Dual-task activities impact the gait kinematics of both amputated and healthy participants similarly

As atividades de dupla tarefa impactam a cinemática da marcha de participantes amputados e saudáveis de forma semelhante

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Abstract

Introduction: Gait is the motor task most impacted by amputation, requiring several physical and cognitive adaptations. The interaction between cognition and movement can be validly assessed through dual-tasks analysis. **Objective:** To analyze the kinematics of single and dual-motor tasks of participants with transfemoral amputation and compare it with healthy participants. **Methods:** This is a comparative cross-sectional study in which 14 participants in the transfemoral amputee group and 14 non-amputee participants attended the Gait Laboratory of the Clinical Center of the Universidade de Caxias do Sul to perform cognitive and motor activities tests. Speed, cadence, stride width, stride length, step length and step time were analyzed. **Results:** Participants in the transfemoral amputee group presented impaired gait kinematic parameters when compared to non-amputates during single and dual-tasks. Both groups showed a similar percentage decrease in performance on the dual-task compared to the single task. **Conclusion:** There is a distinction observed in the gait patterns and parameters of both groups, as evidenced in both the simple gait assessment and the dual-task evaluation. The primary finding of our study suggests that changes in gait kinematics appear to be exacerbated by dual-tasking rather than solely by amputation.

Keywords: Amputation. Cognitive training. Dual-task. Gait. Motor task.

Resumo

Introdução: *A marcha é a tarefa motora mais impactada pela amputação, exigindo várias adaptações físicas e cognitivas. A interação entre cognição e movimento pode ser validamente avaliada por meio da análise de duplas tarefas.* ***Objetivo:*** *Analisar a cinemática de tarefas motoras simples e duplas de participantes com amputação transfemoral e compará-las com participantes saudáveis.* ***Métodos:*** *Estudo transversal comparativo no qual 14 participantes do grupo de amputados transfemorais e 14 participantes não amputados compareceram ao Laboratório de Marcha do Centro Clínico da Universidade de Caxias do Sul para realizar testes de atividades cognitivas e motoras. Foram analisados a velocidade, cadência, largura do passo, comprimento do passo, comprimento da passada e tempo de passo.* ***Resultados:*** *Os participantes do grupo de amputados transfemorais apresentaram parâmetros cinemáticos da marcha prejudicados em comparação com os não amputados durante as tarefas simples e duplas. Ambos os grupos mostraram uma diminuição percentual semelhante no desempenho na tarefa dupla em comparação com a tarefa simples.* ***Conclusão:*** *Uma distinção pode ser vista nos padrões e parâmetros da marcha de ambos os grupos, e não apenas na avaliação simples da marcha, mas especialmente na avaliação da dupla tarefa. A principal descoberta do nosso estudo sugere que as mudanças nos parâmetros da cinemática da marcha parecem ser exacerbadas não só pela amputação, mas também pela realização de duplas tarefas.*

Palavras-chave: *Amputação. Treino cognitivo. Dupla tarefa. Marcha. Tarefa motora.*

Introduction

Amputations account for a relevant fraction of surgical procedures. In 2023, more than 25,000 lower limbs were surgically amputated in Brazil, representing 94% of amputations authorized by the Unified Health System.[1] Several physical and cognitive adaptations are observed in lower extremity amputees, most of them related to gait tasks.[2] Gait performance and the prosthetization process are affected by factors such as age, level of amputation, time since amputation, length and condition of the stump, mobility, motivation, and type of prosthesis.[3] Transfemoral amputees, for example, present compensation and have greater asymmetries in the gait pattern when compared with both transtibial person with an amputation and people with unaffected lower limbs.[4]

The use of transfemoral prosthesis requires additional cognitive skills and greater energy expenditure which does not prevent them from reduced balance and dynamic mobility during gait, hindering this motor performance.[5] To properly gait, 40.9% of stabilized amputees need to focus on the task,[6] which may result from the loss of somatosensory feedback from the amputee limb partially supplied by the attention given to vision for walking.[7] The concomitant use of cognitive areas can compromise additional tasks such as social interaction, establishing a conversation or observing the surrounding environment while walking.[6] The interference of cognitive tasks in gait performance may be related to a limiting capacity of cognitive resources, known as the Capacity Theory, or a limitation in the processing of stimuli, named Bottleneck Theory.[8]

