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Relationship between level of daily activity and upper-body aerobic capacity in adults with a lower limb amputation

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Abstract

Background: Previous studies show that people with lower limb amputation (LLA) have a sedentary lifestyle, reduced walking capacity, and low cardiorespiratory fitness (VO_2peak). There is, however, no knowledge on the relationship between cardiorespiratory fitness and objectively measured level of physical activity in daily life.

Objectives: To investigate the relationship between upper-body VO_2peak, physical activity levels, and walking capacity in persons with LLA.

Study design: Correlational and descriptive study.

Methods: Fourteen participants with LLA performed an assessment of VO_2peak on an arm-crank ergometer and walking capacity (preferred walking speed and 2-minute walking test). Level of physical activity was measured over 7 days with a step activity monitor (number of steps; sedentary time; and proportion of low-intensity, moderate-intensity, high-intensity, and peak-intensity activity level).

Results: VO_2peak correlated significantly with number of steps per day ($r = 0.696$, $p = 0.006$), sedentary time ($r = -0.618$, $p = 0.019$), high-intensity activity level ($r = 0.769$, $p = 0.001$), and peak-intensity activity level ($r = 0.674$, $p = 0.008$). After correcting for age, correlations were still large and significant. Large correlations were also found between VO_2peak, preferred walking speed ($r = 0.586$, $p = 0.027$), and 2-minute walking test ($r = 0.649$, $p = 0.012$).

Conclusions: We provide the first evidence of the strong relationships between upper-body VO_2peak, sedentary behavior, high-intensity activity level, and walking capacity in persons with LLA. Further research is needed to investigate the potential effect of upper-body cardiorespiratory fitness on the level of activity in daily life, or vice versa.

Keywords

physical activity, VO_2peak, cardiorespiratory fitness, walking capacity, arm cranking

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Background

Losing a lower limb has a major impact on a person's life. Limitations in mobility, physical functions, and capacity caused by limb loss require substantial adaptations by the individual to achieve a satisfactory level of functioning. Yet, many people with lower limb amputation (LLA) are not able to meet sufficient levels of physical activity and adopt a sedentary lifestyle.[1] Physical inactivity is associated with a decline in cardiorespiratory fitness, which is a significant predictor of cardiovascular disease and all-cause mortality.[2] On the other hand, studies have consistently demonstrated the positive effect of physical activity on health-related quality of life and reduction of all-cause mortality in the general adult population[2] and the elderly.[3] Similarly, the physical activity level is also positively associated with walking speed, walking capacity, and quality of life in people with LLA.[4] To date, there is no knowledge about the relationship between cardiorespiratory fitness and physical activity level in people with LLA's daily lives.

In the general population, strong evidence exists that sedentary behavior and physical activity levels are associated with cardiorespiratory fitness. The National Health and Nutrition Examination Survey showed that an additional hour of daily activity time positively influenced cardiorespiratory fitness, whereas an additional hour of sedentary time was negatively associated with cardiorespiratory fitness.[5] Correspondingly, in a large study of 2500 participants, Santos et al[6] reported that persons with a high level of sedentary behavior showed lower cardiorespiratory fitness compared with persons with little sedentary behavior, *regardless* of the amount of moderate-to-vigorous intensity physical activity the latter group performed. These findings suggest that the level of activity and sedentary behavior have an independent relationship with aerobic capacity.

Lower levels of physical activity in people with LLA might be associated with a reduced walking capacity. People with LLA have a substantially lower preferred walking speed (PWS) and increased oxygen uptake per meter walked (i.e. worsened walking economy) compared with able-bodied persons.[7] The worsened walking economy is associated with a higher rating of perceived exertion

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and limited ability to sustain walking activity.[7] In addition, people with LLA use a higher proportion of the peak aerobic capacity (VO_2peak) during ambulation.[8] Because of deconditioning and/or comorbidities, people with LLA commonly have lower VO_2peak values than able-bodied controls.[9] Consequently, normal ambulation and other daily physical activities require more physical effort in percent utilization of the VO_2peak. Studies have shown that persons with LLA use approximately 55%–73% of their VO_2peak and control persons 31%–50% during walking at their respective PWS, despite the 20%–44% lower PWS for persons with LLA compared with controls.[10,11]

