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A Case Study of Energy Expenditure of a Lower Limb Amputee Using a Running Blade Compared to a Non-Amputee

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Energy Expenditure of Lower Limb Amputees Using a Running Blade Compared to Non-Amputees

A THESIS

APPROVED FOR THE DEPARTMENT OF KINESIOLOGY AND HEALTH STUDIES

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Abstract

The purpose of this case study was to determine if energy expenditure of a lower limb amputee (LLA) with a running specific prosthesis would be different from an able-bodied person. There is little research on running specific prosthesis and energy expenditure compared to an able-bodied person. There, were two participants (1-amputee, 1-able-bodied). Data was collected from the LLA first and then able-bodied participant was recruited as closely to match based on height, age, and sex. The modified Costill/Fox Protocol was used as the testing method. The participants started with a light warm-up on the treadmill at a speed of 3.1 mph for 4 minutes. The protocol includes the speed in mph to increase every 4 minutes (5.9, 7.5, 8.4, & 9.9). When the participant reaches an RPE of 13 the speed stayed constant and the grade increased 2% every 2 minutes until exhaustion. The Parvo-Medics was used to measure gas exchange. Both the LLA and the able-bodied participant made it to stage 3 of the modified Costill/Fox protocol. In stage 3 VO_2 for the LLA was 29.6ml/kg/min, able-bodied participant was 35.9ml/kg/min, and the calculation intensity is 38ml/kg/min. The percent difference shows that the LLA was 19.2% lower when compared to the able-bodied participant. When the LLA was compared to the calculation the percent difference showed the LLA was 24.9% lower than the calculation. While no statistical comparison was made, the case study indicates that this LLA did not expend more energy that the matched control or the metabolic calculation. It appears this is the first study to directly compare the RSP to an able body participant and leads the way for future studies.

Chapter One: Introduction

In the United States, approximately two million people have lost a limb which means one in 190 people in the United States have some level of amputation (Ziegler-Graham, MacKenzie, Ephraim, Travison & Brookmeyer, 2008). Each year in the U.S. there are estimated to be 185,000 people that receive an amputation (Owings & Kozak, 1998). In Iraq and Afghanistan1,227 limb amputations occurred to military personnel (Walter Reed Amputee Database, 2011). A survey conducted by the Amputee Coalition of America (ACA) and Johns Hopkins University of 954 amputees, found that 843 or 88% of those surveyed had a lower limb amputation (People with amputations speak out, 2005). It has been estimated that in 2009 more than $8.3 billion dollars has been spent on hospital care due to amputations (Healthcare Cost and Utilization Project [HCUP] Nationwide Inpatient Sample, 2009).

The two most common causes of amputations of a lower limb are trauma and vascular disease (People with amputations speak out, 2005). There are three different levels of lower limb amputation: transfemoral, transtibial, and syme's (Waters, Perry, Antonelli, Daniel & Hislop, 2010). Transfemoral amputation is when the limb loss is from above the knee. Transtibial amputation is when the limb loss is from below the knee. Syme's amputation is a partial foot or toe loss (Amputee coalition, 2008).

Energy expenditure of those with lower limp amputations (LLA) has been found to be greater during walking (Esposito, Rodriguez, Rabago & Wilken, 2014). It has also been found that using different prostheses can affect the energy expenditure of LLA (Schmalz, Thomas, Blumentritt, Siegmar & Jarasch, 2002). Level of amputation also has an effect on energy expenditure; transfemoral has the most energy cost and Syme's with the lowest energy cost (Graham, Datta, Heller & Howitt, 2008).

Exercise prescription for LLA for strength training is the same as an apparent healthy person. Cardiovascular recommendations for LLA are to perform an aerobic activity that incorporates enough muscle groups so that it will make up for the missing limb to equal an able bodied person, and to avoid aerobic exercises that will cause skin breakdown and overuse injury (Durstine, Moore, Painter, & Roberts, 2009). Throughout the years, technological advances, such as running specific prostheses (RSP) have helped LLA partake in sports (Brown, Millard-Stafford & Allison, 2009).

Background

Before running specific prostheses (RSP) the traditional prostheses did not allow amputees to perform at running speeds (Brown et al., 2009). A traditional prosthesis included a shank, ankle, and heel portions, which made the prostheses less elastic (Brown et al., 2009). RSP store elastic energy because they are J-shaped and do not have a heel, the energy is stored during the loading portion and released during the terminal phase while running (Brown et al., 2009).

Energy cost for LLA's has been found to be greater during walking when compared to an able-bodied counterpart (Gailey, Wenger, Raya, Kirk, Erbs, Spyropoulos & Nash, 1994). This means that LLA will use more energy than an able bodied person while doing the same task, such as walking. This means that the LLA may fatigue more quickly or at a lower intensity of exercise. In both cases, the LLA will likely not perform the same benefit as an able-bodied participant. Newer studies with RSP are closing the gap in energy expenditure between amputees and the able-bodied (Brown et al., 2009). Other advances in prostheses include better comfort level and patient satisfaction of the prostheses (Goktepe, Cakir, Yilmaz, & Yazicioglu, 2010).

RSP are starting to open more doors for amputees in the sports world. For the first time in the 2016 Paralympic Games there was a paratriathlon, which is a triathalon with a 750-m swim, 20-km bike, and 5-km run for those with a physical impairment (Mujika, Orbananos, & Salazar, 2015). The inclusion of this new sport has piqued the interest of many athletes and set new goals for a higher level of competition (Mujika et al., 2015).

Purpose

The purpose of this study was to determine if energy expenditure of a LLA with a RSP is different from an able-bodied person of similar age, height, and runs at minimum twice a week. There is little research on RSP and energy expenditure compared to an able-bodied person.

Hypothesis

It is hypothesized by the researcher, that energy expenditure will not be significantly different in the LLA using a RSP and able-bodied person. The hypothesis is based on previous studies that looked at energy expenditure of lower limb amputees, with a non running prosthetic, compared to able-bodied persons (Schmalz et al., 2002; Esposito et al., 2014; Gjovaag et al., 2014; Schnall et al., 2012; & Hunter et al., 1995).

