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Physical activity, functional capacity, and step variability during walking in people with lower-limb amputation

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ABSTRACT

Physical activity is important for general health. For an individual with amputation to sustain physical activity, certain functional capacity might be needed. Gait variability is related to the incidence of falls. This study explored the relationship between physical activity and a few common performance measures (six-minute walk test, step length variability, step width variability, and comfortable walking speed) in individuals with unilateral lower-limb amputation. Twenty individuals completed the study (age: 50 ± 11 yrs). Twelve of them had transtibial amputation, seven had transfemoral amputation, and one had through-knee amputation. Gait data was collected by the GaitRite instrumented walkway while participants performed a 3-min comfortable walking trial followed by a six-minute walk test. Physical activity was indicated by the mean of 7-day step counts via a pedometer. Gait variability was calculated by the coefficient of variation. Pearson correlation analysis was conducted between physical activity level and the 4 performance measures. Significance level was set at 0.05. Physical activity correlates strongly to comfortable walking speed ($r = 0.76$), six-minute walk distance ($r = 0.67$), and correlates fairly to step width variability ($r = 0.44$). On the contrary, physical activity is inversely related to step length variability of the prosthetic leg ($r = -0.46$) and of the sound leg ($r = -0.47$). Having better functional capacity and lateral stability might enable an individual with lower-limb amputation to engage in a higher physical activity level, or vise versa. However, our conclusions are only preliminary as limited by the small sample size.

1. Introduction

Studies have consistently showed a positive association between physical activity and health-related quality of life and a reduction of all-cause mortality [1]. Current guidelines recommend that adults engage in moderate-intensity physical activity 5 days a week or vigorous-intensity activity 30 min a day for at least 3 days a week [2]. Physical activity can be estimated by a self-reported questionnaire, an accelerometer, or a pedometer [1,3]. A pedometer recording step counts is inexpensive, reliable, and correlates well with an accelerometer [4]. To sustain optimal physical activity a person may require a certain degree of aerobic capacity, muscle strength, and balance abilities.

Most people with a lower-limb amputation are less active. Ten thousand steps per day is the recommended activity level for adults [2], whereas a sedentary lifestyle is generally defined as fewer than 5000 steps per day [5]. Daily step counts in individuals with lower-limb amputation range from 2500 to 8500 steps depending on age, reason of amputation (vascular vs. traumatic) [6,7], level of amputation, comorbidity [8], and types of prosthetic foot [9]. For individuals with lower-limb amputation, a higher physical activity level was associated with a better perceived quality of life [10]. Therefore, promoting physical activity is important in this population.

A person's self-selected walking speed (SSWV) is very close to speeds with the least energy consumption per distance traveled [11]. It is a reliable measure and a strong predictor of disability [12]. In general, It ranges from 1.27 m/s to 1.46 m/s in normal adults and decreases with age [13]. In individuals with transtibial amputation, it ranges from 1.12 m/s to 1.18 m/s [9], which is just slightly faster than the speed required for community ambulation [14]. A person with a higher physical activity level is shown to have a faster SSWV [15]. However, we do not know whether this is also true for individuals with lower-limb amputation.

Determining exercise capacity is challenging for people with disabilities, and standard equipment may not be applicable such as treadmill, upright cycle ergometer, and stair stepper machine. Field exercise tests, such as walk tests, provide an alternative. The

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six-minute walk test measures the maximal distance a person can cover in 6 min (distance of the six-minute walk test, or 6MWD). It is easy to administer, relates to day-to-day activity, and physiological responses can be monitored. In addition, it demonstrates good test-retest reliability [16], and is strongly related to a person's peak oxygen consumption [17]. A 6MWD of less than 300 m predicts an increased likelihood of death within 6 months in patients with heart failure [17]. Relationship between physical activity and 6MWD has not been reported in individuals with amputation.

During walking, the anterior/posterior stepping motion control is passive in nature or only requires a low level of control; whereas lateral stability requires more active control through adjusting step width continuously [18,19]. At normal walking speed, the preferred step width is about 12 cm, which is the most energy efficient [20]. During running, the step width is near zero, in order to enhance step-to-step transition. People with lower-limb amputation often adapt a larger base of support for compensation of impaired sensation due to limb loss [21]. If an amputee can narrow the step width of walking to be close to that of non-amputees, then he/she must have a better control of lateral stability and could walk faster. At normal walking speed, mechanical efficiency is known to inversely relate to step length variability [11]. Gait variability is often expressed as the standard deviation, or coefficient of variation, of a series of steps. Increased step length variability or reduced step width variability is associated with increased risk of falls [22,23]. Exploring the relationship between physical activity and gait variability may shed light on the effects of promoting physical activity on gait performance in amputees.