Thus, the interaction between cognition and movement can be validly assessed through dual-tasks analysis[9] as both need adequate attention to be concurrently successful in common activities of daily living.[10] Lower limb amputees can present impairments in both the cognitive and motor tasks, but they tend to prioritize the latter as a safety strategy to prevent incidents such as accidental falls that could result in injuries.[10] Changes in gait are usually quantified by kinematic analyzes and some studies have identified, for example, differences in variables such as stride length and support time during gait between prosthetized and non-prosthetized individuals.[11] However, most of these studies use less accurate instruments, have small samples and present methodological problems such as the absence of a control group. Thus, this study aims to compare the gait alone with the addition of cognitive tasks of transfemoral amputation participants and compare it with healthy participants.

Methods

This cross-sectional study was approved by the Ethics and Research Committee of the Universidade de Caxias do Sul (UCS), under protocol No. 3,114,517). Data collection took place at the Gait Laboratory of the Clinical Center of the Universidade de Caxias do Sul.

The convenience sample was constituted through the database of the Physical Therapy Service of the Clinical Center of the same university. Twenty-eight participants were included in the study, 14 participants in the transfemoral amputee group with transfemoral prosthesis and 14 participants without amputation, which formed the transfemoral (TG) e control group (CG), respectively. All volunteers signed an informed consent form before their participation to the study.

The inclusion criteria for the TG were: a) to be registered at the Clinical Center of the UCS; b) to have unilateral transfemoral am-putation; c) to be in the final stage or have completed the rehabilitation process; d) to be able to walk for at least 15 min; e) to be over 18 years old and under 85 years old; f) to be fluent in Portuguese.

Exclusion criteria for both groups were: a) presence of cardiovascular, neurological, musculoskeletal instability or any condition that would interfere with the autonomous, independent and safe assessment of gait; b) severe visual and/or hearing impairment; c) to be illiterate; d) cognitive deficits that interfere with the understanding of the informed consent and/or the gait evaluation protocol.

Study protocol and data collection

Participants characterization

Data on age (years), weight (kg), height (m), and body mass index (BMI; kg/m^2) were first collected. The level of physical activity was defined by answering the International Physical Activity Questionnaire (IPAQ) about activities performed in the week before the assessment. The IPAQ questions cover the physical activities performed at work, at home, in sport and exercises, leisure, and time spent sitting. Depending on the results, participants can be classified as very active, active, irregularly active (irregularly active A and irregularly active B), or sedentary.[12]

The Mini-Mental State Examination MMSE questionnaire[13] was applied for cognitive assessment, which includes 19 specific items comprising five domains (spatial and temporal orientation; immediate memory; attention and calculation; evocation; and language). The maximum score of the questionnaire is 30 points and the cutoff point of the original study is 24.[13]

Single tasks: gait, subtraction arithmetic, and verbal fluency

Gait was assessed using the protocol proposed by Laroche et al.[14] For the protocol familiarization, participants were asked to walk eight meters in a straight line at a self-selected speed at the data collection local. Afterward, reflective markers were fixed at the following anatomical points: anterosuperior iliac spines, posterosuperior iliac spines, mediolateral portions of the femurs, mediolateral portions of the knees, mediolateral portions of the tibias, lateral malleolus of the ankles, central-posterior portions of the calcaneus, and dorsal aspect of the second metatarsals. On the prosthetized limb, the markers were placed in locations that most resembled the corresponding anatomical points.

The motion capture system with seven integrated cameras (VICON MX systems, Oxford Metrics Group, UK) was used to track the three-dimensional trajectory of the markers positioned on the volunteers' anatomical sites during gait. Kinematic data were collected at a sampling rate of 100Hz. Some attempts were made until participants took eight steps fully captured by the capture system. The variables recorded were speed (m/s), cadence (steps/min), stride length (m), stride time (s), step width (m), step length (m), and step time of both member(s). The average of limbs was used for further analysis.