Although the assessment of VO_2peak is not a standard procedure in studies focusing on the mobility of people with LLA,[7] there is evidence showing that aerobic capacity is an important determinant for walking capacity.[11,12] A higher level of physical fitness is reported as a predictor of successful prosthetic rehabilitation.[13] Moreover, improvement of aerobic capacity has demonstrated positive effects on walking economy,[12] prosthetic ambulatory capacity,[14] and gait symmetry.[15] Whereas most of these studies use 1-leg cycling or other test modalities that involve the lower body,[12,14,16] exercise involving the lower limbs is sometimes discouraged because of the risk of skin infections of the stump and is not feasible during preprosthetic rehabilitation.[17] Alternative exercise modalities that involve the intact upper body, such as arm-crank ergometry, reduce the burden on the amputated limb and allow comparison of measurements across different patient populations and healthy persons. Arm-crank ergometry is shown to be a good predictor of prosthetic fitting after amputation and to be effective in improving physical fitness of people with LLA.[18] To date, arm-crank ergometry has never been used to investigate the relationship between VO_2peak and the level of physical activity in people with LLA.

Therefore, the primary aim of this study was to analyze the relationship between levels of physical activity in daily life and peak aerobic capacity (VO_2peak) using an incremental arm-cranking protocol, in people with LLA. The level of activity was objectively measured with a step monitoring device for 7 days and analyzed as the number of steps per day and the proportion of sedentary behavior time and physical activity categorized in low, moderate, high, and peak intensity. The secondary aim was to investigate the relationship between walking capacity, assessed as PWS and performance on the 2-minute walking test (2MWT), and VO_2peak. We hypothesized that the proportion of sedentary time would be negatively associated with VO_2peak values, whereas physical activity regarding steps per day and higher proportions of high-intensity and peak-intensity activity levels would be positively associated with VO_2peak. Furthermore, we hypothesized that PWS and distance on the 2MWT would be positively associated with VO_2peak.

Methods

Participants

The recruitment of participants was performed in collaboration with the user organization momentum who sent an invitation letter to patients and/or members in their database to provide information about voluntary participation in the project. Interested persons then contacted the researchers regarding participation in this study. The following inclusion criteria were applied: age between 18 and 75 years, unilateral transtibial, transfemoral, or knee-disarticulation amputation, minimum of 1 year since amputation, minimum of 6 months of experience with a prosthesis, and the ability to walk 500 m without walking aid. To avoid any health-related risk that could arise with maximal exercise testing, persons with an amputation due to vascular disease were excluded. This research project was approved by the Regional Committee for Medical and Health Research Ethics in Norway and the Norwegian Centre for Research Data. All participants signed informed consent before data collection.

Procedure

Participants were instructed to avoid strenuous exercise and alcohol consumption 24 hours before their visit to the Motion Analysis Laboratory at Oslo Metropolitan University. With arrival to the laboratory, the following demographic and clinical data were collected: sex, age, weight with prosthesis, height, level of amputation, etiology of amputation, number of years since amputation, occupation, and use of medication and/or tobacco. The body mass index was calculated as weight (kg)/height (m).[2] In addition, participants were asked whether they used a walking aid and/or wheelchair, and what type of recreational physical activities they performed.

Testing started with measurements of walking capacity, that is, PWS and 2MWT. After a resting period, participants performed a maximal incremental exercise test on an arm-crank ergometer. At the end of the testing session, participants were fitted with a StepWatch Activity Monitor (SAM) (Modus Health) to monitor daily-life ambulation and physical activity for seven consecutive days. Participants were asked to send the SAM back to the researchers by mail service.