This study will differ from previous studies because the researchers did not test energy expenditure of LLA with a RSP and able-bodied people.

Operational Definitions

- VO_2-Maximal oxygen uptake percentage, how much oxygen the body can utilize for exercise. VO_2 was measured in ml/kg/min (Thompson, Gordon, & Pescatello, 2014).
- Prostheses- Running Specific Prostheses (see Fig. 1).
- Able-bodied persons are someone that does not have an amputation (Brown et al., 2009).

Limitations and Delimitations

Limitations of this study include:

- being able to recruit enough participants for a sufficient sample size.
- being able to match LLA and able-bodied comparison group, based on age, height, sex, and activity level.

Delimitations of this study include:

- participants must be a lower limb amputee.
- participants must have a RSP.
- participants must currently be involved in a sport or run recreationally.

Assumptions

The researcher assumes that all participants will complete the study without dropping out or becoming injured. All participants will be able to reach their VO_2 max during testing.

Chapter Two: Systematic Literature Review

Introduction

The purpose of this systematic literature review was to look at Lower Limb Amputees (LLA) and energy cost. The methods used for this review includes search of online databases through the University of Central Oklahoma (UCO), public online domains, and references from found articles and other literature reviews. The inclusion criteria for the articles were LLA, energy cost, treadmill test, and amputations due to vascular disease or trauma. The results of the review show that energy cost for amputees is still greater than that of able-bodied participants but in some cases not significantly different. Studies that looked at residual limb length and energy cost had mixed results with some saying the residual limb length was a significant factor to energy cost while some said the length did not matter. Other studies looked at different prostheses and energy cost, unfortunately none of the researchers studied the same prosthetics for comparison. Studies of RSP and energy cost are limited in number.

Purpose

The purpose of this systematic literature review was to look at energy expenditure of walking and running of lower limb amputees. Understanding energy expenditure for this group can help with future research to find out how to lower energy costs of persons with a lower limb amputation.

Methods

Search Procedure

The included articles were found by using the University of Central Oklahoma's online database as well as online public databases. The following search terms were used: prosthetic/prostheses oxygen consumption, prosthetic/prostheses energy expenditure, and amputation and energy cost. The search terms yielded approximately 501 articles. In addition to these search terms, references from the articles selected for inclusion and literature reviews were also used.

Inclusion Procedure

From the search procedure articles were reviewed in detail if they included:

- The study was peer reviewed
- Participants had a transfemoral, transtibial, or syme's amputation
- Energy expenditure of a lower limb amputation
- Energy expenditure was measured by walking or running
- Amputation was caused due to trauma or peripheral arterial disease

Results

The results in Table 1 are an overview of the research found on lower limb amputees and energy expenditure. The results in Table 1 are categorized by the type of aerobic protocol used: self-selected walking pace, a set pace, and VO_2 max test. There is a mix of results, it cannot be determined what prostheses will cause a more equal energy expenditure. No prosthesis has been consistently compared against all others to find out if it is the best one and will result in less energy expenditure.

Table 1

Results of lower limb amputee and energy expenditure

Author	Population	Purpose	Results
Self-selected walking pace			
Bell et al., 2014	26 transfemoral amputees	Calculate energy expenditure on transfemoral amputee. If residual limb length made a difference on energy expenditure. Participants walked around a track at a self selected pace	No significant difference in energy expenditure between limb lengths (p=.38).
Detrembleur et al., 2004	6 transfemoral and 6 transtibial	Calculate metabolic energy cost at a speed determined during the assessment. Participants walked at steady state for at least 2 minutes.	Energy cost was similar in both groups during self-selected walking speed (p=.013).

Waters et al., 2010	70 lower limb amputees due to trauma and vascular. 28 above the knee, 27 below the knee and 15 syme amputation. 5 nonamputee of both sex from each decade from the third to the seventh as a control group.	To compare the energy cost of three different amputation levels (transfemoral, transtibial, and symes). They walked at a self-selected pace.	Energy cost of the traumatic participants with above and below the knee amputation (37% and 35% greater) were similar to the control group (34% greater). The vascular group was similar to the control group (41% greater) as well with below the knee (42% greater) and symes (43% greater)
Torburn et al., 1995	17 below the knee amputation	Energy expenditure of five different prosthetic legs (Solid ankle cushion heel (SACH), Carbon Copy II, Seattle Lite, Quantum and Flex-Foot). Participants walked at a self-selected pace.	No significant difference between any of the different prosthetic legs $p>.05$
Popielarz et al., 2014	13 below the knee amputation	If wearing a shock absorber will decrease energy expenditure wearing a SACH or articulated prostheses while walking at a self selected pace.	When the groups were compared together there was no significant difference in energy expenditure. When the groups were separated the SACH group showed improvement, used less energy expenditure ($p=.02$).
Mohanty et al., 2012	30 transtibial amputees	Energy expenditure difference between wearing a prostheses and using crutches. Participants used a self-selected walking pace.	Energy expenditure for prosthesis was less and significant ($p<.025$) when prostheses were used compared to crutches

Lin-Chan et al., 2003	1 amputee	Compare energy expenditure on the same participant that had a syme amputation and then a transtibial amputation of the same leg. The participant chose a self selected walking speed.	Energy expenditure did not improve from walking with a syme's prosthetic to a transtibial prosthetic (0-5% difference)
Pre-selected treadmill pace			
Klodd et al., 2010	13 transtibial amputees	Energy expenditure on five different forefoot flexibility prostheses. Participants did not know the forefoot flexibility during the five tests and the order was randomly assigned of the prostheses. All participants walked at the same speed on the treadmill.	There was no significance on energy expenditure for any of the forefoot flexibility (p=.17). There was also no significance in what order the forefoot was tested on energy expenditure (p=.94).
Starholm et al., 2010	8 transfemoral amputees	Energy expenditure on different inclines and tilts on a treadmill. The treadmill was randomly set for the participants at a flat position, incline and incline with a sideways tilt.	There was a significant difference between walking with an incline and sideways tilt compared to a flat treadmill walk (p<.05). Walking with the incline and tilt was 27.3% higher than walking on a flat treadmill.
A.D. Segal et al., 2012	7 transtibial amputees	To compare energy expenditure of the amputees prescribes prosthetic and Controlled Energy Storage and Return (CESR) prototype prostheses. All participants walked at a speed of 1.14 m/s.	CESR had less energy expenditure and was significantly greater (p=.007).