For the cognitive tasks, participants sat in a comfortable chair in a quiet room. The arithmetic task consisted of successively subtracting every 5 from the number 400. The total number of correct subtractions for one minute was registered. In the verbal fluency task, participants should speak as many words as possible beginning with the letters "P" or "B" in one minute. The total words correctly spoken was registered. Before the assessment, the letter to be used in the single-task and the double-task was randomized for each volunteer.

Dual-tasks

After performing the single tasks, the participants did the dual-task activities, which was the motor task represented by walking along with the execution of one of the cognitive tasks described above: gait subtraction arithmetic and verbal fluency. Figure 1 shows in detail the methodology timeline.

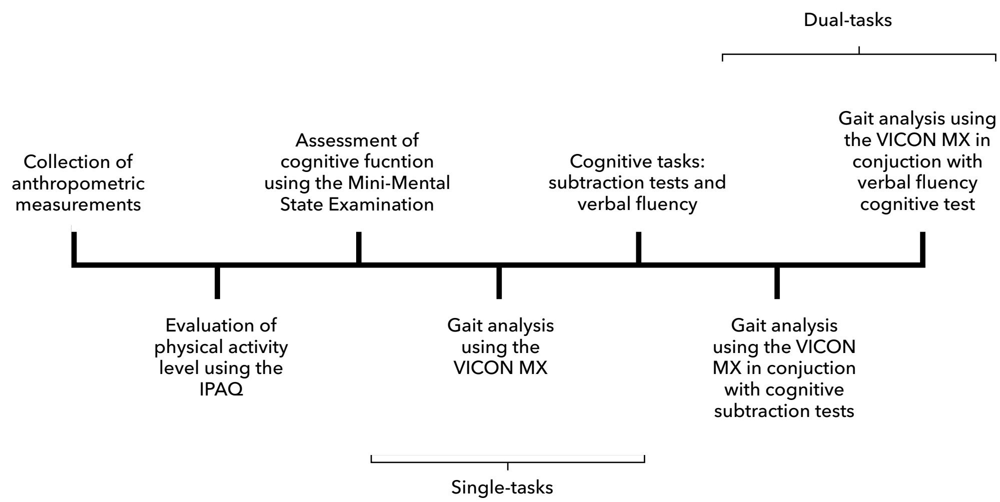

Figure 1 - Methodology timeline.

Note: IPAQ = International Physical Activity Questionnaire; VICON X = system of integrated cameras (Oxford Metrics Group, UK).

Statistical analysis

The sample size was based on the results shown by Morgan et al.,[15] in which the intergroup change in walking speed (m/s) during the dual-task (1.10 ± 0.17 and 1.45 ± 0.18), with significance ($p < 0.05$) and 90% power, added 30% for eventual losses; therefore, twelve participants should be allocated in each group.

Data were analyzed with JASP software (version 0.14.1; JASP Team, Amsterdam, Netherlands). Data distribution was verified with the Shapiro-Wilk test. Independent T-test or Mann-Whitney test were used to the intergroup comparison of the characteristics and cognitive tests. Paired T-test or Wilcoxon was used to compare intra-group cognitive values (simple task vs. isolated gait). ANOVA of repeated measures with Bonferroni post hoc was used to compare the gait of the volunteers (gait alone, gait with subtraction arithmetic, and gait with verbal fluency) of the TG. The significance level was set at $p < 0.05$.

Results

Table 1 shows the characteristics of the participants, which consisted of six women and eight men in the CG, and one woman and thirteen men in the TG. All participants were above the MMSE cutoff point, which is 24 points according to the original study.[13] There was no statistically significant difference for all characterization variables evaluated. The categorical data of level of activity (IPAQ) is expressed in absolute and relative values.

