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Spatiotemporal characteristics of gait in partial foot amputation versus peripheral neuropathy

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***Abstract*---**Background: Partial foot amputation (PFA) is defined as a surgical loss of part of either the forefoot or mid-foot. It is usually secondary to physiological foot dysfunctions such as peripheral neuropathy (PN). The effect of amputation on spatiotemporal characteristics of gait in patients with PFA secondary to PN is still not well established yet Purpose: The aim of the study was to evaluate the effect of PFA on characteristics of gait in patients with PFA secondary to PN compared to PN patients without amputation. Methods: Cadence, stance, swing, double limb support, stride time, step length, and stride length were assessed for 53 participants divided into two groups; (A) PFA group: 25 subjects with healed unilateral PFA and (B) PN Groups: 28 subjects with PN with neither ulcer nor amputation. The gait analysis was conducted at a self-selected speed using the STT three-dimensional motion analysis system. Results: The MANOVA main effect revealed no significant difference between the two groups (p = 0.102). The post hoc test revealed no significant difference between the two groups in all spatiotemporal variables (p > 0.05). Conclusion: Both groups walked at a slow cadence, taking short steps with increased percentage of stance and double limb support.

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Therefore, gait pattern compensations associated with PFA was similar to that of PN suggesting that such alterations may be attributed to the systemic disease of PN rather than secondary to foot amputation.

***Keywords*---**Spatiotemporal, Gait, Partial Foot Amputation, Peripheral Neuropathy.

Introduction

Partial foot amputation (PFA) is a common surgical excision of part of either the forefoot or mid-foot, resulting in anatomical foot dysfunction The common indications for amputation include sever trauma, infection or systemic illness such as peripheral vascular diseases **(Martins-Mendes et al., 2014; Moura-Neto et al., 2013; Siitonen et al., 1993).** Physiological foot dysfunction is a complication of advanced peripheral neuropathy (PN) and is associated with loss of the peripheral sensation, which predisposes the foot to injury unconsciously and is associated with of intrinsic foot muscles atrophy **(Lamola et al., 2015).**

Both the prevalence of diabetes and the number of diabetics have almost doubled since the 1980s, rising to 8.5% and 422 million in 2014, worldwide **(World Health Organization, 2016).** Since advanced PN is the most common reason for partial foot amputation, the number of people requiring partial foot amputation will increase as well **(Wild et al., 2004).**

Several musculoskeletal deviations may develop in PN patients to compensate for sensory and motor deficits. Furthermore, similar deviations were observed in PFA patients to compensate for loss of anatomical foot length. These musculoskeletal deviations may be responsible for the observed gait abnormalities **(Lamola et al., 2015; Schuch & Pritham, 1994).** Moreover, these gait abnormalities may increase risk of fall up to 15 times compared to healthy subjects **(Almurdhi et al., 2017; Dingwell & Cavanagh, 2001).** The majority of falls occur during walking, leading to dangerous health issues, especially in geriatrics, and can be a significant cause of morbidity and mortality **(Timsina et al., 2017).**

Earlier studies that examined PN gait reported slower and more cautious gait **(Allet et al., 2008).** On the other hand, for most of the last few decades, what was known about PFA gait was based on theoretical analyses, with speculations about the effects of amputation. At the beginning of the 21th century, a limited number of studies investigated PFA gait **(Dillon et al., 2007).** Most of these studies focused on trans-metatarsal (TMT) amputation **(Dillon et al., 2011; Kelly et al., 2000; Mueller et al., 1997; Tang et al., 2004).**

However, these studies have certain limitations such as small sample size, insufficient details concerning practical procedures, and inclusion of subjects with bilateral feet amputation. Besides those methodological issues, the effect of PFA on spatiotemporal characteristics of gait in patients with PFA secondary to PN complications is still not well established yet **(Dillon et al., 2007).** Therefore, the purpose of the current study was to explore the effect of PFA on spatiotemporal characteristics of gait in patients with PFA secondary to PN complications compared to PN patients without amputation.

The current research used a more comprehensive and appropriate design, aiming to fill the gap of knowledge associated with the previous studies. Furthermore, it may improve our understanding of the characteristics of gait together with the findings of the previous studies, leading to more effective rehabilitation, avoidance of complications and further amputation, proper prosthetic fitting, reduction of the risk of falling, and improvement of quality of life.