Goktepe et al., 2010	64 lower limb amputees. 22 partial foot, 31 transtibial and 9 transfemoral. 2 amputees were excluded from the results due to their low scores.	Energy expenditure between three different amputation levels (partial foot, transtibial and transfemoral). An incremental treadmill test was used at four different speeds and an increase in slope.	No significant difference in energy expenditure was found (p>.05). Energy expenditure was the least for transtibial and greatest for transfemoral.
Schmalz et al., 2002	15 transtibial and 12 transfemoral amputees	Energy expenditure of transfemoral and transtibial amputees and the affect of the alignment of the prostheses. Four different tests were performed. Test 1 was transtibial amputees wearing the same prosthetic foot. Test 2 transtibial amputees wearing five different prosthetic feet. Test 3 transfemoral wearing the same prosthesis. Test 4 transfemoral wearing a hydraulic single axis knee joint and an electronically controlled hydraulic single axis knee joint.	Test 2 and test 3 were the only test that showed any significance (p<.05). For test 2 transtibial amputees showed significance when there was a greater dorsi-flexion and plantar flexion. For test 3 transfemoral amputees saw significance when the knee was shifted posteriorly by 2 cm.
Esposito et al., 2014	13 transtibial amputees and 13 nonamputee as a control group	To compare energy expenditure of currently active transtibial amputee and nonamputee participants. Walking protocol was five different speeds and a self-selected pace.	Energy expenditure was not significant between the groups at any of the five speeds (p>.05).
Gjovaag et al., 2014	12 transfemoral amputees and 12 non-amputees as a control group	To compare energy expenditure of transfemoral amputees and able-bodied non-amputees participants. Modified incremental treadmill test was used.	The transfemoral group had about 30% lower VO_{2max} when compared to their equal counterparts of the control group.

Schnall et al., 2012	12 transtibial amputees and 12 non-amputees as a control group	To compare energy expenditure of transtibial service members and nonamputee service members while having a military load during two walking speeds.	Energy cost was greater for transtibial amputees than the control group at both speeds (p=.03 at 1.34 m/s and p=.04 at 1.52 m/s).
Hunter et al., 1995	7 below the knee amputees and 10 non-amputees for control group	To compare energy expenditure of the below the knee amputees and control group during a harness-supported treadmill test. Two different speeds were tested (.67 and 1.34 m/s) and two different harness supports (20% and 40% of body weight).	There was no significance between the groups while being supported 20% and 0% or at either speed of .67m/s and 1.34 m/s (p<.05).
Heller et al., 2005	10 transfemoral amputees	To compare energy cost of transfemoral amputees using an intelligent prostheses and a damped knee swing-phase control. The test was done on a treadmill starting at 2.5 km/h and increased 0.5 km/h every 3 minutes until 5 km/h was meet.	There was a significance between pneumatic swing-phase control was lower when the speed increased compared to the intelligent prosthesis (p<.05).
Graham et al., 2008	6 transfemoral amputees	To compare energy expenditure of two prosthetic legs (conventional prosthetic foot and an energy storing prosthetic foot). An incremental treadmill test was used.	There was a significance of more oxygen consumption for the conventional prosthetic (p<.001).
VO_2 max test			
Mujika et al., 2015	1 transfemoral paralympic athlete	To assess physiological attributes (maximal aerobic power, maximal aerobic velocity, and onset of blood lactate accumulation) over a 19-month follow up. Four incremental treadmill tests were conducted over the follow up period. The start speed was 8.5 km/h and increased 1.5	Maximum aerobic velocity increased by 12.8% over the 19-months.

		km/h every 4 minutes until the participant could no longer keep the same speed.	
Brown et al., 2009	5 unilateral transtibial, 1 bilateral transtibial and 6 nonamputee for control group	To compare physiological reactions of 6 lower-limb amputees using a traditional prosthesis and a running specific prostheses and 6 control participants. The participants did an incremental speed treadmill test to calculate VO_2max.	Comparing the running specific prostheses and the traditional prostheses there was a significant difference (p<.05) in VO_2 with the traditional prostheses being higher by 8 ml/kg/min. There was no significant difference between either prostheses and the control group.

Discussion

The major findings from the review of literature is that someone with a LLA uses more energy when compared to an able-bodied person, that matches fitness level, body weight, and height (Esposito et al., 2014; Gjovaag et al.; Schnall et al., 2012; Waters et al., 1976; Hunter et al., 1995; Brown et al., 2009). The fact that LLA use more energy compared to an able-bodied person can be due to the type of prosthesis used or could possibly be the alteration in their gait from wearing a prosthesis. The results of these studies also showed that transtibial and transfemoral amputees did not differ significantly in energy cost (Detrembleur et al., 2005; Goktepe et al., 2010; Schmalz et al., 2002). No significance between the amputation level can possibly mean different prosthetics are needed with different mechanics for each level of amputation. This could also mean that no matter the level of amputation the same amount of energy is used no matter the prosthetic.

Some studies compared different prosthetic legs to find out which prosthesis used less energy for the amputee, in which, many found non-significant results of energy expenditure between two or more prostheses (Klodd et al., 2010; Popielarz et al., 2014; Torburn et al., 1995) and some studies did find significant difference between two or more prostheses (Datta et al., 2005; Graham et al., 2008; Popielarz et al., 2014; Schmalz et al., 2002; Segal et al., 2012). The conflicting results for different prostheses can be explained by the fact that none of the studies compared the same prostheses. Without studies conducting research over the same type of legs there will most likely always be conflicting research because mechanics and how the prostheses are built will be different. Conducting research with the same type of prosthetic legs will help with further research on finding which prosthetic legs will be most beneficial and energy efficient for amputees.