Peak aerobic capacity

Upper-body VO_2peak was assessed with an incremental exercise test on a Monark 881 Arm Ergometer (Monark Exercise, Varberg, Sweden), which was calibrated according to the manufacturer's instructions. Throughout the test, oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER: VCO_2/VO_2) were measured breath-by-breath with a validated and portable metabolic analyzer (Metamax 3B, Cortex Biophysik, Leipzig, Germany).[19] The heart rate was recorded beat-by-beat (Polar, Kempele, Finland) and interfaced with the metabolic analyzer. Before each test session, the flow-volume turbine was calibrated using a standardized 3-L syringe (Hans Rudolph, Shawnee). The oxygen analyzer was calibrated for barometric pressure and ambient air that was verified with a reference gas mixture of 16% O_2 and 4% CO_2, according to the manufacturer's instructions. Before testing started, the position of the ergometer was adjusted with the participant in a seated position with both feet flat on the ground. The knee and hip joints were in a 90-degree angle, and the crankshaft was in alignment with the center of the shoulder joint. The distance between the ergometer and the participant was adjusted such that the elbow had an angle of approximately 15 degrees at maximal elbow extension while holding the handgrip. The participants were instructed to maintain a cadence of 50 rotations per minute (rpm) throughout the test. After a 3-minute familiarization and warm-up period with a work rate of 10 W, the work rate increased to 25 W, and the load was then increased 10 W each minute. Participants were verbally encouraged to exercise until volitional exhaustion.

In contrast to lower-body exercise, there are no fixed end criteria for termination of arm-cranking exercise. Because of the limited muscle mass in the upper extremities, most people are not able to sustain the exercise until maximal cardiorespiratory levels reach a plateau in oxygen uptake.[20] Thus, local fatigue, rather than cardiorespiratory exhaustion, is often the reason for test termination. Therefore, based on previous protocols for upper-body modality exercise, the following criteria were applied to determine if the test was maximal: the inability to maintain the predetermined crank rate of 50 rpm,[21] a rating of perceived exertion ≥18 using the 6–20 Borg scale,[21] RER values >1.1,[22] and volitional exhaustion. To further assess whether the exertion was maximal, capillary blood lactate (La^-) samples (Lactate Pro2, Arkrav, Shiga, Japan) were taken before and 1 minute after testing.

Walking capacity

Preferred walking speed was measured with a 5-m Optogait system (Microgate, Bolsano-Bozen, Italy) that was placed in the middle of a 10-m walking course. The Optogait system is a floor-based photocell system that detects gait parameters during walking and has strong concurrent validity and test-retest reliability.[23] The average value of two completed walking measurements was considered as the individual's PWS.

The 2MWT is a standard time-fixed test to assess walking capacity. Because of space limitation in the laboratory, a 15-m course with cones at each end was chosen as a valid course layout.[24] Participants were instructed to walk as far as they could in 2 minutes. The test was scored with the distance in meters, a greater distance indicating a higher walking capacity. The 2MWT has high interrater and intrarater reliability, is responsive to change before and after rehabilitation,[25] and is a good predictor of the 6-minute walking test and community ambulation potential in people with LLA.[26]

Level of physical activity

Level of physical activity was measured with the SAM attached to the prosthetic limb at the ankle level and calibrated according to the manufacturer's instructions. It is an accurate and reliable monitor for analyzing slow, irregular, or impaired gait in people with LLA.[27] The SAM reports the number of steps taken with the prosthetic limb in 10-second intervals, and multiplying by 2 provides the total number of steps taken with both limbs. The number of steps taken per minute (cadence) is a measure of the intensity of walking activity and has been reported as a good indicator of ambulatory skills.[28] For this study, we used the mean value of the total number of steps taken each day and the intensity of walking activity categorized as sedentary (0 steps per minute), low-intensity (1–15 steps per minute), moderate-intensity (16–40 steps per minute), or high-intensity (>40 steps per minute) activity.[29] In addition, we calculated the peak-intensity activity level, which is the average value of the 30 nonconsecutive minutes with the highest cadence throughout a 24-hour day.

Data analysis

MATLAB software (R2019a, Mathworks) was used to extract VO_2peak values from cardiorespiratory data and to calculate step count data from the SAM. Statistical analysis was performed in SPSS Statistics version 25.0 for Windows10 (IBM). Descriptive data are presented as means ± SD and range values. All variables were tested for normality using the Shapiro-Wilk test. We performed a Pearson correlation analysis without correction, followed by a Pearson correlation analysis corrected for the variable age, because VO_2peak declines with aging.[30] Correlation coefficient values of 0.1, 0.3, and 0.5 are considered as small, moderate, and large correlations, respectively.[31] Statistical significance is reported as either $p < 0.05$ or $p < 0.01$.