Methods

This study is a prospective observational cohort study. The study was executed under the ethical guidelines of 1964 Declaration of Helsinki. The study was approved by the Ethical Committee for Human Research at the Faculty of Physical Therapy, Cairo University, Egypt. Participants were invited to join the study and signed written consent form for their approval to participate in the current work.

Participants:

Patients with a diagnosis of PN with or without PFA were invited by their physicians or orthopedic surgeons to participate in our study. The diagnosis of PN was carried out based on the appropriated diagnostic criteria before the referral process.

Subjects with a diagnosis of PN with/without PFA of both genders ranging in age from 40 to 70 years were included in the study. PN patients with a grade I and II PN were included. Furthermore, patients with healed PFA after at least 6 months since the amputation surgery and didn’t use a prosthesis were included. The level of amputation was from partial toe amputation up to the level of metatarsophalangeal (MTP) disarticulation.

Patients with amputation levels above the MTP joint, bilateral PFA, active foot problems, acute inflammation symptoms such as pain, swelling, and redness of PN or PFA, ulcer, infection, or gangrene were excluded. Furthermore, participants with systematic musculoskeletal-related conditions that may affect gait or balance as major surgery, spinal problems, or ankle instability, were excluded as well. Moreover, subjects with acute symptoms of cardiovascular or nephropathy complications and subjects who take medication with known effects on the central nervous system were excluded.

Following the approval of participation, patients were allocated into two groups: (**A) PFA group:** patients with healed unilateral PFAs caused by PN; and (**B) PN group:** patients with PN but no ulcer or amputation. All the participants were capable of walking independently to perform their activities of daily living (ADL) with or without assistive devices. However, no walking aids were used during the testing procedures.

Assessment tools:

The STT three-dimensional motion analysis (3DMA) system (STT Systems Company, Zuatzu Business Park, Easo Building, 2nd Floor, San Sebastián, Spain) was used for the assessment of spatiotemporal characteristics of gait. It is an indoor optical system that consists of four cameras, fifteen markers, and computer software for automatic three-dimensional motion capture and analysis **(Fig. 1).** CLINICAL 3DMA V.6.11 is professional software with highly accurate marker tracking. The STT Helen Hayes protocol was used for the gait analysis in this study.

Figure 1: STT 3DMA system.

Gait analysis procedures:

The participant was asked to take off the shoes and the 15 reflective markers were placed on his/her according to STT Helen Hayes Protocol for the lower limb **(Fig. 2) (Kadaba et al., 1990).** The CLINICAL 3DMA system calibration was checked before each assessment session. If the result was correct, the assessment session was initiated, but if it was incorrect, recalibration was done. Participants were instructed to walk inside the capture field of the CLINICAL 3DMA system. Furthermore, they were instructed to walk normally and steadily at their self-preferred speed. Recording for 1 minute was started once the participant got comfortable with the test environment. Once the recording session was successfully completed, it was saved to the computer.

Figure 2*: Makers placement***.**

Measurement of the outcomes:

CLINICAL 3DMA software automatically captures and analyzes spatiotemporal parameters (cadence, percentage of stance, swing, and double limb support, stride time, step length, and stride length) of gait. The software measures the cadence as total number of steps per minute, and it measures the stride time as the time (in sec) from heel strike of one limb to the next heel strike of the same limb. Also, the software measures the duration of stance, swing, and double limb support as percentage of stride time. Also, the software measures the step and stride length (in cm). Step length is the longitudinal distance from the heel of one limb to the heel of the contralateral limb. Stride length is the longitudinal distance from the heel of one limb to the next heel of the same limb. The data of all spatiotemporal variables was exported as a PDF file for each patient **(Fig. 3).**

