TAB B

Spatiotemporal Parameters and Step Activity of a Specialized Stepping Pattern Used by a Transtibial Amputee During a Denali Mountaineering Expedition.
A Case Report

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Abstract

There are numerous mountain climbing stepping patterns including the *French Technique*. The *French Technique,* reportedly eases the ability to ambulate in ice, snow and sloped terrain. Specialized step patterns for mountaineering expeditions have not been studied in transtibial amputees (TTA). Therefore, the purpose of this report was to describe spatiotemporal differences between French and traditional stepping in a TTA and report his step activity during an climbing expedition on Mt. Mckinley in Denali, Alaska, USA. A well conditioned 51yr old male with right TTA was provided a step counter, daily journal and event log to utilize and complete during a summit attempt on Mt. McKinley's West Buttress Route. Following the climb, the subject traversed a Gaitrite portable walkway while demonstrating the French Step technique and traditional stepping in a laboratory setting to compare spatiotemporal differences in the stepping patterns. Ultimately, the case climber completed 8 days on the trail, which included three crevasse falls and a total step count of 62,421. The average daily step count for active climbing days was 10,404. An estimated 27% of steps were taken with the French Step technique. Five total events were logged; one dermatologic, three musculoskeletal events and the culminating event was cardiovascular in nature where the climber reported overheating and exertion and ultimately "bonking" requiring climb cessation and evacuation. For velocity, the French stepping technique was significantly slower than traditional stepping. Stride, step and double support times were all greater in French stepping compared to traditional stepping. Spatially, stride and step lengths were greater in traditional stepping compared to French stepping. The width of the base of support was significantly wider in the French Step than in traditional stepping. We hypothesized dermatologic and prosthetic issues would predominate the event log. Instead, musculoskeletal issues predominated. A fatigue issue ultimately concluded the climb warranting further investigation into balancing component durability and mass in terms of prosthetic foot selection. Regarding stepping techniques, as the altitude got progressively higher, the French Step was selected as the preferred strategy. The French Step is ultimately a slower stepping technique with qualities suggestive of heightened stepping stability as opposed to mobility.

Background

There are numerous mountain climbing techniques and stepping patterns such as the *French Technique* and the *Rest Step*.[1] The *French Technique,* is described as easing the ability to traverse ice, snow and gentle to steep mountain grades (0-60° pitch). French Stepping is also known as *Flat Footing* because one of this pattern's goals is to keep the soul of the footwear parallel to the snow/ice. The rest step is a mountaineering stepping pattern reportedly used to ascend steep slopes. It incorporates a pause on the fully extended trailing leg, while the front leg is relaxed except as needed for postural adjustment and balance. The rest step is so named as it is believed to relieve leg muscle exertion in an alternating pattern throughout the ascent. Specialized gait patterns and their potential benefit or detriment for mountaineering expeditions have not been studied in persons with transtibial amputation (TTA). Therefore, the purpose of this case report was to 1) describe spatiotemporal differences between the French Step and typical walking patterns of a TTA in a laboratory setting and 2) to report the qualitative and quantitative step activity of a TTA during an actual climbing expedition on Mt. Mckinley in Denali, Alaska, USA.

Methods

Subject and Prosthesis

The subject was a 51yr old male (height 183 cm and weight 96 kg) with right transtibial amputation. On the five level functional ambulation scale where level 0 are non-ambulators, level 1 is supervised prosthetic use for transfers and therapy, level 2 are household ambulators, level 3 are community ambulators and level 4 classifies prosthetic use beyond basic ambulation, he was a functional level 4 ambulator.[2] He received a score of 45/47 on the amputee mobility predictor which corroborates his clinically determined level 4 ambulation skills.[3] During medical evaluation he was found to have comorbid but pharmacologically controlled hypertension, gastroesophageal reflux disease and phantom limb pain. The subject's primary care physician cleared him to participate in an expeditionary summit attempt on Mt. McKinley in Denali, Alaska, USA. His amputation was of traumatic etiology 4 yr prior to this report. His cylindrically shaped residual limb was 28cm long (53% length of sound tibia- Figure 1.) with bone bridging procedure,[4] posterior flap closure and its characteristic anterior-distal scar. The subject had 5/5 extensor and flexor strength (manual muscle test)[5] bilaterally in the hips, knees and sound side ankle. Subject's range of motion was normal for age at all lower extremity joints.[6] The subject's prosthesis included a carbon fiber laminated total surface bearing socket with a uniform Alps cushion liner (St. Petersburg, FL, USA) Otto Bock Derma ProFlex suspension sleeve (Duderstadt, Germany) and an Ossur Vertical Shock Pylon (VSP) foot component (Reykjavik, Iceland). The subject reported having his current socket for 2 yr and his foot component for 4 yr with no modifications, repairs or adjustments. He further reported that he routinely fluctuates between 10 sock plies (achieved via two, 5-ply socks) and 12 plies (achieved by adding two additional one-ply socks) in a given day. His weekly activity was self-described as "highly active", including 6 days per week of circuit training exercise with primary emphasis on large muscle groups of the lower extremity (such as the quadriceps femoris, gluteal group, hamstrings and sound plantar flexors). In preparation for the Denali expedition, this training routine was highly consistent for 7 months. Prior to this time, the subject's exercise preference was biased toward upper extremity strengthening. Additionally, the subject self-reported an estimated daily 2500 to 3000 kCal diet consistent with caloric output paying attention to avoid caloric deficit given the increased metabolic demands for the aforementioned circuit training. The subject specifically increased protein and reduced carbohydrate intake while maintaining a variety of fruit and vegetable intake.