Results

Demographic and clinical data

Fourteen participants (2 females) with LLA volunteered for this study (Table 1). All participants reported that they used their prosthesis daily, and 2 participants reported that they used a wheelchair in their home. Ten participants performed recreational physical activities, of which 5 participants were engaged in upper-body activities that did not involve prosthetic use. Four participants did not perform recreational activities. Participants reported the following medication use: beta-blocker (4), antihistamine (2), pain relief (2), cholesterol-lowering drugs (1), blood thinner (1), and antiepileptica (1).

Walking capacity and physical activity measurements

The number of steps per day showed a large range, with the most active participant taking approximately 3 times as many steps as the most inactive participant, that is, approximately 9000 vs. 3000 steps per day (Table 2). On average, participants spent approximately 3.5 hours with step activity throughout a 24-hour day, whereas the SAM did not record steps in the remaining 20.5 hours, that is, 85.2 ± 4.3 percent of the time. This indicates that the participant was sitting, sleeping, using a wheelchair, or did not wear the prosthesis for other reasons. Only about 2.8 ± 1.4 percent of the total time was characterized as high intensity (>40 steps per minute), corresponding to approximately 40 minutes of high-intensity walking per day.

Peak aerobic capacity

All participants exercised until volitional exhaustion with the inability to maintain the predetermined crank rate and rated their performance with an rating of perceived exertion value ≥18 (Table 2). Objective measures of maximal exertion included an average postexercise blood lactate value of 8.8 mmol/L and an average RERpeak value of 1.23. Hence, we judged that all participants achieved valid VO_2peak values during arm-cranking exercise.

Correlations

Pearson correlation analyses were performed between VO_2peak and walking capacity (PWS, 2MWT) and SAM measures, with and without correction for age (Table 3). After correction for age, significant large positive correlations were found between VO_2peak, steps per day, high-intensity activity level, and peak-intensity activity

Table 1. Demographic and clinical data (n = 14).

ID	Sex	Age (yr)	BMI (kg/m^2)	Time since amputation (yr)	Level of amputation	Etiology	Occupation	Tobacco use	Activity
1	F	62	21.5	57	KD	Trauma	Employed	Yes	NA
2	M	38	31.7	6	TTA	Trauma	Employed	No	UBA, LBA
3[a]	M	64	25.2	7	TFA	Arthrofibrosis	Unemployed	No	UBA
4	M	47	32.0	15	TTA	Trauma	Employed	No	WBA, LBA
5	M	47	24.9	23	TFA	Cancer	Employed	Yes	UBA
6	M	59	21.0	6	TTA	Trauma	Employed	No	UBA
7	M	48	24.0	48	KD	Congenital	Employed	Yes	WBA
8	M	62	26.2	10	TTA	Trauma	Retired	No	WBA
9	F	61	26.6	8	TTA	Surgery error	Retired	Yes	NA
10	M	68	25.0	24	TFA	Infection	Employed	No	N
11	M	69	20.4	52	TTA	Trauma	Retired	Yes	NA
12	M	44	22.9	26	TTA	Cancer	Employed	No	WBA, LBA
13	M	55	25.7	5	TFA	Trauma	Employed	No	WBA
14[a]	M	45	25.4	15	TFA	Trauma	Employed	No	UBA
Mean ± SD		55.7± 10.1	26.3± 5.5	20.5± 18.0					

F: female; M: male; BMI: body mass index; KD: knee disarticulation, TTA: transtibial amputation; TFA: transfemoral amputation; NA: no activity; UBA: upper-body activity; LBA: lower-body activity; WBA: whole-body activity.

[a] *Participants who use a wheelchair in their home.*

level. There was a significant large negative correlation between VO$_2$peak and sedentary time. VO$_2$peak showed a significant large positive correlation between VO$_2$peak and 2MWT. The 4 participants who performed no recreational physical activity in their daily life showed lower VO$_2$peak than the ten participants who were engaged in recreational physical activity including upper-body, whole-body, or lower-body exercise (Figure 1).

Discussion

The primary aim of this study was to analyze the relationship between levels of physical activity and upper-body VO$_2$peak. Following our hypotheses, the correlation analysis after correcting for age showed that VO$_2$peak was significantly correlated with the number of steps per day, and high-intensity and peak-intensity activity level. In agreement with our findings, Lin et al showed that

Table 2. Upper-body aerobic capacity, walking capacity, and activity level data (n=14).