Different amputation levels were also studied. Two studies looked at limb length and compared each length to each other and found no significance in energy cost (Bell et al., 2014; Goktepe et al., 2010), while one study compared limb length to able-bodied participants and found that above and below the knee amputation was similar to the able-bodied group (Waters et al., 1976). This shows that LLA (transtibial or transfemoral) use more energy than an able-bodied person. No significant difference in energy expenditure between limb length could be found because the amputation would be considered the same, transfemoral or transtibial, and the prosthetic would be the same just adjusted to a different height. This would mean that the mechanics of the prosthetic would be the same for the different limb lengths. This would also mean that energy cost is the same for the different levels of LLA.

Only one study found that compared a lower limb amputation and control group on the treadmill for a VO_2 max running protocol test. The study found that there was no significant difference in the RSP and the able-bodied group (Brown et al., 2009). The results from this study show the improvement of prostheses and that someone with a RSP may be getting close to having the same energy cost as an able-bodied person. More research needs to be conducted on the RSP to find more variances or similarities. Having a prosthetic that had the same energy cost as an able-bodied person would allow someone with an amputation to play sports and daily activities at the same cost. Being able to do things at the same cost would mean that someone with a LLA would not have to work harder to do the same task as an able-bodied person.

Some limitations of this review are that it went through a one-reviewer process. Also only LLA was looked at with energy cost only. For future studies RSP could be looked into more detail about energy cost and look into some specific sports.

Chapter Three: Methods

Participants

The amputee participant was recruited by a flyer (Appendix C) at Scott Sabolich Prosthetics & Research. Scott Sabolich Prosthetics & Research facility is located in Oklahoma City, they make and fit prosthetics for people with an amputation. A significant effort was made to recruit from this prosthetics company. However, two factors limited recruitment. First, in any given geographic area there is a small pool of LLA with their own RSP and experience running with it consistently. Second, it is difficult to reach participants with a LLA in a way that ensure voluntary participation and ensures confidently. The non-amputee participant was recruited by a flyer (Appendix D) that was put up in the Health and Physical Education Building at UCO. There was one LLA participant that was recruited, and one able-bodied participant that closely matched age, height, and both ran a minimum of twice a week was recruited. It would have been ideal for the LLA and matched participant to have similar weights as well. However, since the focus of the research was relative VO_2 measured in mL/kg/min, which allows comparison of participants with different body weights (Thompson et al., 2014). Participants were 18 years of age or older in the study. The amputee participant had a RSP of his own and had trained with for six months or more and to which were accustomed. Participants were involved in a running sport or ran for recreational purposes.

Participants were verbally informed of the risks and benefits during recruitment before arriving for testing. Participants then signed an informed consent (Appendix B) and filled out a physical activity readiness questionnaire (PAR-Q) before testing (Appendix F). Participants were encouraged to continue their normal regime the day before testing but advised to avoid alcohol, smoking, caffeine, and working out the day of testing.

Instruments

Parvo-Medics Metabolic Cart. The Parvo-Medics is a commercial system used to measure gas exchange. Measuring gas exchange is the most reliable and accurate method of measuring VO_2 (Thompson et al., 2014). The Parvo-Medics at the University of Central Oklahoma was used due to accessibility after authorization was approved. Participants wear a facemask that is connected to the gas analyzer by a hose. All expired air passes through the analyzer and is measured to determine how much oxygen the participant is using. All data is automatically collected through the associated computer. A professor or other trained individual from the University was present, to assist with equipment, data collection, and as a second responder in case of medical emergency during testing. This researcher has previous experience working with the Parvo-Medics.

Rate of Perceived Exertion (RPE). A RPE scale is measuring how the participant perceives their exertion level while performing some type of physical activity. The RPE scale used was the 6-20 Borg Scale (Appendix E). A poster of the scale was set up in front of the treadmill for the participants to see. The participants were asked during each stage what their RPE was. The 6-20 Borg scale was used due to that is has been found valid and reliable during treadmill running research (Doherty, Smith, Hughes, & Collins, 2001).

Modified Costill/Fox Protocol. The participants started with a light warm-up on the treadmill at a speed of 3.1 mph for 4 minutes. The protocol includes the speed in mph to increase every 4 minutes (5.9, 7.5, 8.4, & 9.9). When the participant reaches an RPE of 13 the speed stayed constant and the grade increased 2% every 2 minutes until exhaustion (Kaminsky, 2014). The Costill/Fox Protocol has been found to be valid and reliable in studies for VO_2 max when compared to the Bruce Treadmill and Astrand protocol (Kang, Chaloupka, Mastrangelo, Biren, & Robertson, 2001). This protocol was selected because it relies less on the grade to increase the intensity.

Metabolic Calculations for Energy Expenditure

Metabolic calculations were used to compare the measured VO_2 of the participants to widely accepted estimations of energy expenditure at each stage. For stage 1 a walking equation was used [$VO_2=3.5+(0.1*speed)+(1.8*speed*grade)$] (Thompson et al., 2014). For stages 2 and 3 the running equation was used [$VO_2=3.5+(0.2*speed)+(0.9*speed*grade)$] (Thompson et al., 2014). Using the equations provided a second aspect of comparison to see if the measured energy expenditure was similar to the estimation as well as to the matched participant.

Procedures

The study was approved by the institution review board (Appendix A). When the participants came in for testing, the researcher reviewed the purpose and methods of the study. The researcher went over the Costill/Fox Treadmill Protocol to make sure the participant was able to complete the test to the best of their capability. Informed consent was signed prior to testing. After the informed consent was signed and the PAR-Q (Appendix F) was filled out resting measurements (age, HR, BP, height, & weight) were taken. After resting vitals were taken the participant started the warm-up and then they started the Costill/Fox Protocol. When the test was completed the demographics of the LLA were used to recruit the able-bodied participant to test and compare their results. An iDXA scan was offered to each participant, to measure bone mineral density and body fat percentage. Participants signed a separate informed consent for the scan.