Data Form & Step Activity Monitor

A daily data journal was developed to include the day of the week/date, daily step count, peak daily altitude, duration spent climbing, an overall daily rating of perceived exertion (0-10 scale) [7] and notes for freeform comments. In addition to the daily journal, an event log was provided that prompted the subject to capture any event of consequence (such as dermatologic, prosthetic, musculoskeletal issues, etc.), the pedometry count and time at the instance such an event was recognized, the day of the climb, a description of both the problem and solution and a prompt to take a photo of the issue. Step count was monitored both daily and at events (as previously described) using a Sportline ThinQ XA Model 305 Pedometer (Yonkers, New York, USA). The pedometer was hung on a lanyard around the climber's neck such that the climber's core temperature would keep the instrument within its described operating temperature range and such that clothing and gear strapping would minimize extraneous instrument movement that could erroneously be counted as steps.

Mt. McKinley Denali Mountaineering Plan

The 15 member expedition team included professionally trained mountaineering guides and emergency medical personnel. The team planned to traverse the 26.7 km (16.6 mile) trail along Denali's West Buttress route. Once on the trail, the expedition was scheduled to take approximately 17 days to reach the summit notwithstanding inclement weather. The planned ascent would start at 2,195 m (7,200 ft) and elevate to 6,194 m (20,320 ft) of altitude at the summit. The team planned to encounter perilous crevasses and thus trained and equipped to rescue fallen climbers. Because the snow covered ground would soften during the daylight hours due to increased temperature and ground-thaw, the team planned to travel at night. Specific training immediately preceding and during the climb occurred daily and included vital topics ranging from knot tying, crevasse rescue, acute mountain sickness (AMS) symptom recognition and varied gait patterns to accomplish such goals as team stepping synchrony.

Spatiotemporal Gait Data Collection

Two weeks following the climbing expedition, the climber with amputation reported to the University of South Florida's Human Functional Performance Laboratory for a debriefing interview and to demonstrate French Stepping, self-selected walking speed ([SSWS] and gait pattern) and fastest possible walking speed ([FPWS] and gait pattern). At debriefing, investigators and climber reviewed the daily climbing journal and event log. Following debriefing, the subject traversed a7.92 m (26 ft) GaitRite portable walkway (Haverton, PA) three times each with the stepping patterns and velocities previously described. The GaitRite portable walkway is a valid and reliable instrument for recording spatiotemporal parameters of gait which has been used in the amputee population. [8] While all of the spatiotemporal gait parameters captured by the GaitRite walkway were collected, the following variables were selected *a priori* for analysis:

1. velocity
2. stride length
3. step length
4. base of support (BOS) width
5. stride time
6. step time
7. double support time (time with both feet on the ground)

It is known that side to side asymmetry exists with unilateral TTA.[8] However, the purpose of this report is to gain a preliminary understanding of spatiotemporal differences between these particular gait patterns. Therefore, left and right side data (i.e. unilaterally recorded data) were averaged together to describe the given stepping pattern's bilaterally averaged parameter (e.g. stride time, stride length, etc.). Between pattern differences were compared with a repeated measures ANOVA and statistical significance was set at $p \leq 0.05$. Statistical analyses were performed using SPSS 2011 (Armonk, New York, USA).