Parameter	Mean ± SD	Range
Aerobic capacity		
VO$_2$peak (L/minute)	2.04 ± 0.60	0.98–3.17
VO$_2$peak (mL/minute/kg^{-1})	24.5 ± 6.4	10.75–38.40
RERpeak (VCO$_2$/VO$_2$)	1.23 ± 0.078	1.12–1.34
RPE, post-test	18.3 ± 0.7	18.0–20.0
[La$^-$]$_b$ (mMol/L), post-test	8.8 ± 2.7	4.8–15.0
Walking capacity		
PWS (m/second)	1.25 ± 0.23	0.69–1.55
2MWT (m)	171.1 ± 33.1	110.0–240.0
Activity level		
SAM (steps per day)	5537 ± 2093	2700–8733
SAM sedentary time (% of 24-hour day)	85.2 ± 4.3	78.0–92.2
SAM low-intensity level (% of 24-hour day)	6.0 ± 1.7	3.0–9.3
SAM moderate-intensity level (% of 24-hour day)	5.9 ± 1.7	2.5–7.1
SAM high-intensity level (% of 24-hour day)	2.8 ± 1.4	0.9–5.5
SAM peak-intensity level (steps per minute)	66 ± 16	42–90

VO$_2$peak: peak aerobic capacity; RERpeak: peak respiratory exchange ratio; RPE: rating of perceived exertion; [La$^-$]$_b$: blood lactate concentration; PWS: preferred walking speed; 2MWT: 2-minute walking test; SAM: step activity monitor.

Table 3. Correlation coefficients between parameters of activity level, walking capacity, and VO$_2$peak (n = 14).

	VO$_2$peak	
	No correction	**Corrected for age**
Activity level		
SAM (steps per day)	0.696 (0.006)[a]	0.663 (0.014)[b]
SAM sedentary time (% of 24-hour day)	−0.618 (0.019)[b]	−0.569 (0.042)[b]
SAM low-intensity activity level (% of 24-hour day)	0.562 (0.037)[b]	0.499 (0.082)
SAM moderate-intensity activity level (% of 24-hour day)	0.331 (0.247)	0.272 (0.369)
SAM high-intensity activity level (% of 24-hour day)	0.769 (0.001)[a]	0.754 (0.004)[a]
SAM peak-intensity activity index (steps per day)	0.674 (0.008)[a]	0.606 (0.028)[b]
Walking capacity		
PWS	0.586 (0.027)[b]	0.443 (0.130)
2MWT	0.649 (0.012)[b]	0.567 (0.043)[b]

2MWT: 2-minute walking test; PWS: preferred walking speed; SAM: step activity monitor.
[a] *Correlation is significant at the 0.01 level.*
[b] *Correlation is significant at the 0.05 level.*

the physical activity level (mean steps per day) was positively correlated with the 6-minute walking test, which is considered as a good predictor of VO$_2$peak.[4] In addition, we found a significant negative correlation between VO$_2$peak and sedentary time, which has also been reported in the general population by Kulinski et al.[5] This is an important finding considering the increased sedentary behavior after an amputation and could be useful in designing early rehabilitation strategies. Our results indicate that persons with a higher aerobic capacity exhibit less sedentary behavior and perform larger proportions of high-intensity activity (cadence above 40 steps minute). Interestingly, we observed only a small change in correlation coefficients after correcting for age. VO$_2$peak is shown to decrease with aging, but physical activity can counteract this decline.[30] Our findings emphasize the strong relationship between VO$_2$peak and physical activity and indicate that sedentary behavior and level of physical activity may act independently in relation to VO$_2$peak, as previously reported by Santos et al.[6]

The secondary aim was to investigate the relationship between walking capacity and upper-body VO$_2$peak. We found a significant large correlation between VO$_2$peak, PWS, and 2MWT. After correcting for age, the correlation coefficients were still large, but only the correlation between VO$_2$peak and 2MWT was significant. The findings indicate that persons with a higher aerobic capacity have a higher walking capacity, as shown by a higher PWS and longer walking distance on the 2MWT. Wezenberg et al[11] suggested that the VO$_2$peak is an important determinant for improvement in walking capacity based on a construct model predicting that a 10% increase in VO$_2$peak could potentially result in a 9.1% reduction in the relative aerobic load, a 13.9% increase in PWS, and a 2.9% improvement in walking economy for people with traumatic LLA. Individual scores in our study demonstrate higher VO$_2$peak values and a trend for higher performance on the 2MWT for the ten participants who were engaged in recreational physical activity compared with the 4 participants who performed no recreational physical activity. Our results indicate that cardiorespiratory fitness might play an important role in walking capacity, but the effect of improving VO$_2$peak on walking capacity remains to be investigated.

