will evaluate the angle of the wheels on how the body performs.

I am looking for persons aged 19-44 or 45-75 years old to be part of this study. You will be asked to participate in one study session, approximately 1 1/2 hours to 2 hours long. During the session, you will be asked to wear a heart rate monitor, and a breathing mask so that your body's responses may be measured. The session itself will require that you propel a wheelchair while sitting in it, at a rate of 2 km/hr., for 4 different times (10 minutes each). The total amount of time that you will be required to push the wheelchair is 35 minutes. You will be given rest periods in between each session.

In order to be a participant, you must be:

- within the age group
- free from heart disease
- relatively inactive, and not participating in any aerobic fitness program

You will be paid $20 for your participation, in order to cover parking and travel expenses.

If you are interested in participating, please contact:

Shelley Buckley
2-64 Corbett Hall
Department of Occupational Therapy
University of Alberta
492-2499

NOTE: If you decide to participate, please void consuming large amounts of food and liquids prior to attending.

APPENDIX D

PAR - Q Form

Excerpted from: British Columbia Ministry of Health and the Department of National Health & Welfare (1978). Standardized Test of Fitness. Ottawa: Government of Canada, Fitness and Amateur Sport. p. 2.

PAR Q & YOU

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life.

For most people physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read them carefully and check (√) the ☐ YES or ☐ NO opposite the question if it applies to you.

YES	NO	
☐	☐	1. Has your doctor ever said you have heart trouble?
☐	☐	2. Do you frequently have pains in your heart and chest?
☐	☐	3. Do you often feel faint or have spells of severe dizziness?
☐	☐	4. Has a doctor ever said your blood pressure was too high?
☐	☐	5. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
☐	☐	6. Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
☐	☐	7. Are you over age 70 and not accustomed to vigorous exercise?

If You Answered

YES to one or more questions

If you have not recently done so, consult with your personal physician by telephone or in person BEFORE increasing your physical activity and/or taking a fitness test. Tell him what questions you answered YES on PAR-Q, or show him your copy.

programs

After medical evaluation, seek advice from your physician as to your suitability for:

- unrestricted physical activity, probably on a gradually increasing basis.
- restricted or supervised activity to meet your specific needs, at least on an initial basis. Check in your community for special programs or services

NO to all questions

If you answered PAR-Q accurately, you have reasonable assurance of your present suitability for:

- A GRADUATED EXERCISE PROGRAM - A gradual increase in proper exercise promotes good, fitness development while minimizing or eliminating discomfort.
- AN EXERCISE TEST - Simple tests of fitness (such as the Canadian Home Fitness Test) or more complex types may be undertaken if you so desire.

postpone

If you have a temporary minor illness, such as a common cold.

* Developed by the British Columbia Ministry of Health. Conceptualized and critiqued by the Multidisciplinary Advisory Board on Exercise (MABE). Translation, reproduction and use in its entirety is encouraged. Modifications by written permission only. Not to be used for commercial

APPENDIX E
ACTIVITY QUESTIONNAIRE

Participant:____________________

ACTIVITY QUESTIONNAIRE

1. During the last 2 weeks, how many times did you perform the following tasks around your home? Please indicate the amount of time you spent at each of these tasks (in minutes).

Activity	How often	Minutes(total)
(a) mowing the grass	(__)	(__)
(b) shovelling snow/dirt	(__)	(__)
(c) cleaning floors	(__)	(__)
(d) raking leaves	(__)	(__)
(e) gardening	(__)	(__)
(f) making beds	(__)	(__)
(g) carpentry	(__)	(__)
(h) handyman work	(__)	(__)
(i) ironing	(__)	(__)
(j) other (specify)	(__)	(__)

2. During the last 2 weeks, how many times did you engage in any of the following activities, and for how long on each occasion?

Activity	How often	Minutes(total)
(a) walking	(__)	(__)

average distance each time? ____________		
(b) jogging or running	(__)	(__)
average distance each time? ____________		
(c) calisthenics	(__)	(__)
(d) bicycling	(__)	(__)
(e) bowling	(__)	(__)
(f) vigorous dancing	(__)	(__)
(g) skating	(__)	(__)
(h) skiing	(__)	(__)
(i) curling	(__)	(__)
(j) racquet sports	(__)	(__)
(k) baseball/softball	(__)	(__)
(l) other sports	(__)	(__)
(m) golf	(__)	(__)
(n) swimming	(__)	(__)
(o) other (specify)	(__)	(__)

3. If you are still currently employed, how many hours of the day do you work, and how would you describe your work (in terms of activity): light, medium, or very active? Do you perform any lifting?

APPENDIX F

Consent Form

Title: Effects of Wheelchair Camber on Physiological Parameters

The purpose of this project is to determine the effect of rear wheel camber (the angle of rear wheels) on physiological responses. Specifically, this study will examine how the angle of rear wheels on a wheelchair effects how much air you breathe, how efficiently your body uses that air, and your heart rate. In addition, you will be asked to rate the difficulty of the task on a scale of 6-20.