Design and Analysis

The purpose of this study was to determine if energy expenditure of a LLA is different from a matched able-bodied participant. The independent variable of this study was LLA, while the dependent variable was energy expenditure. The researcher focused on percent differences between the two participants since typically statistics are not applicable in a case study. These percentages help describe any similarities and differences.

Chapter Four: Results

Energy cost for lower limb amputees using a traditional prosthesis has been found to be greater during walking when compared to an able-bodied counterpart (Gailey et al., 1994). Newer studies with RSP are showing a closing of the gap between amputees and the able-bodied for energy expenditure (Brown et al., 2009). Therefore, the purpose of this study was to determine if energy expenditure of lower limb amputees with a RSP is different from an able-bodied person of similar age and height.

Participant Characteristics

There were a total of two participants (one amputee, one able-bodied) that completed the study. The amputee participant age was 39 years old, height was 75in, weight (without prosthetic) 280.6lbs. The amputee had a transtibial amputation on his right side. The able-bodied participant age was 38 years old, height was 74in, weight was 202.0lbs. Other characteristics collected from the iDXA scan are shown in Table 1.

VO_2

The participants, amputee and able-bodied, progressed to stage 3 of the Modified Costill/Fox Protocol. Relative VO_2 (mL/kg/min) was measured, therefore body weight could differ and still allow for comparison. The amputee participant terminated the testing due to hip pain. Test termination time for the amputee was 9.20min. The able-bodied participant terminated testing due to fatigue when entering into stage 4. Test termination time for the non-amputee was 12.01min.

The measured relative VO_2 for the participant with an amputation was: Stage 1: 12.5 ml/kg/min, Stage 2: 27.0 ml/kg/min, and Stage 3: 29.6 ml/kg/min. The measured relative VO_2 for the able-bodied participant was: Stage 1: 13.4 ml/kg/min, Stage 2: 29.4 ml/kg/min and Stage 3: 35.9 ml/kg/min. The standard metabolic equations show that VO_2 for each stage is estimated to be: Stage 1: 11.8 ml/kg/min, Stage 2: 35.1, and Stage 3: 38 ml/kg/min. See figure 2 for Stage 1, figure 3 for Stage 2, and figure 4 for Stage 3. This standard estimation was compared to the actual measured VO_2 for each.

Percent differences were calculated between the amputee and able-bodied participant and also calculated for the amputee and metabolic equations. The closer the measured VO_2 (smaller percent difference) is to the calculation means energy cost for an individual with an amputation is working at what has been calculated as average. The percent difference between the amputee and able-bodied participant show the non-amputee with greater VO_2 during each stage; Stage 1: 6.9%, Stage 2: 8.5%, and Stage 3: 19.2%. When the amputee was compared to the calculation, stage 1 the amputee had a greater percentage at 5.7% higher. Stages 2 and 3 the amputee's percentage was below the calculation at Stage 2: 26.1% and Stage 3: 24.9%.

Chapter Five: Discussion

Purpose/Hypothesis

The aim of this study was to determine if energy expenditure of lower limb amputees with a RSP is different from an able-bodied person of similar age and height. It was hypothesized that energy expenditure would not be significantly different in lower limb amputees using a RSP and able-bodied person.

Restatement of Results

Both the LLA and the able-bodied participant made it to Stage 3 of the modified Costill/Fox protocol. In Stage 3 VO_2 for the LLA was 29.6ml/kg/min, able-bodied participant was 35.9ml/kg/min, and the calculation intensity is 38ml/kg/min. The percent difference shows that the LLA was 19.2% lower when compared to the able-bodied participant. When the LLA was compared to the calculation, the percent difference showed the LLA was 24.9% lower than the calculation.

Comparison to Literature

The current study is unique in that it is the first study to compare a LLA with a RSP and an able-bodied participant during an incremental treadmill protocol. The current study is based off previous research comparing LLA and able-bodied participants during a discontinuous treadmill test with no grade (Brown et al., 2009). Studies that focused on walking protocols with LLA and included non-running specific prosthesis did not compare to able-bodied participants (Goktepe et al., 2010; Starholm et al., 2010). Studies that compared LLA and able-bodied participants using a walking protocol showed LLA without a RSP to have greater energy expenditure (Esposito et al., 2014; Gjovaag et al., 2014; Hunter et al., 1995; Schnall et al., 2012).

The current study is important that knowing if a LLA uses more energy than an able-bodied person to do the same task then possibly more advances in RSP could help. Better advances could range from comfort level to the mechanics of a RSP, to help reduce the energy cost so that sports and recreational activities can be easier and not at a possible disadvantage for having a prosthetic. This could mean, someone with an amputation fatigues earlier than their counterpart during a bout of exercise or during a competition. During a competition higher energy expenditure could result in lower placement standings.

Limitations

The primary limitation of this study is the number of participants recruited, without a sufficient sample size significance, similarities, or differences cannot be shown between the two groups. Additionally, the walking warm-up of the treadmill protocol caused pain in the hip of the LLA participant and he was not able to perform at his full potential due to the hip pain. The LLA participant terminated the test because of the hip pain. When the test was terminated the LLA informed the researchers that walking in the RSP caused pain due to the nature of it being designed for running, so the warm up would have been more beneficial as a jog for the LLA. However, other LLA report walking to be comfortable with the RSP. Such differences in how LLA are able to use the RSP creates challenges in selecting protocols to study energy expenditure in this group.

Strengths

The design of the study was a strength for this study, the researcher used variables, such as RSP and an incremental treadmill test, that have not been used in the established literature. Furthermore, this research compared the results to an able-bodied participant, also unique in the literature. The design of the study was the first to use an incremental treadmill protocol with LLA with a RSP

Future Research

Researchers wanting to investigate energy expenditure of LLA with a RSP compared to an able-bodied should look at changing the warm up of treadmill protocols. It was found that the warm up as a walk caused pain to LLA participants. Also, getting in connection with companies, support groups, and trainers that work with LLA to help recruit and how it can benefit them to help aid recruitment.