Results

Daily Step Activity Data and Event Journal

The daily step count revealed 8 days on the trail (Table 1), 2 of which were predominated by rest (day 2) or inclement weather (day7). The subject reported three crevasse falls through ice (days 2 and 3). The total step count on the trail was 62,421 (days 2 and 7 not included). The average daily step count for the 6 active climbing days was 10,404 (range 6,640 to 12,540). Of active climbing days, the climber estimated that 27% of steps (17,095 steps) were taken with the French Step technique. The event log documents five total events (Table 2). Of these, one was dermatologic in nature, three musculoskeletal events were documented and the culminating event was cardiovascular in nature where the TTA climber reported overheating, exertion and ultimately, "hitting the wall" or "bonking" requiring cessation to his climb and evacuation from the summit attempt. The climb terminated at 4,115 m (13,500 ft) of altitude which is greater than half of the total trek.

Spatiotemporal Gait Data

Figure 2. demonstrates that gait velocity was 185±1.1cm/s (FPWS), 140±5.4cm/s (SSWS) and 20±9.8cm/s (French Step) and each value was significantly different from both others ($p \leq 0.01$). *A priori* selected temporal parameters were also all significantly different ($p \leq 0.05$) from the respective measures from the other stepping patterns (Figure 3). These measures included stride time (1.1±0.0sec [SSWS], 1.0±0.0sec [FPWS] and 4.7±1.7sec [French Step]), step time (0.6±0.0sec [SSWS], 0.5±0.0sec [FPWS] and 2.4±0.8sec [French Step]) and double support time (0.3±0.0sec [SSWS], 0.2±0.0sec [FPWS] and 3.7±1.9sec [French Step]). Two of three of the selected spatial parameters (stride and step length) were also all significantly different ($p \leq 0.01$) from the respective measures from the other stepping patterns (Figure 4). Stride lengths were 157.9±2.3 cm [SSWS], 176.1±0.9 cm [FPWS] and 81.7±5.1 cm [French Step]. Step lengths were 79.0±1.1 cm [SSWS], 88.0±0.6 cm [FPWS] and 40.4±2.6 cm [French Step]. The width of the base of support (BOS) was significantly wider in the French Step (24.9±1.9cm) than in both SSWS (13.2±0.6cm) and FPWS (12.9±1.7cm) typical walking. The BOS in SSWS and FPWS typical walking patterns were not different.

Discussion

The purpose of this case report was to 1) report the qualitative and quantitative step activity of a TTA during an actual climbing expedition on Mt. Mckinley in Denali, Alaska, USA and 2) to describe spatiotemporal differences between the French Step and typical walking patterns of a TTA in a laboratory setting.

Based on laboratory measured step length of traditional stepping at SSWS (79cm) and the French Step (40cm), we estimate that with a step count of 62,421 steps where 27% were taken with the French technique and 73% with traditional stepping, approximately 46.9 km were covered in total. We recognize that this is potentially an overestimation as it is likely that the step length of traditional stepping during the climb was shorter due to a number of factors including ground inclination, depth of snow, pack load, adverse weather, etc. Nonetheless, this seems to coincide with the climbing team's reported stopping location. The case climber reported utilizing the French Stepping technique as the rest step of choice as the altitude of the climb got progressively higher.

The daily step count averaged 10,404 steps on active climbing days. This is greater than the typical daily step count measured in community ambulating lower limb amputees which is 6,000 steps.[9, 10] This is of course expected given the nature of the expedition where destinations must be reached for critical reasons such as safety. Interestingly however, the average daily step count on the trail is only slightly greater than the 10,000 daily steps recommended for a healthy lifestyle.[11] This highlights a considerable limitation with step counting. That is, step counting provides no information about the intensity of stepping (i.e. the step rate).[10] Therefore, in order to understand the difficulty of stepping, choices would be journaling, rating exertion or utilizing more sophisticated instruments to capture step rate, bout duration and other parameters associated with ambulation. In this case, more sophisticated instrumentation was cost prohibitive and presented potential reliability challenges in terms of thermal affects regarding equipment function. Therefore, we opted for both journaling and rating exertion.

Table 1. Daily Step Activity

Day #	Steps	Predominant Gait Pattern (FS or TS)	Altitude (m)	Time on Trail (hr)	RPE (0-10)
1	10,688	TS	2,195	1	3
2	1,292	TS	2,195	0*	1
3	11,640	TS	2,080	6†	4
4	12,540	TS	2,320	5	6
5	10,458	TS	2,813	8	6
6	10,455	FS	3,566	9	7
7	1,100	FS	3,566	0**	3
8	6,640	FS	4,115	3	10

French Step (FS); Not Tested (NT); Rate of Perceived Exertion for cumulative daily effort (RPE: 0 to 10 Scale where 0 is no exertion at all and 10 is equivalent to a maximal effort); Traditional Step (TS); *Planned rest day and one fall through ice; †Two falls through ice; **Inclement weather.