You will be asked to participate in one study session which will consist of:

(a) a familiarization period - during which you will be asked to practice wheeling a wheelchair for 5 minutes with breathing apparatus and heart rate electrodes on.

(b) 3 camber sessions - during which the researcher will adjust the camber to 3 different settings and then request that you wheel the wheelchair for a period of 10 minutes for each different camber, at a rate of 2 km/hr. During this time, you will have the breathing apparatus and heart rate electrodes attached.

(c) 4 rest periods - during which you will be given 15 minute rest breaks to allow your physiological responses to return to normal. The rest breaks will occur between each different camber session.

The entire test is expected to take a total of 1 1/2 - 2 hours of non - continuous exercise.

Although people do not normally experience discomfort, some dryness around the mouth from the breathing apparatus, or some fatigue from the exercise itself. However, the discomfort, if any, should be minimal.

You will be reimbursed for parking and travel costs related to this study.

Principal Investigator: Shelley M. Buckley
Department of Occupational Therapy
2-64 Corbett Hall
University of Alberta
492 -2499

Supervisor: Dr. Y. Bhambhani
Dept. of Occupational Therapy
University of Alberta
Edmonton, Alberta
492 - 7248

CONSENT:

I, ______________________________, agree to participate in
(name)
the project described above.

I understand that my participation is voluntary.

I understand that I may withdraw from the study at any time, without any repercussions.

I may stop the test at any time.

I understand that I will be reimbursed for parking and travel costs associated with this study.

I am aware that although I may not directly benefit from this study, the information that is gathered here will be beneficial for rehabilitation engineers, wheelchair designers, and to rehabilitation professionals who prescribe wheelchairs for disabled individuals, especially in geriatric settings.

I understand that all information gathered here is confidential, and that the information related to myself will be treated confidentially. My name will not appear on any documentation, but will be coded for identification purposes.

I understand that only the researcher and her advisor will have access to the information gathered.

My name will not be associated with any publications arising from this research.

By signing this consent form, of which I will receive a copy, I have indicated my willingness to participate in this study.

Subject:____________________ Date:________________

Researcher:__________________ Date:________________

APPENDIX G
DATA COLLECTION FORM

DATE:

PARTICIPANT:

STUDY ID#:

ADDRESS:

TELEPHONE #:

HEIGHT(cms):

AGE(yrs.):

WEIGHT(kgs):

TRAINING STATUS:

CAMBER TESTING ORDER:

AXIS LENGTH(cms):

TIRE PRESSURE(psi):

APPENDIX H
Study Wheelchair - Quickie GPS

One of the advantages of this particular wheelchair is the ease of adjustment of camber. Due to the engineering design feature of pre-formed, rigid cross-braces, with machine engineered camber angles being built in, there is no allowance for error in changing between cambers, and therefore, no extraneous effects can be expected due to maladjustment of camber.

In addition, it should be noted that these changes in camber are achieved through the use of a bent-angle cross brace, which also controls for the effects of von Mises forces through the cross-braces, by guaranteeing that the moment of force through the cross bracing remains constant, regardless of the camber angle.