Conclusion

This case study compared LLA with a RSP to an able bodied matched participant. In the last stage completed of the protocol there was less than a twenty percent difference between the LLA participant and the able-bodied participant, with the LLA expending the least amount of energy. When compared to the literature one study compared LLA with a RSP and able-bodied participants and found no significant difference between the two groups ($p>.05$) (Brown et al., 2009). In order to find that the RSP has lowered energy expenditure to match able-bodied participants future research should conduct this protocol with the alteration of the warm up to a jog. More research could possibly help

LLA do any activity, such as sports, recreational activities, and walking and not be at a possible disadvantage from an able-bodied person by using more energy.

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Tables and Figures

Table 1

Participant Characteristics

	Amputee	Non-Amputee
Height (in)	75.0	74.0
Weight (lbs)	280.6	202.0
Sex	Male	Male
Age (years)	39	38
Run 2x or more a week	Yes	Yes

Figure 1. Photograph of a RSP.

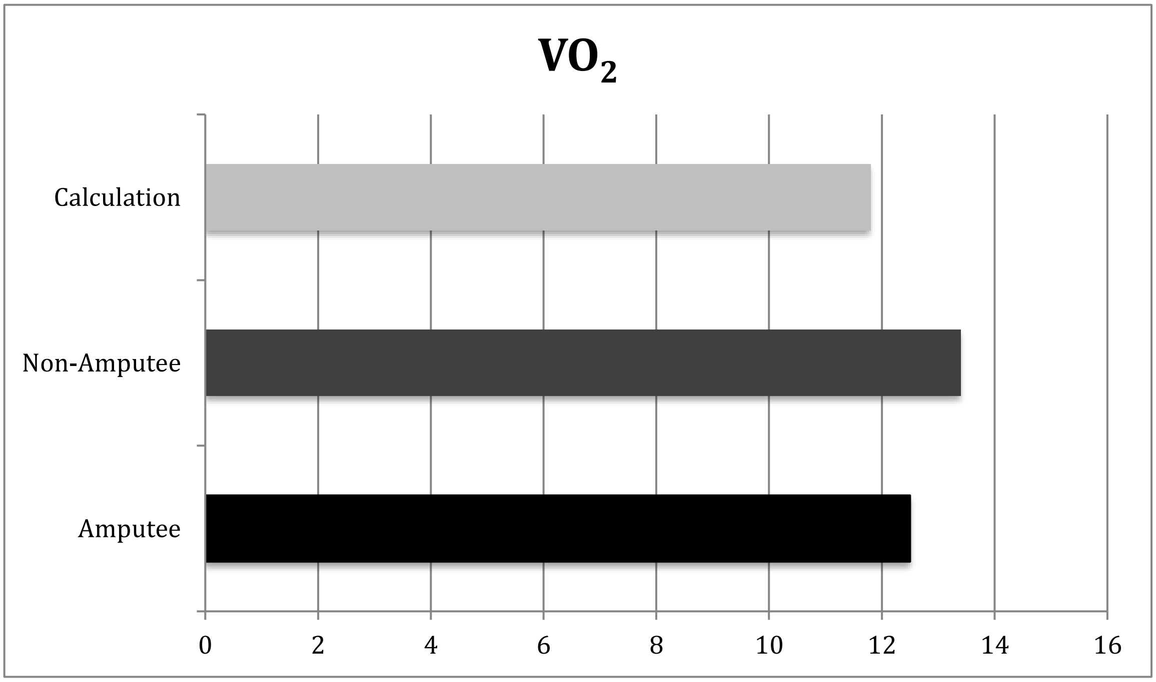

Figure 2. VO_2 results for Stage 1. VO_2 is measured in ml/kg/min.

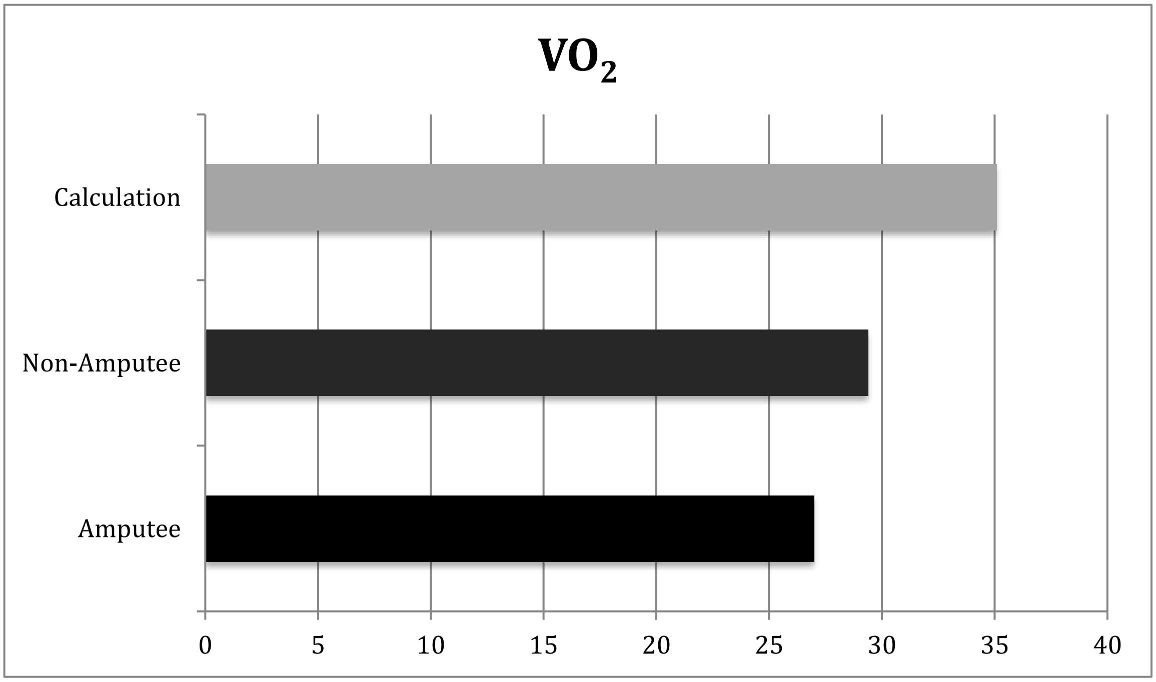

Figure 3. VO_2 results for Stage 2. VO_2 is measured in ml/kg/min.