The purpose of this study was to explore the associations between physical activity level and physical performance measures (self-selected walking velocity, 6MWD, step length variability, and step width variability) in individuals with lower-limb amputation. We hypothesized that a higher physical activity level, as indicated by daily step count, would be associated with a faster self-selected walking velocity, a higher functional capacity, a smaller step length variability, and a larger step width variability during comfortable walking in persons with lower-limb amputation.

2. Materials and methods

2.1. Subjects

An appropriate sample size was estimated based on the finding that 6MWD was a strong predictor of step count and step rate, accounting for 38–54% of the variance [15,24]. Assuming the standardized effect size for Pearson's correlation of 0.62, to achieve a statistical power of 80% at an $\alpha 2$ level of 0.05, we estimated that about 18 subjects were needed.

Subjects were recruited from local amputee support groups in a metropolitan area. The inclusion criteria were: (1) independent walking with a prosthesis, (2) experience with prosthesis use over 6 months, (3) intact skin condition of the residual limb, and (4) well controlled medical conditions. Thirty-five people with lower-limb amputation were recruited. Thirteen individuals were excluded due to the following reasons: 2 required a walking aid, 2 were having their prostheses adjusted, 1 had an ankle fusion, 1 had a bilateral amputation, 2 had health issues, and 5 decided not to participate due to commuting or scheduling conflicts. Therefore, a total of 22 subjects were enrolled and informed consent was obtained. This study was approved by the Institutional Review Board of our institution.

2.2. Protocol

Each subject came in for a one-hour session consisting of a history interview for demographic data and measurement of self-selected walking velocity and 6MWD. Each subject was instructed to walk at his/her comfortable speed for three minutes back and forth across a 13.41 m (44 ft) segment of a hallway with a 4-m GAITRite[1] instrumented mat placed at the middle of the segment. The GAITRite system was shown to have good test-retest reliability and concurrent validity [25]. Step length is defined as the distance from the heel center of the current footprint to the heel center of the previous footprint on the opposite foot along the line of progression. Step width is defined as the mediolateral distance from the midline midpoint of one footprint to the line formed by the midline midpoint of two footprints of the opposite foot. Step variability is expressed as the coefficient of variation of a series of steps (i.e. (standard deviation/mean) $\times$ 100%).

For the six-minute walk test, each participant was instructed to walk as far as they could for 6 min along a 150 ft segment of a hallway. Vital signs were obtained before and after the test, including heart rate, blood pressure, and perceived exertion [26]. Subjects were instructed to stop immediately if signs and symptoms of exercise intolerance were experienced or observed [16]. After testing, each subject was given a pedometer[2] to wear at the waist level and to attempt walking for a short distance to make sure the pedometer was functioning properly. Then they were instructed to wear the pedometer for the next 7 days from the time they woke up until they went to bed, except when they took a shower, and to continue their normal routine. They recorded the number of steps each day, then either emailed, called, or texted our research team their daily step counts. The reliability of the pedometer was previously tested on a few healthy individuals in our lab (Appendix 1).

2.3. Data analysis

Descriptive statistics were used for demographic data. Gait data were exported to Excel for initial analysis. Pearson's Product Moment Correlation analysis was conducted with SPSS 15.0 for Windows[3] to examine the relationships between physical activity and the following performance measures: self-selected walking velocity, distance of the six-minute walk test, step length variability of the sound leg, step length variability of the amputated leg, and step width variability. We used the mean of 7-day step count to represent physical activity level since daily step count is a common measure of physical activity. To account for possible variation in the day to day step counts, we also examined the correlation between the mean of 7-day step counts and the total 7-day step counts.

In view of the small sample size, regression analysis was not applicable. Therefore, we examined the correlations between physical activity level and anthropometric characteristics to identify potential co-variables. We also examined the relationship between step width and step width variability, and between step width and physical activity level to help us better understand the trend of step width variability. Statistical significance level was set at 0.05.

3. Results

Two subjects dropped out from the study. One individual had back pain. The other individual developed redness in the residual limb and required prosthesis adjustment, so they stopped

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[2] Impulse, model B-1, Deer Park, NY 11729, USA.
[3] IBM Corporation, 1 New Orchard Rd., Armonk, NY 10504, USA.