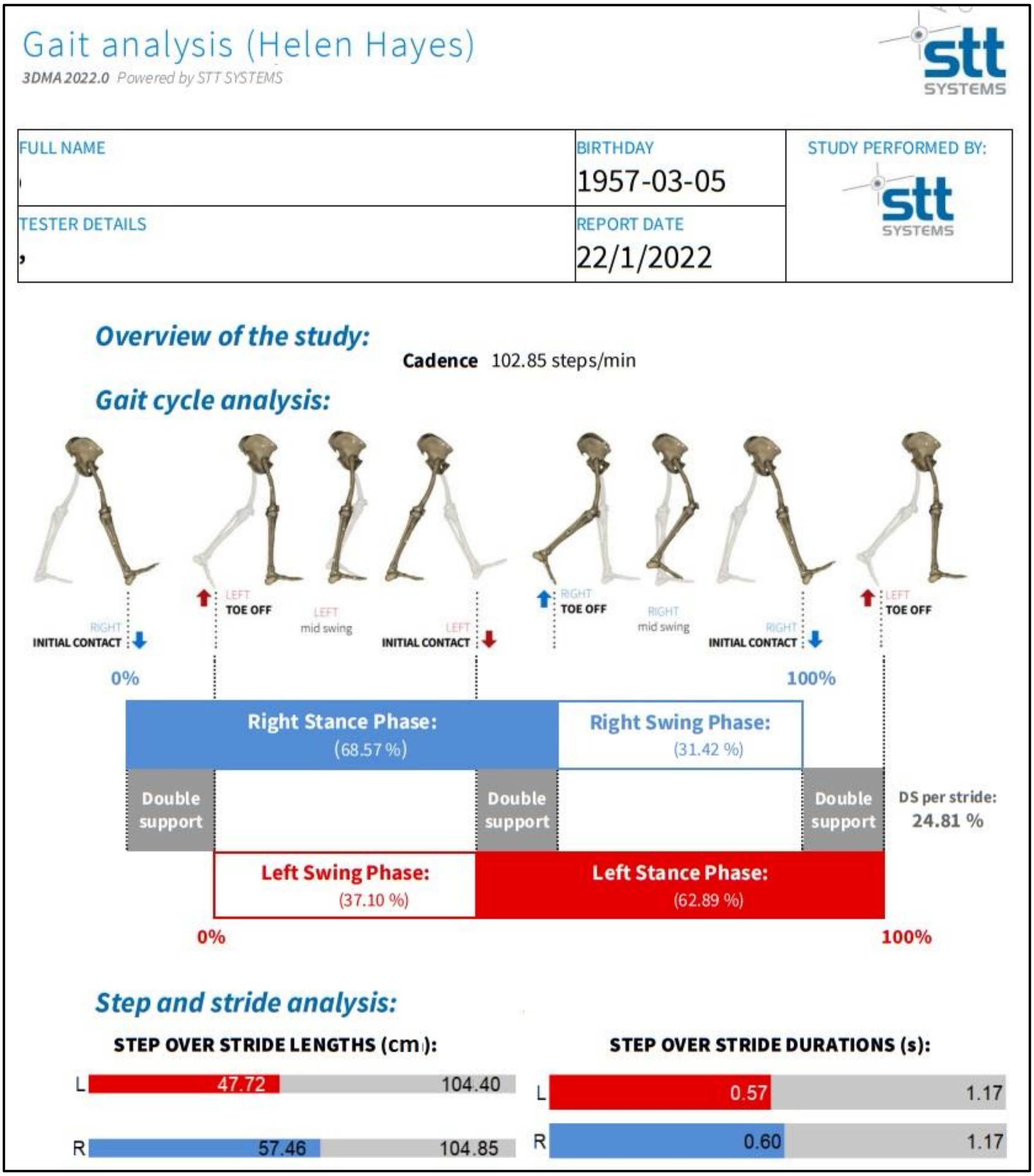

Figure 3*: The* CLINICAL 3DMA exported report

Statistical analysis

The Statistical Package for Social Sciences (SPSS) V.26 (Charles R. Flint, New York, US) was used to analyze the reported data. The demographic data (age, weight, height, body mass index (BMI), gender, and affected side), and the recorded data of the spatiotemporal outcomes were assessed for normality using the Shapiro–Wilk test. Descriptive statistics (mean and standard deviation) of the demographic data and spatiotemporal variables for all patients in the two groups were presented. MANOVA was used to examine the effects of partial foot amputation and peripheral neuropathy for all dependent variables, and multiple comparisons were analyzed by Bonferroni post hoc. The level of significance for all tests was set at a *p*-value ≤ 0.05.