Table 1 - Participants´ characteristics

Variable	CG (n = 14)	TG (n = 14)	p-value
Age (years)	53.5 ± 16.35	54.64 ± 11.07	0.75
Weight (kg)	79.37 ± 14.09	79.65 ± 13.04	0.96
Height (m)	1.65 ± 0.08	1.72 ± 0.07	0.13
BMI (kg/m²)	28.73 ± 3.87	26.92 ± 5.52	0.33
MMST	25.42 ± 3.89	26.85 ± 3.48	0.28
IPAQ			
Highly active	1 (7.0)	2 (14.5)	-
Active	1 (7.0)	7 (50.0)	-
RA	3 (21.0)	0 (0.0)	-
IA A	4 (29.0)	3 (21.0)	-
IA B	4 (29.0)	2 (14.5)	-
Sedentary	1 (7.0)	0 (0.0)	-

Note: CG = control group; TG = transfemoral amputee group; BMI = body mass index; MMST = Mini Mental State Examination; IPAQ = International Physical Activity Questionnaire: absolute frequency (%); RA = regulary active; IA = irregulary active. Mean ± standard deviation. $p > 0.05$ for all comparisons.

The absolute parameters of gait alone and with the cognitive tasks can be observed in Table 2. In this intergroup comparison, all variables were statistically different, except for step width during gait with the arithmetic task. In addition, declines up to 50% are observed in the gait parameters of the TG when the cognitive task was added (stride time with the arithmetic task).

Table 3 shows data for all variables normalized by gait values (without the addition of cognitive tasks), considered as 1 (100%). Values below 1 represent a percentage decrease in the variable. Values above 1 mean percentage increase in the variable. There were no inter-group significant differences in dual-task when the absolute values were normalized by single gait. In the TG intragroup comparison, as shown in Table 4, gait variables, except for cadence and step width, were affected by cognitive tasks with greater percentage change observed for stride speed and time. However, there was not statistically difference between the dual tasks (gait with arithmetic vs. gait with verbal fluency) compared to each other. It is also noted that the stride length is only different when comparing gait alone with gait with verbal fluency.

Table 2 - Intergroup comparisons

Variable	Gait			Arithmetic			Verbal fluency		
	CG	TG	Δ%	CG	TG	Δ%	CG	TG	Δ%
Speed (m/s)	1.13 ± 0.16	0.63 ± 0.14**	-43.7	0.98 ± 0.23	0.54 ± 0.18**	-44.4	0.95 ± 0.22	0.52 ± 0.16**	-44.7
Cadence (steps/min)	110.78 ± 9.07	84.91 ± 28.97**#	-23.3	103.97 ± 12.73	76.00 ± 21.77**#	-28.9	101.25 ± 13.21	69.82 ± 11.05**	-31.0
Stride length (m)	1.22 ± 0.13	0.98 ± 0.22*	-19.7	1.13 ± 0.17	0.91 ± 0.24*	-18.6	1.11 ± 0.15	0.90 ± 0.22*	-19.4
Stride time (s)	1.09 ± 0.09	1.54 ± 0.24**	41.4	1.17 ± 0.15	1.76 ± 0.37**#	50.4	1.20 ± 0.16	1.77 ± 0.33**#	47.7
Step width (m)	0.18 ± 0.05	0.24 ± 0.05*	32.7	0.21 ± 0.10	0.25 ± 0.06#	15.2	0.19 ± 0.05	0.25 ± 0.07*	30.9
Step length (m)	0.61 ± 0.06	0.49 ± 0.10*	-19.5	0.56 ± 0.08	0.46 ± 0.12*	-18.2	0.55 ± 0.08	0.44 ± 0.11*	-19.5
Step time (s)	0.54 ± 0.04	0.77 ± 0.10**	42.7	0.58 ± 0.07	0.87 ± 0.17**#	49.6	0.60 ± 0.08	0.88 ± 0.15**	46.1

Note: CG = control group; TG = transfemoral amputee group. Δ% = TG percentage change compared to CG; m/s = meters per second. *p > 0.05. **p < 0.001. #Mann-Whitney test for non-parametric variables. Mean ± standard deviation.