It is obvious that stepping in this environment is more challenging, regardless of step count but it is important to gain an understanding of what the stepping demands are, in terms of volume of activity, so that appropriate prosthetic components can be selected to minimize potential durability issues. In the case climber, a durable foot was selected, which by the event log, presented no issues. Conversely, the climber bonked and was evacuated. It is therefore attractive to speculate if a foot component with less mass could meet the durability challenge while simultaneously being less fatiguing allowing for greater distance on the climb to be achieved. Though this is a difficult environment in which to conduct such study, the information is vital for select populations. For instance, military personnel who have sustained service related amputations may need to perform with minimal impairment in comparable environments in order to continue service. Ecologically valid data such as these provide some insight into human performance under these circumstances.

Table 2. Event Log

Day #	Event: Cardiovascular, Dermatologic, Musculoskeletal, Prosthetic	Description of Problem	Description of Solution
1	Musculoskeletal	Pain due to excessive lateral knee pressure.	Concentrate on even weight distribution and knee flexion. Use sound leg maximally to ensure equal line tension and prevent damage to residual limb/prosthesis.
2	1) Dermatologic 2) Musculoskeletal	1) Skin breakdown left (sound side) ankle. 2) Fall thru ice strained right knee.	1) Friction from boot. Taping to ankle as barrier remedied issue. 2) Rest.
4	Musculoskeletal	Experienced compression to lumbar spine on landing from crevasse jump.	Following experience, no problems noted so no solution required.
8	Cardiovascular	Bonked and overheated.	Climbing cessation. Rest. Oxygen. Routine vital sign monitoring. Evacuation.

Finally, we presented spatiotemporal differences between traditional and French Stepping. The French Step technique incorporates decreased velocity, step & stride length and an increased BOS relative to traditional stepping at comfortable and fast speeds. Relative to temporal differences, French Stepping utilizes increased stride, step and double support time. Ultimately, the French Step is a slower more deliberate gait that takes on similarities to populations that utilize more stable stepping patterns such as the gait observed in toddlers, geriatric persons and bilaterally involved amputees of dysvascular.[8, 12, 13] Each of these groups have the tendency to walk slower, increase step width and double support time, all parameters that decrease mobility, in order to improve the stability profile of their gait pattern.

Cumulatively, in the laboratory setting, the distance traversed by the French Step is approximately half that covered by traditional SSWS. Furthermore, the duration required to complete steps and/or strides were 4 to 5 times greater in French stepping than traditional stepping. Finally, the velocity was also 4 to 5 times slower in French stepping. Taken in total, this quantitative spatiotemporal profile of French stepping agrees with aspects of the qualitatively outlined description which describes a stepping pattern that favors stability and optimizes rest.[1] Other means of study are necessary to determine if ground reaction forces approximate joint centers minimizing environmental influence on joints and whether or not muscles are less active using the French step technique relative to other stepping patterns.

Limitations

This project had several limitations that must be considered. To begin with, data collected on an expedition such as this is justifiably at risk of being a secondary responsibility and thus at risk of being of sub-optimal quality and/or incomplete. Potential sources of such error include the journal and exertion ratings. Step counters as an instrument have potential error associated with extraneous movement despite attempts to minimize them. Finally, making field inferences from laboratory collected data will have obvious limitations in terms of precision.

Conclusion

We hypothesized that dermatological and prosthetic component issues would predominate the case climber's event log. In fact, musculoskeletal issues predominated and the only skin issue was not associated directly with the prosthesis. Similarly, the prosthesis presented no failure issues. However, a fatigue issue ultimately concluded the climb which warrants further investigation into balancing component durability and mass in terms of prosthetic foot selection. In terms of stepping techniques, as the altitude got progressively higher, the French Step technique was selected by the climber as the strategy of choice. The French Step technique is ultimately a slower stepping techniques with qualities suggestive of heightened stepping stability as opposed to mobility.