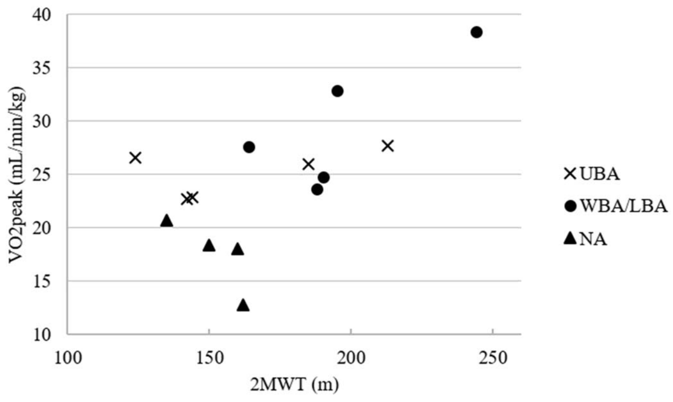

Figure 1. Upper-body VO$_2$peak and distance walked on the 2-minute walking test (2MWT) for participants performing upper-body physical activity (UBA), whole-body and/or lower-body physical activity (WBA/LBA), and no physical activity (NA).

In previous research, there has been little emphasis on the essential role of cardiorespiratory fitness in people with LLA. A longitudinal study by Blair et al[32] demonstrated that low cardiorespiratory fitness was an independent predictor of cardiovascular disease and all-cause mortality in able-bodied persons. People with LLA are shown to have higher morbidity and mortality from cardiovascular disease compared with nonamputees.[33] Hence, more attention to improvement in cardiorespiratory fitness in this particular population is needed. The current findings indicate that persons with high sedentary behavior and lower levels of high-intensity physical activity have lower cardiorespiratory fitness. Future studies should examine whether cardiorespiratory fitness can be improved by decreasing sedentary behavior and/or increasing the amount of high-intensity physical activity in daily life. From this perspective, arm cranking could be a potential exercise modality for people with LLA who may have limitations in performing larger amounts of lower-body exercise. Previous studies report that people with LLA after an aerobic training program with lower-body exercise resulted in an increase in

VO_2peak between 18% and 27.3%,[12,14,15] but whether upper-body exercise might have similar positive effects on VO_2peak remains to be investigated.

In this study, arm-crank ergometry was chosen as the exercise modality for VO_2peak assessment, unlike previous studies in people with LLA that use lower-body exercise modalities, such as 1-leg cycle ergometry,[11] combined upper/lower extremity ergometry,[34] and treadmill walking.[8] In able-bodied people, lower peak aerobic capacity values are observed in upper-body modality exercise vs. lower-body modality exercise,[35] and similarly, lower values are observed for one-leg cycle exercise vs. two-leg cycle exercise.[36] The mean VO_2peak value of 24.5 mL/minute/kg found in our study is comparable with values reported for persons with LLA performing a maximal one-leg cycling exercise test (ranged 17.10–28.1 mL/minute/kg).[11,12,16] This agrees with findings from Olivier et al,[37] who found no difference in maximal cardiorespiratory values between arm cranking and one-leg cycling in persons who had undergone knee surgery. Hence, we propose that arm-cranking exercise is suitable for assessing cardiorespiratory fitness in persons with LLA.

Study limitations

Several limitations should be considered when the results are interpreted. First, the sample size was small and restricted to experienced prosthetic limb users with nonvascular reasons for amputation, limiting the generalizability of the results. Future studies should build on this piloting work.

Second, because the SAM is worn on the prosthetic leg and two of our participants used a wheelchair in their home, we were unable to detect the time of sleep. Therefore, we used the 24-hour day in our analysis, which means that sleeping time is included in the calculation of sedentary time. In addition, the SAM is limited to monitoring ambulatory activity only and cannot distinguish between a donned or doffed prosthesis. Physical activities that did not involve prosthetic use, such as sitting sports or moving around with a wheelchair, were measured as sedentary time. Consequently, our measurements on physical activity might have been slightly underestimated for some participants.