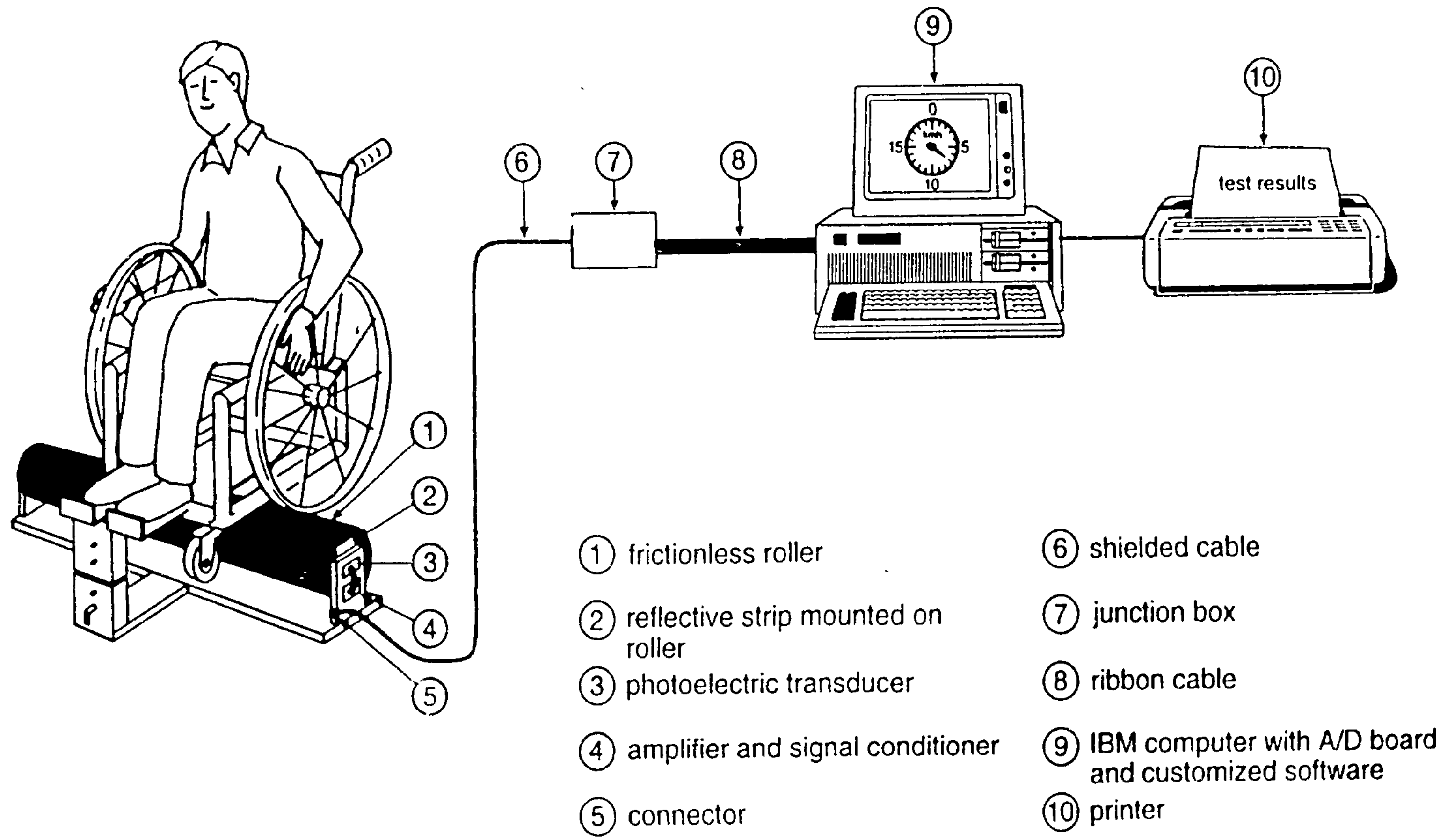
Therefore, threats to external validity will be controlled through the use of this particular model of wheelchair as opposed to employing any other model of wheelchair.

The wheelchair allows for the study of rear wheel camber angles of 0, 4, and 8 degrees.

Tire pressure will be controlled for by maintaining tire pressure constant according to the manufacturer's suggested guidelines. Pressure will be monitored using a bicycle tire pressure gauge.

APPENDIX I
SCHEMATIC REPRESENTATION OF WHEELCHAIR ROLLER SYSTEM

Components of the Roller System for Determining Wheelchair Velocity



APPENDIX J
SUMMARY OF WHEELCHAIR CALIBRATION PROCEDURES

WHEELCHAIR CALIBRATION JUNE '94

ROLLER DATA - MANUAL COUNT

TIME min	ROL.RPM rev/min	ROL.VEL kmh	ROL.DIS km
1.000	85.000	2.703	0.045
2.000	78.000	2.480	0.041
3.000	75.000	2.385	0.040
4.000	84.000	2.671	0.045
5.000	103.000	3.275	0.055
MEAN	85.000	2.703	0.045

SUMMARY OF RESULTS

	ROLLER	WCHAIR	COR.COM
RPM	85.000	24.400	83.600
VELOCITY	2.703	2.758	2.668
DISTANCE	0.045	0.046	0.044

WHEELCHAIR DATA - MANUAL COUNT

TIME min	WHE.RPM rev/min	WHE.VEL kmh	WHE.DIS km
1.000	28.000	3.165	0.053
2.000	22.000	2.487	0.041
3.000	22.000	2.487	0.041
4.000	24.000	2.713	0.045
5.000	26.000	2.939	0.049
MEAN	24.400	2.758	0.046

COMPUTER DATA - RECORDED BY SOFTWARE

TIME min	COM.RPM rev/min	COM.VEL kmh	COM.DIS km
1.000	46.000	1.470	0.020
2.000	39.000	1.240	0.030
3.000	39.000	1.250	0.020
4.000	41.000	1.310	0.020
5.000	44.000	1.400	0.020
MEAN	41.800	1.334	0.022

CORRECTED COMPUTER DATA - MULTIPLIED BY 2

TIME min	COR.RPM rev/min	COR.VEL kmh	COR.DIS km
1.000	92.000	2.940	0.040
2.000	78.000	2.480	0.060
3.000	78.000	2.500	0.040
4.000	82.000	2.620	0.040
5.000	88.000	2.800	0.040
MEAN	83.600	2.668	0.044

NOTE: SPEEDOMETER ON COMPUTER IS INDICATING PROPER SPEED. THE RPM, VELOCITY, AND DISTANCE TRAVELLED REPORTED ON THE PRINTOUT IS HALF OF THOSE MANUALLY RECORDED. HENCE THESE VALUES ARE MULTIPLIED BY 2

APPENDIX K
Borg Scale of Perceived Exertion

•

6
7 very, very light
8
9 very light
10
11 fairly light
12
13 somewhat hard
14
15 hard
16
17 very hard
18
19 very, very hard
20

Excerpted from: Borg, G. (1970). Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitation Medicine, 2-3, p. 93.