Results

One hundred and sixty-seven subjects were screened for eligibility criteria. Sixty patients met the eligibility criteria, but only fifty-three subjects were included in the multivariate test. They were allocated into two groups; (**A) PFA group:** 25 subjects with healed unilateral PFAs due to PN with no active ulcers (fifth toe = 2; third toe = 2; middle 2 toes = 2; lateral 2 toes = 2; lateral 3 toes = 1; Lateral 4 toes = 2; hallux = 7; MTP disarticulation = 7); (**B) PN group:** 28 subjects with PN with neither ulcer nor amputation. Participant's recruitment and retention are shown in **Figure 4.** The PFA and PN groups were well-matched in terms of age, mass and height, with no significant differences in their physical measures (*p* = .103) **(Table 1)**.

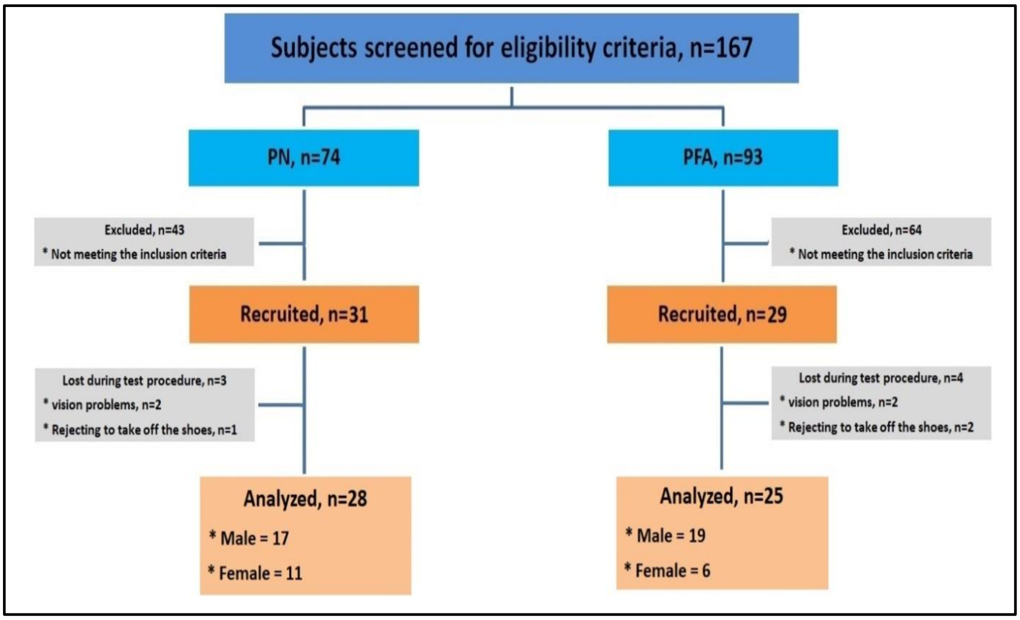

Figure 4: Subject's flow chart

Table 1
Demographic characteristics of the subjects

Demographic	PN N = 28		PFA N = 25		F	95% Confidence Interval		*P* value
	Mean	SD	Mean	SD		Lower Bound	Upper Bound	
AGE	55.54	7.23	54.80	7.96	.124	53.073	57.262	.726
Height (cm)	167.21	8.64	170.76	7.50	2.515	166.743	171.231	.119
Weight (kg)	97.48	15.10	93.64	14.49	.888	91.468	99.654	.351
BMI	34.77	3.79	32.07	4.57	5.541	32.267	34.573	.022*

The reported outcomes for all variables for both groups were normally distributed. The MANOVA main effect test result (Wilks' lambda multivariate test) between the PN group and the PFA group and showed no significant difference between the two groups (p = 0.102) The Bonferroni post hoc test revealed no significant differences between the two groups in all variables; cadence, duration of stance, duration of swing, duration of double limb support, stride time, step length, and stride length (p = 0.994, p = 0.902, p = 0.275, p = 0.559, p = 226, p = 0.381, and p = 0.241, respectively) **(Table 2).**