Table 3 - Intergroup relativized data comparison

Variable	Arithmetic		Verbal fluency	
	CG	TG	CG	TG
Speed (m/s)	0.86 ± 0.10	0.83 ± 0.11	0.83 ± 0.12	0.81 ± 0.12
Cadence (steps/min)	0.93 ± 0.07	0.94 ± 0.33	0.91 ± 0.09	0.85 ± 0.15
Stride length (m)	0.91 ± 0.06	0.92 ± 0.10	0.90 ± 0.06	0.91 ± 0.11
Stride time (s)	1.07 ± 0.08	1.15 ± 0.14	1.10 ± 0.12	1.16 ± 0.15
Step width (m)	1.26 ± 0.86	1.03 ± 0.11	1.04 ± 0.14	1.02 ± 0.13
Step length (m)	0.91 ± 0.06	0.92 ± 0.11	0.90 ± 0.06	0.90 ± 0.11
Step time (s)	1.06 ± 0.08	1.12 ± 0.11	1.11 ± 0.12	1.14 ± 0.09

Note: CG = control group; TG = transfemoral amputee group; m/s = meters per second. Gait variables = 1 (100%). Mean ± standard deviation. p > 0.05 for all comparisons.

Table 4 - Intragroup comparison of the transfemoral amputee group

Variable	Gait	Arithmetic	Δ%	Verbal fluency	Δ%
Speed. (m/s)**§	0.63 ± 0.14	0.54 ± 0.18	-15.5	0.52 ± 0.16	-17.9
Cadence (steps/min)	84.9 ± 28.9	76.0 ± 21.77	-5.6	69.82 ± 11.05	-13.7
Stride length (m)*&	0.98 ± 0.22	0.91 ± 0.24	-7.0	0.90 ± 0.22	-8.2
Stride time (s)**§	1.54 ± 0.24	1.76 ± 0.37	14.2	1.77 ± 0.33	15.7
Step width (m)	0.24 ± 0.05	0.25 ± 0.06	3.1	0.25 ± 0.07	2.6
Step length (m)*§	0.49 ± 0.10	0.46 ± 0.12	-6.8	0.44 ± 0.11	-8.8
Step time (s)**§	0.77 ± 0.11	0.87 ± 0.17	11.7	0.88 ± 0.15	13.8

Note: Δ% = percentage difference between dual-task and gait alone; m/s = meters per second; *p > 0.05; **p < 0.001; §Ggait alone different from gait + arithmetic and different from gait + verbal fluency (Bonferroni test); &Gait alone different from gait + verbal fluency. Mean ± standard deviation.

Discussion

Considering the motor and cognitive impairments observed in amputees in previous studies, this study aimed to analyze the kinematics of the single motor gait task and dual-tasks of participants with transfemoral amputation and compare them with healthy participants. Our main findings are: 1) the gait parameters of the participants in the transfemoral amputee group differ from those observed in healthy participants; 2) gait performance is impaired when this task is accompanied by cognitive demands in both groups; 3) the percent change in performance during dual-task is similar for the participants in the transfemoral amputee group and non-amputated participants; put differently, the performance of dual tasks induces comparable modifications in gait kinematics across both groups, suggesting that amputation does not primarily drive these alterations.

Changes were observed in the spatiotemporal gait patterns of participants in the transfemoral amputee group compared to non-amputates. There were alterations in the width of the walking base, which was wider for amputees, a decrease in walking speed due to fewer steps per minute, a decrease in step length, a decrease in stride length, and consequently, increases in the stride and step times. These findings corroborate Morgan et al.,[15] who demonstrated that transfemoral amputees walk slower, with a wider stride and with stride time asymmetry compared to participants in a group without amputation in the single gait task, suggesting that a more cautious gait pattern is adopted by amputees. These changes in the motor pattern may result from the neuromuscular adaptations that amputation imposes, such as the loss of sensory inputs from the amputated segments that no longer provide information to the nervous system.[4]

The deleterious effects caused by the dual-task are evident when looking at the absolute values of the kinematic parameters presented in the tables. The inter-group comparison of absolute data reveals that in all single task and dual-task parameters, the participants in the transfemoral amputee group have deficits in gait performance, except for step width concomitant to the arithmetic cognitive task, that did not differ between groups. Morgan et al.[15] also found differences related to dual-task, whose reported cognitive stimulus was to recognize high or low tones in the patterns of sounds provided via headphones, suggesting that inclusions of different cognitive tasks result in speed reductions, increase in step width, and step times asymmetries. A plausible hypothesis is that the dual-task demands more attention from participants to perform the additional cognitive task and that there may be a limit both in the capacity of cognitive resources and in the stimuli processing.[6-8] Interestingly, transfemoral amputee rehabilitation professionals are aware of these changes in the gait with additional tasks to properly monitor the patients´ evolution.