APPENDIX L
SESSION FORMAT

FLOW CHART: STUDY SESSION

Pre-test data collection

:

Baseline data - 4 minutes

:

Familiarization period - 5 minutes

:

REST - 8 MINUTES

:

Camber Session #1 - 8 minutes 30 seconds

:

REST - 8 MINUTES

:

Camber Session #2 - 8 minutes 30 seconds

:

REST - 8 MINUTES

:

Camber Session #3 - 8 minutes 30 seconds

FLOWCHART: CAMBER TESTING SESSION

	Camber selection and preparation
	:
	MMC and HR monitor applied
	:
minute "0"	Start Testing
	:
minutes "0"	Continuous MMC monitoring
to	HR(s) recorded every 20 seconds
8 min. 30 s	Wheelchair velocity recorded every minute
	:
8 min. 30 s	End test

APPENDIX M
NON-PROTEIN RQ TABLE FOR CONVERTING OXYGEN CONSUMPTION INTO ENERGY EQUIVALENTS

Non-protein RQ	KCAL/litre oxygen consumed	% KCAL derived from carbohydrate	/ fat	Grams/litre O_2 carbohydrate	/ fat
.707	4.686	0	100	.000	.496
.71	4.690	1.10	98.9	.012	.491
.72	4.702	4.76	95.2	.051	.476
.73	4.714	8.40	91.6	.90	.460
.74	4.727	12.0	88.0	.130	.444
.75	4.739	15.6	84.4	.170	.428
.76	4.751	19.2	80.8	.211	.412
.77	4.764	22.8	77.2	.250	.396
.78	4.776	26.3	73.7	.290	.380
.79	4.788	29.9	70.1	.330	.363
.80	4.801	33.4	66.6	.371	.347
.81	4.813	36.9	63.1	.413	.330
.82	4.825	40.3	59.7	.454	.313
.83	4.838	43.8	56.2	.496	.297
.84	4.850	47.2	52.8	.537	.280
.85	4.862	50.7	49.3	.579	.263
.86	4.875	54.1	45.9	.621	.247
.87	4.887	57.5	42.5	.663	.230
.88	4.899	60.8	39.2	.705	.213
.89	4.911	64.2	35.8	.749	.195
.90	4.924	67.5	32.5	.791	.178
.91	4.936	70.8	29.2	.834	.160
.92	4.948	74.1	25.9	.877	.143
.93	4.961	77.4	22.6	.921	.125
.94	4.973	80.7	19.3	.964	.108
.95	4.985	84.0	16.0	1.008	.090
.96	4.998	87.2	12.8	1.052	.072
.97	5.010	90.4	9.58	1.097	.054
.98	5.022	93.6	6.37	1.142	.036
.99	5.035	96.8	3.18	1.186	.018
1.00	5.047	100.0	0	1.231	.00

Excerpted From: McArdle, Katch & Katch, 1991, Exercise Physiology: Energy, Nutrition, and Human Performance. Philadephia: Lea & Febiger, p.153.

APPENDIX N
SUMMARIES OF ANOVA PROCEDURES

Table 23: Summary of Analysis of Variance: Absolute Oxygen Consumption (L/min^{-1})

Tests involving 'CAMBER' Within-Subject Effect.

AVERAGED Tests of Significance for AVO using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	433993.42	70	6199.91		
(Greenhouse-Geisser)		52.27			
(Huynh-Feldt)		58.75			
(Lower bound)		35.00			
CAMBER	139377.39	2	69688.69	11.24	.000
(Greenhouse-Geisser)		1.49		11.24	.000
(Huynh-Feldt)		1.68		11.24	.000
(Lower bound)		1.00		11.24	.002
GROUPXX BY CAMBER	2596.09	2	1298.04	.21	.812
(Greenhouse-Geisser)		1.49		.21	.746
(Huynh-Feldt)		1.68		.21	.773
(Lower bound)		1.00		.21	.650
GENDER BY CAMBER	27402.01	2	13701.00	2.21	.117
(Greenhouse-Geisser)		1.49		2.21	.132
(Huynh-Feldt)		1.68		2.21	.127
(Lower bound)		1.00		2.21	.146
GROUPXX BY GENDER BY CAMBER	11544.17	2	5772.09	.93	.399
(Greenhouse-Geisser)		1.49		.93	.376
(Huynh-Feldt)		1.68		.93	.385
(Lower bound)		1.00		.93	.341

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	820296.71	35	23437.05		
GENDER	480329.29	1	480329.29	20.49	.000
GROUPXX	79843.00	1	79843.00	3.41	.073
GENDER BY GROUPXX	1242.40	1	1242.40	.05	.819

Table 24: Summary of Analysis of Variance: Relative Oxygen Consumption (ml/kg/min)