Finally, it remains unknown to what extent upper-body cardiorespiratory fitness influences the level of activity in daily life, or vice versa. The task-specificity of VO_2peak improvement, shown in the study by James,[15] indicates that upper-body training is a potential contributing factor, rather than a substitute for walking activity on VO_2peak improvement. In addition, it should be emphasized that VO_2peak improvement does not have an isolated effect on physical functioning and general health but that it is considered as an important determinant.

Conclusions

To the best of our knowledge, this is the first study to demonstrate the strong relationship between objectively measured levels of physical activity in daily life and upper-body aerobic capacity in people with LLA. In addition, we argue that upper-body VO_2peak testing may be an attractive testing modality for persons with LLA. Our results indicate that upper-body aerobic capacity is an important factor for walking capacity. Further studies are needed to examine the potential effect of decreasing sedentary behavior and/or increasing physical activity in daily life on aerobic capacity, and whether this might improve walking capacity in this population.

Declaration of conflicting interests

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Supplemental material

No supplemental digital content is available in this article.

References

1. Halsne EG, Waddingham MG and Hafner BJ. Long-term activity in and among persons with transfemoral amputation. *J Rehabil Res Dev* 2013; 50: 515–530.
2. Bize R, Johnson JA and Plotnikoff RC. Physical activity level and health-related quality of life in the general adult population: A systematic review. *Prev Med* 2007; 45: 401–415.
3. Vagetti GC, Barbosa Filho VC, Moreira NB, et al. Association between physical activity and quality of life in the elderly: a systematic review, 2000-2012. *Braz J Psychiatry* 2014; 36: 76–88.
4. Lin SJ, Winston KD, Mitchell J, et al. Physical activity, functional capacity, and step variability during walking in people with lower-limb amputation. *Gait Posture* 2014; 40: 140–144.
5. Kulinski JP, Khera A, Ayers CR, et al. Association between cardiorespiratory fitness and accelerometer-derived physical activity and sedentary time in the general population. *Mayo Clin Proc* 2014; 89: 1063–1071.
6. Santos R, Mota J, Okely AD, et al. The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. *Br J Sports Med* 2014; 48: 1508–1512.
7. Czerniecki JM and Morgenroth DC. Metabolic energy expenditure of ambulation in lower extremity amputees: what have we learned and what are the next steps? *Disabil Rehabil* 2017; 39: 143–151.
8. Gjovaag T, Starholm IM, Mirtaheri P, et al. Assessment of aerobic capacity and walking economy of unilateral transfemoral amputees. *Prosthet Orthot Int* 2014; 38: 140–147.
9. van Schaik L, Geertzen JHB, Dijkstra PU, et al. Metabolic costs of activities of daily living in persons with a lower limb amputation: a systematic review and meta-analysis. *PLoS One* 2019; 14: e0213256.
10. Gjovaag T, Mirtaheri P and Starholm IM. Carbohydrate and fat oxidation in persons with lower limb amputation during walking with different speeds. *Prosthet Orthot Int* 2018; 42: 304–310.
11. Wezenberg D, van der Woude LH, Faber WX, et al. Relation between aerobic capacity and walking ability in older adults with a lower-limb amputation. *Arch Phys Med Rehabil* 2013; 94: 1714–1720.
12. Pitetti KH, Snell PG, Stray-Gundersen J, et al. Aerobic training exercises for individuals who had amputation of the lower limb. *J Bone Joint Surg Am* 1987; 69: 914–921.
13. Toda M, Chin T, Maeda N, et al. The threshold of physical fitness in terms of maximum oxygen uptake as a predictive factor for achieving prosthetic

walking in elderly with unilateral trans-femoral amputation or hip disarticulation. *SEMOJ* 2015; 1: 126–132.