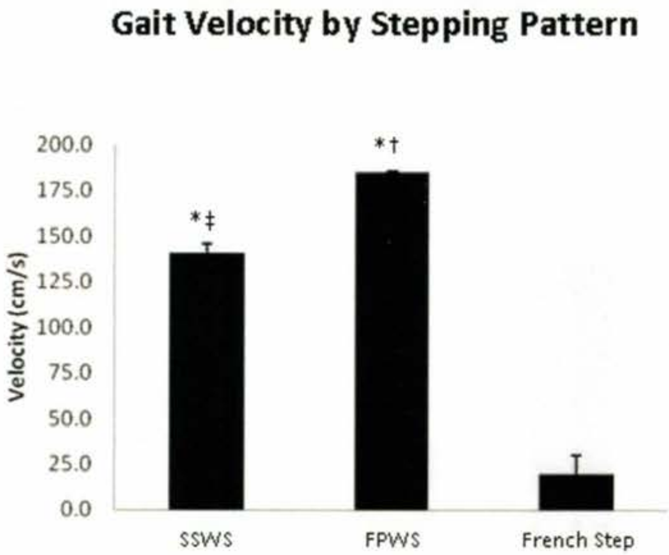
Acknowledgements

This project was unfunded and authors declare no conflict of interest.

Figure Captions:

Figure 1: A) Anterior view of case climber's residual limb. B) Posterior view of case climber's residual limb. C) Case climber wearing prosthesis used during his summit attempt on Mt. McKinley.

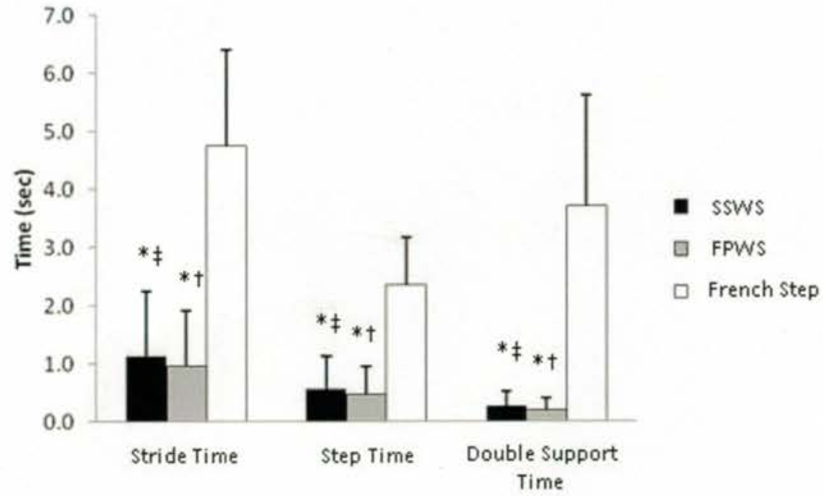
Figure 1



Fastest Possible Walking Speed (FPWS); Self Selected Walking Speed (SSWS); * p≤ 0.01 vs. French Step; † p≤ 0.01 vs. SSWS; ‡ p≤ 0.01 vs. FPWS

Figure 2

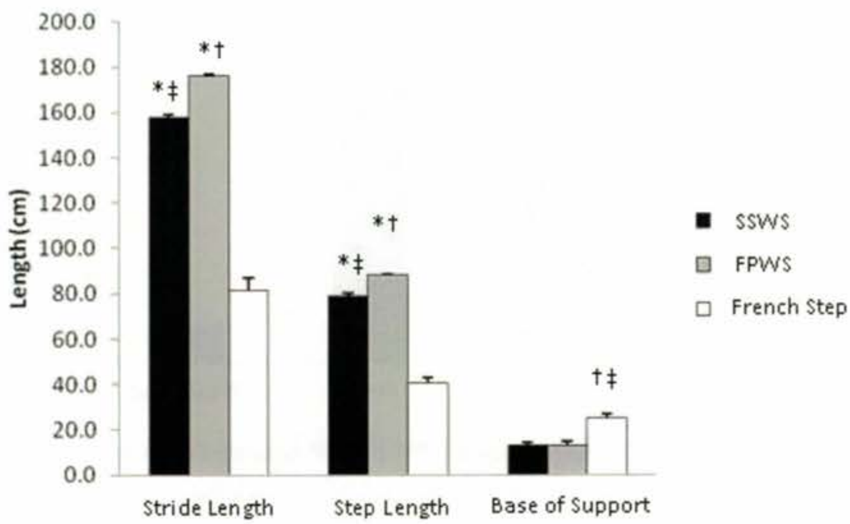
Temporal Parameters



Fastest Possible Walking Speed (FPWS); Self Selected Walking Speed (SSWS); * p≤ 0.05 vs. French Step; † p≤ 0.05 vs. SSWS; ‡ p≤ 0.05 vs. FPWS

Figure 3

Spatial Parameters



Fastest Possible Walking Speed (FPWS); Self Selected Walking Speed (SSWS); * p≤ 0.01 vs. French Step; † p≤ 0.01 vs. SSWS; ‡ p≤ 0.01 vs. FPWS

Figure 4

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