AVERAGED Tests of Significance for RVO using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	33.30	70	.48		
(Greenhouse-Geisser)		52.41			
(Huynh-Feldt)		58.92			
(Lower bound)		35.00			
CAMBER	27.67	2	13.83	29.08	.000
(Greenhouse-Geisser)		1.50		29.08	.000
(Huynh-Feldt)		1.68		29.08	.000
(Lower bound)		1.00		29.08	.000
GROUPXX BY CAMBER	.20	2	.10	.21	.815
(Greenhouse-Geisser)		1.50		.21	.750
(Huynh-Feldt)		1.68		.21	.777
(Lower bound)		1.00		.21	.653
GENDER BY CAMBER	1.17	2	.59	1.23	.298
(Greenhouse-Geisser)		1.50		1.23	.291
(Huynh-Feldt)		1.68		1.23	.294
(Lower bound)		1.00		1.23	.275
GROUPXX BY GENDER BY CAMBER	.93	2	.46	.98	.382
(Greenhouse-Geisser)		1.50		.98	.361
(Huynh-Feldt)		1.68		.98	.370
(Lower bound)		1.00		.98	.330

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	60.92	35	1.74		
GENDER	.06	1	.06	.03	.859
GROUPXX	5.78	1	5.78	3.32	.077
GENDER BY GROUPXX	14.95	1	14.95	8.59	.006

Table 25: Summary of Analysis of Variance: Heart Rate (beats/ min)

AVERAGED Tests of Significance for HR using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1181.06	70	16.87		
(Greenhouse-Geisser)		54.33			
(Huynh-Feldt)		61.25			
(Lower bound)		35.00			
CAMBER	334.27	2	167.14	9.91	.000
(Greenhouse-Geisser)		1.55		9.91	.001
(Huynh-Feldt)		1.75		9.91	.000
(Lower bound)		1.00		9.91	.003
GROUPXX BY CAMBER	7.68	2	3.84	.23	.797
(Greenhouse-Geisser)		1.55		.23	.740
(Huynh-Feldt)		1.75		.23	.768
(Lower bound)		1.00		.23	.636
GENDER BY CAMBER	14.63	2	7.31	.43	.650
(Greenhouse-Geisser)		1.55		.43	.600
(Huynh-Feldt)		1.75		.43	.624
(Lower bound)		1.00		.43	.515
GROUPXX BY GENDER BY CAMBER	17.10	2	8.55	.51	.605
(Greenhouse-Geisser)		1.55		.51	.559
(Huynh-Feldt)		1.75		.51	.581
(Lower bound)		1.00		.51	.481

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	9365.67	35	267.59		
GENDER	892.49	1	892.49	3.34	.076
GROUPXX	151.86	1	151.86	.57	.456
GENDER BY GROUPXX	361.11	1	361.11	1.35	.253

Table 26: Summary of Analysis of Variance: Minute Ventilation (L/min)

AVERAGED Tests of Significance for VE using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	737.67	70	10.54		
(Greenhouse-Geisser)		44.34			
(Huynh-Feldt)		49.19			
(Lower bound)		35.00			
CAMBER	139.04	2	69.52	6.60	.002
(Greenhouse-Geisser)		1.27		6.60	.009
(Huynh-Feldt)		1.41		6.60	.007
(Lower bound)		1.00		6.60	.015
GROUPXX BY CAMBER	3.45	2	1.73	.16	.849
(Greenhouse-Geisser)		1.27		.16	.747
(Huynh-Feldt)		1.41		.16	.771
(Lower bound)		1.00		.16	.688
GENDER BY CAMBER	43.95	2	21.97	2.09	.132
(Greenhouse-Geisser)		1.27		2.09	.152
(Huynh-Feldt)		1.41		2.09	.148
(Lower bound)		1.00		2.09	.158
GROUPXX BY GENDER BY CAMBER	23.07	2	11.54	1.09	.340
(Greenhouse-Geisser)		1.27		1.09	.317
(Huynh-Feldt)		1.41		1.09	.323
(Lower bound)		1.00		1.09	.303

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1064.91	35	30.43		
GENDER	296.77	1	296.77	9.75	.004
GROUPXX	636.14	1	636.14	20.91	.000
GENDER BY GROUPXX	.23	1	.23	.01	.931

Table 27: Summary of Analysis of Variance: Respiratory Exchange Ratio

AVERAGED Tests of Significance for R using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.12	70	.00		
(Greenhouse-Geisser)		68.04			
(Huynh-Feldt)		70.00			
(Lower bound)		35.00			
CAMBER	.01	2	.00	1.66	.198
(Greenhouse-Geisser)		1.94		1.66	.199
(Huynh-Feldt)		2.00		1.66	.198
(Lower bound)		1.00		1.66	.206
GROUPXX BY CAMBER	.00	2	.00	.32	.729
(Greenhouse-Geisser)		1.94		.32	.722
(Huynh-Feldt)		2.00		.32	.729
(Lower bound)		1.00		.32	.576
GENDER BY CAMBER	.00	2	.00	.73	.485
(Greenhouse-Geisser)		1.94		.73	.482
(Huynh-Feldt)		2.00		.73	.485
(Lower bound)		1.00		.73	.398
GROUPXX BY GENDER BY CAMBER	.00	2	.00	.11	.899
(Greenhouse-Geisser)		1.94		.11	.894
(Huynh-Feldt)		2.00		.11	.899
(Lower bound)		1.00		.11	.746