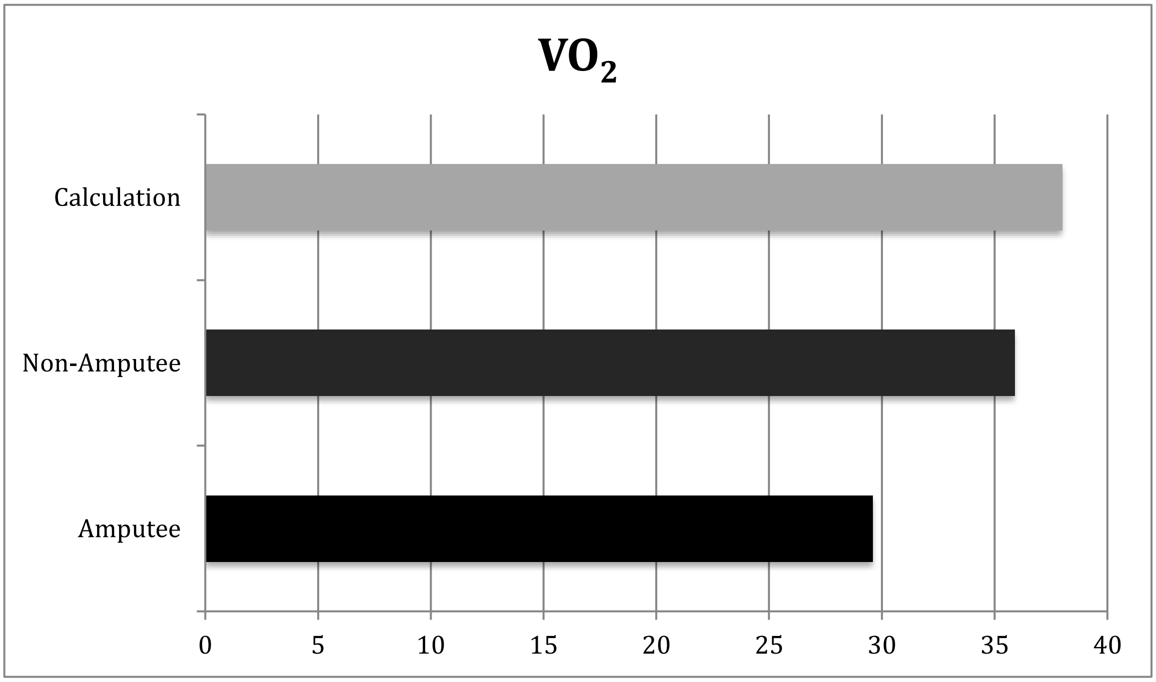

Figure 4. VO_2 results for Stage 3. VO_2 is measured in ml/kg/min.

Appendix A

Institutional Review Board Approval Email

February 15, 2018 IRB Application #: 17207

Proposal Title: Energy Expenditure Of Lower Limb Amputees Using A Running Blade Compared To Non-Amputees

Type of Review: Initial-Expedited

Investigator(s)

Mr. Matthew Blair

Dr. Jacilyn Olson

Department of Kinesiology & Health Studies

College of Education & Professional Studies

Campus Box 189

University of Central Oklahoma

Edmond, OK 73034

Dear Mr. Blair and Dr. Olson:

Re: Application for IRB Review of Research Involving Human Subjects

We have received your materials for your application. The UCO IRB has determined that the above named application is APPROVED BY EXPEDITED REVIEW. The Board has provided expedited review under 45 CFR 46.110, for research involving no more that minimal risk and research category 7.

Date of Approval: 2/15/2018

Date of Approval Expiration: 2/14/2019

If applicable, informed consent (and HIPAA authorization) must be obtained from subjects or their legally authorized representatives and documented prior to research involvement. A stamped, approved copy of the informed consent form will be sent to you via campus mail. The IRB-approved consent form and process must be used. While this project is approved for the period noted above, any modification to the procedures and/or consent form must be approved prior to incorporation into the study. A written request is needed to initiate the amendment process. You will be contacted in writing prior to the approval expiration to determine if a continuing review is needed, which must be obtained before the anniversary date. Notification of the completion of the project must be sent to the IRB office in writing and all records must be retained and available for audit for at least 3 years after the research has ended.

It is the responsibility of the investigators to promptly report to the IRB any serious or unexpected adverse events or unanticipated problems that may be a risk to the subjects.

Please let us know if the IRB or Office of Research Integrity and Compliance can be of any further assistance to your research efforts. Never hesitate to contact us.

Sincerely,

Melissa Powers, Ph.D.
Chair, Institutional Review Board
University of Central Oklahoma
100 N. University Dr.
Edmond, OK 73034
405-974-5497 irb@uco.edu

Appendix B

Informed Consent Form

University of Central Oklahoma

UCO IRB Number 17207
For Office Use Only

UNIVERSITY OF CENTRAL OKLAHOMA
INFORMED CONSENT FORM

This is a template including all of the necessary elements of an Informed Consent Form. It is not necessary to use this form. In some cases, you may need another format, i.e. an online survey, a participant letter, etc. See Informed Consent Guidelines on our website for more information.

Research Project Title: Energy expenditure of lower limb amputees using a running blade compared to non-amputees.