14. Chin T, Sawamura S, Fujita H, et al. Effect of endurance training program based on anaerobic threshold (AT) for lower limb amputees. *J Rehabil Res Dev* 2001; 38: 7–11.
15. James U. Effect of physical training in healthy male unilateral above-knee amputees. *Scand J Rehabil Med* 1973; 5: 88–101.
16. Wezenberg D, de Haan A, Faber WX, et al. Peak oxygen consumption in older adults with a lower limb amputation. *Arch Phys Med Rehabil* 2012; 93: 1924–1929.
17. Pitetti KH, Manske RC. Exercise and lower limb amputation. In: LeMura LM, Von Duvillard SP eds. *Clinical Exercise Physiology: application and Physiological Principles*. Baltimore: Lippincott Williams & Wilkins; 2004: 219–235.
18. Erjavec T, Presern-Strukelj M and Burger H. The diagnostic importance of exercise testing in developing appropriate rehabilitation programmes for patients following transfemoral amputation. *Eur J Phys Rehabil Med* 2008; 44: 133–139.
19. Vogler AJ, Rice AJ and Gore CJ. Validity and reliability of the Cortex MetaMax3B portable metabolic system. *J Sports Sci* 2010; 28: 733–742.
20. Price MJ and Campbell IG. Determination of peak oxygen uptake during upper body exercise. *Ergonomics* 1997; 40: 491–499.
21. Mitropoulos A, Gumber A, Crank H, et al. Validation of an arm crank ergometer test for use in sedentary adults. *J Sports Sci Med* 2017; 16: 558–564.
22. Aspenes ST, Nilsen TI, Skaug EA, et al. Peak oxygen uptake and cardiovascular risk factors in 4631 healthy women and men. *Med Sci Sports Exerc* 2011; 43: 1465–1473.
23. Lee M, Song C, Lee K, et al. Agreement between the spatio-temporal gait parameters from treadmill-based photoelectric cell and the instrumented treadmill system in healthy young adults and stroke patients. *Med Sci Monit* 2014; 20: 1210–1219.
24. Sciurba F, Criner GJ, Lee SM, et al. Six-minute walk distance in chronic obstructive pulmonary disease: reproducibility and effect of walking course layout and length. *Am J Respir Crit Care Med* 2003; 167: 1522–1527.
25. Brooks D, Hunter JP, Parsons J, et al. Reliability of the two-minute walk test in individuals with transtibial amputation. *Arch Phys Med Rehabil* 2002; 83: 1562–1565.
26. Reid L, Thomson P, Besemann M, et al. Going places: does the two-minute walk test predict the six-minute walk test in lower extremity amputees? *J Rehabil Med* 2015; 47: 256–261.
27. Coleman KL, Smith DG, Boone DA, et al. Step activity monitor: long-term, continuous recording of ambulatory function. *J Rehabil Res Dev* 1999; 36: 8–18.
28. Arch ESP, Erol OM, Bortz CBS, et al. Method to quantify cadence variability of individuals with lower-limb amputation. *JPO J Prosthetics Orthot* 2017; 29: 73–79.
29. Stepien JM, Cavenett S, Taylor L, et al. Activity levels among lower-limb amputees: self-report versus step activity monitor. *Arch Phys Med Rehabil* 2007; 88: 896–900.
30. Loe H, Steinshamn S and Wisløff U. Cardio-respiratory reference data in 4631 healthy men and women 20-90 years: the HUNT 3 fitness study. *PLoS One* 2014; 9: e113884.
31. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
32. Blair SN, Kampert JB, Kohl HW III, et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *J Am Med Assoc* 1996; 276: 205–210.
33. Naschitz JE and Lenger R. Why traumatic leg amputees are at increased risk for cardiovascular diseases. *QJM* 2008; 101: 251–259.
34. Vestering MM, Schoppen T, Dekker R, et al. Development of an exercise testing protocol for patients with a lower limb amputation: results of a pilot study. *Int J Rehabil Res* 2005; 28: 237–244.
35. Ade CJ, Broxterman RM, Craig JC, et al. Upper body aerobic exercise as a possible predictor of lower body performance. *Aerosp Med Hum Perform* 2015; 86: 599–605.
36. Wezenberg D, de Haan A, van der Woude LH, et al. Feasibility and validity of a graded one-legged cycle exercise test to determine peak aerobic capacity in older people with a lower-limb amputation. *Phys Ther* 2012; 92: 329–338.
37. Olivier N, Legrand R, Rogez J, et al. One-leg cycling versus arm cranking: which is most appropriate for physical conditioning after knee surgery? *Arch Phys Med Rehabil* 2008; 89: 508–512.