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.11	35	.00		
GENDER	.00	1	.00	.01	.937
GROUPXX	.01	1	.01	2.36	.134
GENDER BY GROUPXX	.00	1	.00	.19	.667

Table 28: Summary of Analysis of Variance: Oxygen Pulse (ml/beat)

AVERAGED Tests of Significance for O2PULSE using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	43.37	70	.62		
(Greenhouse-Geisser)		50.40			
(Huynh-Feldt)		56.48			
(Lower bound)		35.00			
CAMBER	8.36	2	4.18	6.75	.002
(Greenhouse-Geisser)		1.44		6.75	.006
(Huynh-Feldt)		1.61		6.75	.004
(Lower bound)		1.00		6.75	.014
GROUPXX BY CAMBER	.16	2	.08	.13	.882
(Greenhouse-Geisser)		1.44		.13	.814
(Huynh-Feldt)		1.61		.13	.839
(Lower bound)		1.00		.13	.725
GENDER BY CAMBER	1.86	2	.93	1.50	.229
(Greenhouse-Geisser)		1.44		1.50	.232
(Huynh-Feldt)		1.61		1.50	.232
(Lower bound)		1.00		1.50	.228
GROUPXX BY GENDER BY CAMBER	.95	2	.47	.77	.468
(Greenhouse-Geisser)		1.44		.77	.430
(Huynh-Feldt)		1.61		.77	.444
(Lower bound)		1.00		.77	.387

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	165.55	35	4.73		
GENDER	102.45	1	102.45	21.66	.000
GROUPXX	3.67	1	3.67	.78	.385
GENDER BY GROUPXX	.02	1	.02	.00	.951

Table 29: Summary of Analysis of Variance: Carbon Dioxide Production (L/min^{-1})

AVERAGED Tests of Significance for VCO using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	440274.45	70	6289.63		
(Greenhouse-Geisser)		54.11			
(Huynh-Feldt)		60.99			
(Lower bound)		35.00			
CAMBER	135940.47	2	67970.23	10.81	.000
(Greenhouse-Geisser)		1.55		10.81	.000
(Huynh-Feldt)		1.74		10.81	.000
(Lower bound)		1.00		10.81	.002
GROUPXX BY CAMBER	2984.45	2	1492.22	.24	.789
(Greenhouse-Geisser)		1.55		.24	.732
(Huynh-Feldt)		1.74		.24	.759
(Lower bound)		1.00		.24	.629
GENDER BY CAMBER	33411.36	2	16705.68	2.66	.077
(Greenhouse-Geisser)		1.55		2.66	.092
(Huynh-Feldt)		1.74		2.66	.085
(Lower bound)		1.00		2.66	.112
GROUPXX BY GENDER BY CAMBER	14258.68	2	7129.34	1.13	.328
(Greenhouse-Geisser)		1.55		1.13	.317
(Huynh-Feldt)		1.74		1.13	.322
(Lower bound)		1.00		1.13	.294

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	638103.31	35	18231.52		
GENDER	364337.55	1	364337.55	19.98	.000
GROUPXX	100951.40	1	100951.40	5.54	.024
GENDER BY GROUPXX	651.28	1	651.28	.04	.851

Table 30: Summary of Analysis of Variance: Ventilatory Equivalent for Oxygen

AVERAGED Tests of Significance for VEVO using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1078.65	70	15.41		
(Greenhouse-Geisser)		41.38			
(Huynh-Feldt)		45.65			
(Lower bound)		35.00			
CAMBER	3.09	2	1.55	.10	.905
(Greenhouse-Geisser)		1.18		.10	.795
(Huynh-Feldt)		1.30		.10	.818
(Lower bound)		1.00		.10	.753
GROUPXX BY CAMBER	.34	2	.17	.01	.989
(Greenhouse-Geisser)		1.18		.01	.943
(Huynh-Feldt)		1.30		.01	.956
(Lower bound)		1.00		.01	.917
GENDER BY CAMBER	4.69	2	2.34	.15	.859
(Greenhouse-Geisser)		1.18		.15	.741
(Huynh-Feldt)		1.30		.15	.765
(Lower bound)		1.00		.15	.699
GROUPXX BY GENDER BY CAMBER	2.72	2	1.36	.09	.916
(Greenhouse-Geisser)		1.18		.09	.809
(Huynh-Feldt)		1.30		.09	.832
(Lower bound)		1.00		.09	.768

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2322.98	35	66.37		
GENDER	93.30	1	93.30	1.41	.244
GROUPXX	780.19	1	780.19	11.76	.002
GENDER BY GROUPXX	.96	1	.96	.01	.905

Table 31: Summary of Analysis of Variance: Ventilatory Equivalent for Carbon Dioxide