Researcher (s): Matthew Blair and Dr. Jacilyn Olson

A. **Purpose of this research:** The purpose of this study is to determine if energy expenditure of lower limb amputees with a running specific prosthesis would be different of an able-bodied person.
B. **Procedures/treatments involved** When participants come in for testing, the researcher will have the participant complete a physical activity readiness questionnaire (PAR-Q), if they do not check any boxes then what is expected and required of the participants will be discussed. The PAR-Q is a health information sheet to assess if medical clearance is necessary. If any box is checked on the PAR-Q then the participant will not be able to participate. After the informed consent is signed and the PAR-Q is filled out resting measurements (age, heart rate (HR), blood pressure (BP), height, & weight) will be taken. The researcher will ask for date of birth, take the radial pulse for the heart rate (light pressure applied to the wrist), take blood pressure with a blood pressure cuff and stethescope; placing the stethescope right above the brachial artery (tightening of the blood pressure cuff around the upper arm), height and weight will be recorded from the digital scale that is available in the University of Central Oklahoma (UCO) lab. The researcher will go over procedures of the iDXA. The iDXA produces an image that shows body fat percentage and bone density. The participant will remove prosthetic. For the iDXA the participants identification number they were assigned will be used, the participants age, height, and weight will be entered into the computer. After the participants information is entered they will be asked to remove their prosthetic, then asked to lay on the iDXA and be centered on the lines, per the manual. When the participant is ready the start button will be clicked on and the arm on the iDXA will move down the participants body. When the scan is done the results will be printed and the researcher will go over the results with the participant. The researcher will go over the Costill/Fox Treadmill Protocol to make sure the participant is able to complete the test to the best of their capability. The protocal consists of participants starting with a light warm-up on the treadmill at a speed of 3.1 mph for 4 minutes. The protocol includes the speed in mph to increase every 4 minutes (5.9, 7.5, 8.4, & 9.9). When the participant reaches a rate of perceived exhaustion (RPE) of 13 the speed will stay constant and the grade will increase 2% every 2 minutes until exhaustion. Exhuastion for

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the participants will feel like a physical fatigue. Participants will reach exhaustion state when their heart rate gets close to age predicted max, respiratory exchange ratio (RER) is greater than 1.1, or the participant request to stop. During the protocal the participant will experience an increase in heart rate, fatigue, exertion, and lower body fatigue from the grade increases. The researcher will get a print out of the resutls and discuss the results with the participant. When the test is completed the demographics of the LLA's will be taken in order to recruit an able-bodied participant to test and compare their results. An able-bodied participant is someone without an amputation.

C. **Expected length of participation:** 1-2 hours
D. **Potential benefits:** Knowing energy expenditure and VO2 Max, which will show the participant their maximal oxygen intake. iDXA scan results.
E. **Potential risks or discomforts:** Risks include residual limb pain and the participant going to maximal effort on a treadmill protocol. The most common risk of the maximal testing includes muscle soreness and fatigue.The least likely risk is a cardiovascular event, for every 10,000 tests there are six cardiovascular events. The risk for the iDXA scan include small amounts of exposure to ionizing radiaiton. Frequent exposure to radiation has an accumulating effects and potentially harmful.
F. **Medical/mental health contact information (if required):** 100 N. University Drive, Edmond, OK 73134. Wellness Center, Room 105. (405)-974-3161
G. **Contact information for researchers:** Primary Investigator (PI)-Matthew Blair (405)-227-5659, mopp1@uco.edu. Co-PI-Dr. Jacilyn Olson (405)-974-5681, jolson3@uco.edu
H. **Contact information for UCO IRB:** Office of Research Integrity and Compliance. Nigh University Center 341, Box 132. (405)-974-5497 or (405)-974-5479. irb@uco.edu
I. **Explanation of confidentiality and privacy:** All information will be stored in a locked filing cabinet in a locked office. The participants name will not be connected to their results, each participant will have an identification number. The results will be reported together as a collective. The participants identification number will be used for the iDXA scan as their name.
J. **Assurance of voluntary participation:** Participation in this study is completely voluntary. You may choose to stop or leave the study at any time. There is no penalty or loss of benefit for dropping out of the study.

AFFIRMATION BY RESEARCH SUBJECT

I hereby voluntarily agree to participate in the above listed research project and further understand the above listed explanations and descriptions of the research project. I also understand that there is no penalty for refusal to participate, and that I am free to withdraw my consent and participation in this project at any time without penalty. I acknowledge that I am at least 18 years old. I have read and fully understand

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this Informed Consent Form. I sign it freely and voluntarily. I acknowledge that a copy of this

Informed Consent Form has been given to me to keep.

Research Subject's Name: ______

Signature:

Date: ______

Approved
FEB 15 2018
UCO IRB

Approval
FEB 14 2019
Expires

Appendix C

Flyer for Recruitment for Amputees

Looking for Lower Limb Amputee volunteers with a Running Specific Prosthesis

If you enjoy running and would like to find out your VO2 max then contact Matt Blair (contact info below), to find out if you can be a part of this Research Study

FREE iDXA Scan

Must be at least 18 years or older and complete a PAR-Q to participate in the study

Must have a Running Specific Prostheses already and

have had it for at least 6-months and currently

running recreationally or in a group or club

This project has been approved by the

University of Central Oklahoma

Institutional Review Board (#17207)

For more info please contact: Matt Blair, email: mopp1@uco.edu

Appendix D

Flyer for Recruitment for Non-Amputees

Looking for volunteers

Who enjoy running

If you enjoy running and would like to find out your VO2 max then contact Matt Blair (contact info below), to find out if you can be a part of this Research Study

FREE iDXA Scan

Must be at least 18 years or older and complete a PAR-Q to participate in the study

Must currently be running

recreationally or in a group or club

This project has been approved by the

University of Central Oklahoma

Institutional Review Board (#17207)

For more info please contact: Matt Blair, email: mopp1@uco.edu

Appendix E

Rate of Perceived Exertion Scale

RPE Scale

#	Level of Exertion
6	No exertion at all
7	
7.5	Extremely light (7.5)
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Retrieved from Centers for Disease Control and Prevention

Appendix F

PAR-Q

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

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If you answered

YES to one or more questions

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

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

NO to all questions

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

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

DELAY BECOMING MUCH MORE ACTIVE:

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

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

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

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

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

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

NAME ________________________________

SIGNATURE ________________________________ DATE ________________

SIGNATURE OF PARENT ________________________________ WITNESS ________________
or GUARDIAN (for participants under the age of majority)

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

CSEP SCPE © Canadian Society for Exercise Physiology Supported by: Health Canada Santé Canada

continued on other side...