The mean values of cadence, duration of stance, duration of swing, duration of double limb support, stride time, step length, and stride length in both the PN and PFA groups were 94.89 ± 12.28 and 94.86 ± 14.16 (steps/min), 67.87 ± 6.56 and 67.68 ± 3.84 (% of stride time), 34.05 ± 7.16 and 32.27 ± 3.77 (% of stride time), 34.06 ± 8.93 and 35.42 ± 7.61 (% of stride time), 1.29 ± 0.22 and 1.39 ± 0.36 (sec), 50.30± 11.72 and 47.74 ± 9.40 (cm), 101.75± 20.27, and 95.38 ± 18.83 (cm), respectively **(Table 2, Fig. 5)**.

Table 2.
MANOVA and Post hoc analysis for all dependent variables in both PFA group and PN group

Dependent Variables	PN		PFA		F	95% Confidence Interval		*P* value
	Mean	SD	Mean	SD		Lower Bound	Upper Bound	
Cadence (Steps/min)	94.89	12.28	94.86	14.16	0.000	91.228	98.520	0.994
Stance (%)	67.87	6.56	67.68	3.84	0.015	66.252	69.302	0.902
Swing (%)	34.05	7.16	32.27	3.77	1.122	31.532	34.789	0.275
Double limb support (%)	34.06	8.93	35.42	7.61	0.347	32.423	37.054	0.559
Stride time (sec)	1.29	0.22	1.39	0.36	1.499	1.262	1.425	0.226
Step length (cm)	50.30	11.72	47.74	9.40	0.782	46.108	51.930	0.381
Stride length (cm)	101.75	20.27	95.38	18.83	1.405	93.165	103.964	0.241

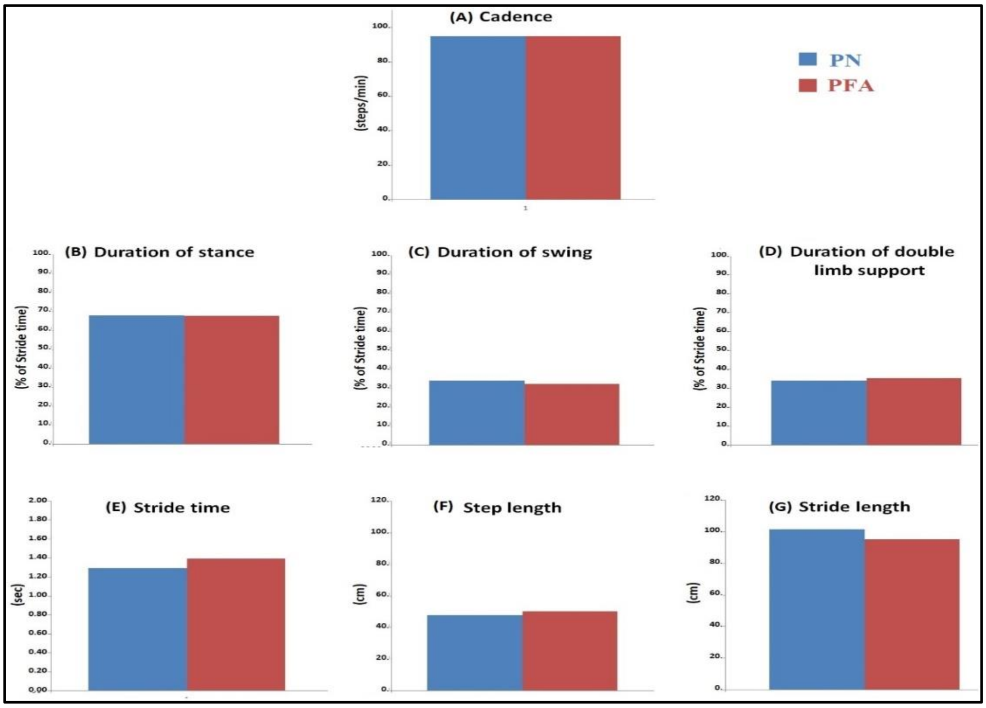

Figure 5: Mean values of the spatiotemporal parameters of both groups; (A) Cadence; (B) Duration of stance; (C) Duration of swing; (D) Duration of double limb support; (E) Stride time; (F) Step length, and (G) Stride length.