AVERAGED Tests of Significance for VEVCO using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1212.15	70	17.32		
(Greenhouse-Geisser)		42.16			
(Huynh-Feldt)		46.58			
(Lower bound)		35.00			
CAMBER	27.99	2	14.00	.81	.450
(Greenhouse-Geisser)		1.20		.81	.395
(Huynh-Feldt)		1.33		.81	.406
(Lower bound)		1.00		.81	.375
GROUPXX BY CAMBER	2.35	2	1.17	.07	.934
(Greenhouse-Geisser)		1.20		.07	.840
(Huynh-Feldt)		1.33		.07	.862
(Lower bound)		1.00		.07	.796
GENDER BY CAMBER	.56	2	.28	.02	.984
(Greenhouse-Geisser)		1.20		.02	.932
(Huynh-Feldt)		1.33		.02	.946
(Lower bound)		1.00		[illegible]	.899
GROUPXX BY GENDER BY CAMBER	4.65	2	2.33	.13	.875
(Greenhouse-Geisser)		1.20		.13	.763
(Huynh-Feldt)		1.33		.13	.787
(Lower bound)		1.00		.13	.716

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2729.78	35	77.99		
GENDER	115.12	1	115.12	1.48	.233
GROUPXX	727.61	1	727.61	9.33	.004
GENDER BY GROUPXX	.23	1	.23	.00	.957

Table 32: Summary of Analysis of Variance: Ratings of Perceived Exertion (Central)

Tests involving 'CAMBER' Within-Subject Effect.

AVERAGED Tests of Significance for RPEC using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	74.60	70	1.07		
(Greenhouse-Geisser)		64.20			
(Huynh-Feldt)		70.00			
(Lower bound)		35.00			
CAMBER	5.20	2	2.60	2.44	.095
(Greenhouse-Geisser)		1.83		2.44	.100
(Huynh-Feldt)		2.00		2.44	.095
(Lower bound)		1.00		2.44	.127
GROUPXX BY CAMBER	3.74	2	1.87	1.76	.180
(Greenhouse-Geisser)		1.83		1.76	.184
(Huynh-Feldt)		2.00		1.76	.180
(Lower bound)		1.00		1.76	.194
GENDER BY CAMBER	1.17	2	.59	1.23	.298
(Greenhouse-Geisser)		1.50		1.23	.291
(Huynh-Feldt)		1.68		1.23	.294
(Lower bound)		1.00		1.23	.275
GROUPXX BY GENDER BY CAMBER	1.15	2	.57	.54	.586
(Greenhouse-Geisser)		1.83		.54	.571
(Huynh-Feldt)		2.00		.54	.586
(Lower bound)		1.00		.54	.468

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	191.90	35	5.48		
GENDER	25.55	1	25.55	4.66	.038
GROUPXX	49.69	1	49.69	9.06	.005
GENDER BY GROUPXX	2.55	1	2.55	.46	.500

Table 33: Summary of Analysis of Variance: Rating of Perceived Exertion (Local)

AVERAGED Tests of Significance for RPEL using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	124.48	70	1.78		
(Greenhouse-Geisser)		62.14			
(Huynh-Feldt)		70.00			
(Lower bound)		35.00			
CAMBER	7.46	2	3.73	2.10	.131
(Greenhouse-Geisser)		1.78		2.10	.137
(Huynh-Feldt)		2.00		2.10	.131
(Lower bound)		1.00		2.10	.157
GROUPXX BY CAMBER	4.20	2	2.10	1.18	.313
(Greenhouse-Geisser)		1.78		1.18	[illegible]
(Huynh-Feldt)		2.00		1.18	.313
(Lower bound)		1.00		1.18	.285
GENDER BY CAMBER	3.42	2	1.71	.96	.388
(Greenhouse-Geisser)		1.78		.96	.379
(Huynh-Feldt)		2.00		.96	.388
(Lower bound)		1.00		.96	.334
GROUPXX BY GENDER BY CAMBER	1.0[illegible]	2	.54	.30	.740
(Greenhouse-Geisser)		1.78		.30	.714
(Huynh-Feldt)		2.00		.30	.740
(Lower bound)		1.00		.30	.586

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	231.39	35	6.61		
GENDER	39.05	1	39.05	5.91	.020
GROUPXX	8.36	1	8.36	1.26	.269
GENDER BY GROUPXX	1.26	1	1.26	.19	.665

Table 34: Summary of Analysis of Variance: Gross Energy Cost (KCals/min)

AVERAGED Tests of Significance for GEC using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	10.80	70	.15		
(Greenhouse-Geisser)		51.87			
(Huynh-Feldt)		56.27			
(Lower bound)		35.00			
CAMBER	3.51	2	1.75	11.36	.000
(Greenhouse-Geisser)		1.48		11.36	.000
(Huynh-Feldt)		1.66		11.36	.000
(Lower bound)		1.00		11.36	.002
GROUPXX BY CAMBER	.08	2	.04	.25	.782
(Greenhouse-Geisser)		1.48		.25	.714
(Huynh-Feldt)		1.66		.25	.741
(Lower bound)		1.00		.25	.622
GENDER BY CAMBER	.72	2	.36	2.34	.103
(Greenhouse-Geisser)		1.48		2.34	.120
(Huynh-Feldt)		1.66		2.34	.114
(Lower bound)		1.00		2.34	.135
GROUPXX BY GENDER BY CAMBER	[illegible]	2	.15	.96	.386
(Greenhouse-Geisser)		1.48		.96	.364
(Huynh-Feldt)		1.66		.96	.373
(Lower bound)		1.00		.96	.333