However, the impairment caused by the dual-task in the gait of the participants in the transfemoral amputee group is not statistically different from non-amputated participants when the dual-tasks kinematic values are presented in percentages of the simple motor task (single gait). Our data show that the transfemoral and control groups have a mean ~14 and 17% decrease in walking speed when adding cognitive tasks, and these inter-group variations are not significantly different. Therefore, it seems that the musculoskeletal changes generated by the amputation did not worsen the performance of the amputee group compared to the non-amputee group. These findings are in line with Morgan et al.[15] and Lamoth et al.[16] who demonstrated that including a cognitive task simultaneously with the walking does not affect speed, stride time, and spatiotemporal variability of gait in participants in the transfemoral amputee group compared to a control group. Thus, it is inferred that other conditions such as aging, diseases with neurological compromise, and cognitive deficits, according to previous studies, have a more negative impact on motor performance than musculoskeletal changes resulting from amputation.[17,18]

In this study, the decrease in gait performance during dual-tasks in the amputee group was evidenced by the significant intragroup differences, in which speed, stride, and step lengths were reduced and stride and step times increased compared to single gait. Our results corroborate the findings by Cielask et al.[19] and Hunter et al.,[20] who demonstrated a decrease in gait speed when performed in dual-task, even after four months of rehabilitation. In that study, the authors used the "L Test" as a field-based gait assessment protocol. Considering that several activities of daily living require the association between motor and cognitive tasks, the findings of the present study show that the impairment observed in gait performance when adding a cognitive task can have negative effects on the daily lives of participants.

Thus, physical therapy interventions, such as those pro-posed by Demirdel and Erbahçeci,[21] may be interesting since the authors demonstrated that when allocated to a dual-task training protocol, transfemoral amputees performed better in the dual-task and cognitive test. The adaptations observed after the intervention may be associated with task automation, highlighting this as a trainable skill. In the present study, the percentage quantification of performance decline seems to be relevant clinical information for the process of patient progress through training, and that can be monitored by therapists in evaluating the success of the intervention.

Transfemoral amputees in the final stage or who had already completed the rehabilitation process were included in the present study. However, the time since amputation and prosthetization time were not controlled. It is expected a better adaptation to the prosthesis and improved gait performance by stabilized amputees.

This study has some limitations. One limiting factor is the inability to match participants in the groups based on sex and age. However, as no statistically significant differences were found among the characterization variables, we consider the samples to be adequately homogeneous. While the groups are heterogeneous in terms of gender, this factor does not directly impact the study's primary outcome, which is based on the influence of dual-tasking by comparing the individual with themselves. However, we recommend that future researches consider these limitations to enable more confident extrapolation of the results to the population. Another limiting factor is that the majority of the amputee participants were either active or highly active. However, this data does not directly impact the study's primary outcome, which is based on the influence of dual-tasking by comparing the individual with themselves.

Additionally, the time since amputation and prosthetization time was not controlled. A better adaptation to the prosthesis and improved gait performance are expected of stabilized amputees. Therefore, data concerning the time since amputation and prosthetic use could potentially affect the result homogenization, as a group of inexperienced amputees may exhibit poorer performance in dual-task gait due to their incomplete adaptation to the prosthesis.

Conclusion

The present study demonstrated that there is a distinction in the gait patterns and parameters (speed, cadence, stride length, stride time, step length and step time) of both groups, as evidenced in both the simple gait assessment and dual-task evaluation. The primary finding of our study suggests that changes in gait kinematics appear to be exacerbated by dual-tasking rather than solely by amputation. However, the impairment caused by the dual-task seems similar in both groups, resulting in that amputation itself should not be considered the cause of the worsening of the motor task. It is imperative for professionals in the field to incorporate dual-task training not only for participants with physical limitations or undergoing rehabilitation but for all participants, given that dual-tasking is a part of daily life.

Authors' contributions

N FM, LVB and SSM were responsible for the study conceptualization, and FC was responsible for the project administration and supervision. All authors participated in the investigation, methodology, writing of the original draft, review, and approval of the final version.

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