Discussion

The aim of the current study was to examine the effect of PFA on spatiotemporal characteristics of gait in patients with PFA secondary to PN complications compared to PN patients without amputation Our study was delimited to both PFA and PN groups as the normative data related to spatiotemporal variables of gait were investigated and presented in several texts and key articles **(Janet & Cerny, 2018; Perry & Burnfield, 2010).**

Our findings revealed that there was no significance difference between the PFA and PN groups, as both groups walked at a slow cadence, taking short steps with increased percentage of stance and double limb support. Our results are consistent with that of the previous study that compared PFA due to PN with PN, which reported no significant difference between both groups **(Pinzur et al., 1992).**

However, whether these gait parameters changes were due to sensorimotor affection of the PN diseases or just an involuntary attempt to protect their forefoot cannot be confirmed. Moreover, PFA may not be the primary cause of the altered gait mechanics, but the underlying systemic disease of loss of sensation which may develop such alterations before the amputation was performed.

The lower cadence and minimal step which were observed for the PFA group compared to norms, were consistent with a previous research that studied the effect of PFA due to PN on both cadence and step length **(Burnfield et al., 1998).** Furthermore, our results for the reduction of the step length in PFA were consistent with a previous study that studied the effect of PFA due to PN on step length **(Dillon, 2001).** However, a previous study of non-diabetic PFA reported no reduction in step length **(Tang et al., 2004).**

On the other hand, the minimal step length which was observed for the PN group compared to norms, was consistent with previous studies that studied the effect of PN on step length **(Courtemanche et al., 1996; Dingwell et al., 2000; Menz et al., 2004a; Mueller et al., 1994, 1995).**

The observed reduction in both cadence and step length for both groups indicated a reduction in walking speed for both groups, as walking speed = cadence x step length **(Janet & Cerny, 2018; Perry & Burnfield, 2010).** The hypothesized reduction in the walking speed for the PN group was consistent with previous studies that reported the same speed reduction for PN patients **(Kwon et al., 2003; Petrofsky et al., 2005a; Petrofsky et al., 2005b; Petrofsky et al., 2005c; Richardson et al., 2004a, 2004b).**

The hypothesized reduction in the walking speed for the PFA group is consistent with previous studies that reported the same speed reduction of PFA due to PN **(Boyd et al., 1999; Burnfield et al., 1998; Kanade et al., 2006; Mueller et al., 1997a; Mueller et al., 1997b; Mueller & Strube, 1997).** On the other hand, previous studies that evaluated walking speed for traumatic PFA reported that traumatic PFA subjects walked at a faster velocity comparable to that of healthy subjects **(Dillon, 2001).**

Both groups walked with short strides compared to norms. The reduced stride length which was observed for the PN group, was consistent with previous two researches that studied the stride length for the PN group compared to the healthy control group **(Savelberg et al., 2010; Sawacha et al., 2009).** The reduced stride length which was observed for the PFA group, was consistent with previous research that studied the effect of PFA due to PN on stride length **(Burnfield et al., 1998).**

Both groups had a prolonged stance phase compared to norms. The longer stance phase which was observed for the PN group, was consistent with a previous researches **(Fernando et al., 2013; Sawacha et al., 2012).**

Limitations:

We had difficulties in recruiting the adequate number of patients with PFAs due to the lower rates of patients in the diabetic foot centers and outpatient clinics due to the pandemic of COVID 19. However, a reasonable sample size allowed us to compare the two groups statistically.

Conclusion:

Regarding to our results along with previous studies, we assume that PFA may not affect the spatiotemporal characteristics of gait in patients with PFA secondary to PN complications but that the underlying systemic pathology (PN) may have caused such alterations before the amputation was performed. Furthermore, our findings strengthens the findings of our previous work that studied gait kinetics and pattern of loading for PFA due to PN compared to PN alone, which revealed that both groups shared the same compensatory mechanism (tend to shift their body loads posteriorly and redistribute their loads to compensate for the insufficient support from the forefoot) and The PFA group was worse than the PN group **(Elabd et al., 2022).**

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Conflict of interest:

The authors declare that there is no conflict of interest.

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