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	19.64	35	.56		
GENDER	11.49	1	11.49	20.47	.000
GROUPXX	2.13	1	2.13	3.79	.060
GENDER BY GROUPXX	.03	1	.03	.06	.812

Table 35: Summary of Analysis of Variance: Relative Gross Energy Cost (Cal/kg/min)

AVERAGED Tests of Significance for RGEC using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	3429.72	70	49.00		
(Greenhouse-Geisser)		42.09			
(Huynh-Feldt)		46.49			
(Lower bound)		35.00			
CAMBER	651.01	2	325.50	6.64	.002
(Greenhouse-Geisser)		1.20		6.64	.010
(Huynh-Feldt)		1.33		6.64	.008
(Lower bound)		1.00		6.64	.014
GROUPXX BY CAMBER	84.44	2	42.22	.86	.427
(Greenhouse-Geisser)		1.20		.86	.378
(Huynh-Feldt)		1.33		.86	.388
(Lower bound)		1.00		.86	.360
GENDER BY CAMBER	198.17	2	99.08	2.02	.140
(Greenhouse-Geisser)		1.20		2.02	.160
(Huynh-Feldt)		1.33		2.02	.157
(Lower bound)		1.00		2.02	.164
GROUPXX BY GENDER BY CAMBER	136.90	2	68.45	1.40	.254
(Greenhouse-Geisser)		1.20		1.40	.250
(Huynh-Feldt)		1.33		1.40	.252
(Lower bound)		1.00		1.40	.245

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1934.24	35	55.26		
GENDER	.06	1	.06	.00	.974
GROUPXX	158.80	1	158.80	2.87	.099
GENDER BY GROUPXX	396.76	1	396.76	7.18	.011

Table 36: Summary of Analysis of Variance: Net Energy Cost (KCals/min)

AVERAGED Tests of Significance for NEC using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	10.80	70	.15		
(Greenhouse-Geisser)		51.87			
(Huynh-Feldt)		58.27			
(Lower bound)		35.00			
CAMBER	3.51	2	1.75	11.36	.000
(Greenhouse-Geisser)		1.48		11.36	.000
(Huynh-Feldt)		1.66		11.36	.000
(Lower bound)		1.00		11.36	.002
GROUPXX BY CAMBER	.08	2	.04	.25	.782
(Greenhouse-Geisser)		1.48		.25	.714
(Huynh-Feldt)		1.66		.25	.741
(Lower bound)		1.00		.25	.622
GENDER BY CAMBER	.72	2	.36	2.34	.103
(Greenhouse-Geisser)		1.48		2.34	.120
(Huynh-Feldt)		1.66		2.34	.114
(Lower bound)		1.00		2.34	.135
GROUPXX BY GENDER BY CAMBER	.30	2	.15	.96	[illegible]
(Greenhouse-Geisser)		1.48		.96	.364
(Huynh-Feldt)		1.66		.96	.373
(Lower bound)		1.00		.96	.333

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	9.86	35	.28		
GENDER	4.38	1	4.38	15.54	.000
GROUPXX	2.26	1	2.26	[illegible]	[illegible]
GENDER BY GROUPXX	.34	1	.34	1.21	.278

Table 37: Summary of Analysis of Variance: Relative Net Energy Cost (Cal/kg/min)

AVERAGED Tests of Significance for RNEC using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	3429.72	70	49.00		
(Greenhouse-Geisser)		42.09			
(Huynh-Feldt)		46.49			
(Lower bound)		35.00			
CAMBER	651.01	2	325.50	6.64	.002
(Greenhouse-Geisser)		1.20		6.64	.010
(Huynh-Feldt)		1.33		6.64	.008
(Lower bound)		1.00		6.64	.014
GROUPXX BY CAMBER	84.44	2	42.22	.86	.427
(Greenhouse-Geisser)		1.20		.86	.378
(Huynh-Feldt)		1.33		.86	.388
(Lower bound)		1.00		.86	.360
GENDER BY CAMBER	198.17	2	99.08	2.02	.140
(Greenhouse-Geisser)		1.20		2.02	.160
(Huynh-Feldt)		1.33		2.02	.157
(Lower bound)		1.00		2.02	.164
GROUPXX BY GENDER BY CAMBER	136.90	2	68.45	1.40	.254
(Greenhouse-Geisser)		1.20		1.40	.250
(Huynh-Feldt)		1.33		1.40	.252
(Lower bound)		1.00		1.40	.245

Tests of Between-Subjects Effects.

Tests of Significance for T1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	1353.63	35	38.68		
GENDER	14.96	1	14.96	.39	.538
GROUPXX	368.33	1	368.33	9.52	.004
GENDER BY GROUPXX	353.01	1	353.01	9.13	.005