Human Movement Science 49 (2016) 186–195

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Mechanisms for regulating step length while running towards and over an obstacle

Roxanne J. Larsen *, William H. Jackson, Daniel Schmitt

Department of Evolutionary Anthropology, Duke University, Durham, NC, USA

ARTICLE INFO

Article history:
Received 1 April 2016
Revised 5 June 2016
Accepted 2 July 2016

Keywords:
Adaptive locomotion
Foot placement
Foot strike
Running
Step length

ABSTRACT

The ability to run across uneven terrain with continuous stable movement is critical to the safety and efficiency of a runner. Successful step-to-step stabilization while running may be mediated by minor adjustments to a few key parameters (e.g., leg stiffness, step length, foot strike pattern). However, it is not known to what degree runners in relatively natural settings (e.g., trails, paved road, curbs) use the same strategies across multiple steps. This study investigates how three readily measurable running parameters – step length, foot placement, and foot strike pattern – are adjusted in response to encountering a typical urban obstacle – a sidewalk curb. Thirteen subjects were video-recorded as they ran at self-selected slow and fast paces. Runners targeted a specific distance before the curb for foot placement, and lengthened their step over the curb ($p < 0.0001$) regardless of where the step over the curb was initiated. These strategies of adaptive locomotion disrupt step cycles temporarily, and may increase locomotor cost and muscle loading, but in the end assure dynamic stability and minimize the risk of injury over the duration of a run.

1. Introduction

Investigating how runners adjust their gait mechanics while navigating changes in terrain is fundamental to understanding locomotor control, cost, and injury risk during running. Extensive research over the past forty years, through both computer modeling and laboratory-based studies, has illuminated a variety of ways to adjust gait mechanics to maintain dynamic and mechanical stability. This strategy is often referred to as "adaptive locomotion" to indicate the adaptations in response to changes in the surface (Berg & Mark, 2005; Bradshaw & Sparrow, 2000; Bradshaw & Sparrow, 2001; Cornus, Laurent, & Laborie, 2009; da Silva, Barbieri, & Gobbi, 2011; de Rugy, Montagne, Buekers, & Laurent, 2000; Gobbi, da Silva, & Barbieri, 2011; Hebert-Losier, Mourot, & Holmberg, 2015; Matthis & Fajen, 2013; Mauroy, Schepens, & Willems, 2013; Moraes, 2014; Moraes, Lewis, & Patla, 2004; Patla, 2003; Patla, Robinson, Samways, & Armstrong, 1989; Rietdyk & Drifmeyer, 2009; Rietdyk & Patla, 1994; Rietdyk & Rhea, 2006; Warren & Yaffe, 1989; Warren, Young, & Lee, 1986). In these studies the lower limb mechanics of a running biped are often modeled as a spring-mass system with the ability to self-stabilize from step to step by managing forces and center of mass movements, adjusting characteristics of the limb, as well as controlling flight and contact time, step length, and step frequency (Alexander, 1992; Blickhan, 1989; Blickhan et al., 2007; Blum, Birn-Jeffery, Daley, & Seyfarth, 2011; Coleman, Cannavan, Horne, & Blazevich, 2012; Farley, Glasheen, & McMahon, 1993; Grimmer, Ernst, Gunther, & Blickhan, 2008; Lee & Farley, 1998; Lipfert, Günther, Renjewski,

* Corresponding author at: Box 90383, 130 Science Dr., Durham, NC 27708, USA.
E-mail address: roxy.larsen@duke.edu (R.J. Larsen).

http://dx.doi.org/10.1016/j.humov.2016.07.002
0167-9457/

Grimmer, & Seyfarth, 2012; McMahon, 1985; McMahon & Cheng, 1990; Morin, Dalleau, Kyrolainen, Jeannin, & Belli, 2005; Muller & Blickhan, 2010; Muller, Ernst, & Blickhan, 2012; Seyfarth, Geyer, Gunther, & Blickhan, 2002; Weyand, Sternlight, Bellizzi, & Wright, 2000; Williams, 1985; Zadpoor & Nikooyan, 2011). These models, as well as extensive work on step length and foot placement during walking (Bradshaw & Sparrow 2001; Patla, 2003), led us to investigate these specific and accessible parameters in the current study.

Generally, runners regulate their locomotion by feed-forward strategies to maintain forward motion and regular kinematic cycles (what might best be defined as "stability" or a stable gait pattern) while also minimizing energy costs (Birn-Jeffery & Daley, 2012; Blum, Lipfert, Rummel, & Seyfarth, 2010; Ernst, Götze, Müller, & Blickhan, 2014; Martin & Morgan, 1992; Muller, Haufle, & Blickhan, 2015; Palmer & Eaton, 2014; Patla, 1997; Seyfarth, Geyer, & Herr, 2003; Seyfarth et al., 2002; Takakusaki, 2013). However, when presented with visible obstacles, runners may rely on either active or passive regulation of limb mechanics depending on the size of the obstacle and distance to the obstacle (Ernst, Geyer, & Blickhan, 2012; Grimmer et al., 2008; Patla, 1997). Runners confront obstacles daily as they run on discontinuous surfaces like trails, urban streets, and sidewalks, where uneven surface topography (e.g., rocks, curbs, irregularities in concrete) appears frequently. Such discontinuities can present challenges to a runner's goals of general forward stability and efficiency. The ability to successfully adjust and accommodate for such obstacles is a high priority in safe and continuous running.

In response to visible obstacles runners may choose to adjust their basic locomotor pattern to accommodate changes in the terrain. According to Patla (1997, 2003) and Moraes (2014), to maintain stability across multiple step cycles, three basic balance control strategies associated with adaptive locomotion can be utilized: anticipatory, predictive and reactive. Anticipatory and predictive strategies are proactively controlled, relying either on vision or past experiences to help identify obstacles in the path, whereas reactive strategies occur in response to a disturbance in the path when it is encountered and do not involve explicit prior planning (da Silva et al., 2011; Moraes, 2014; Patla, 1997). Balance control strategies may be applied across one or two steps (i.e., avoidance strategies), or across several steps (i.e., accommodation strategies) depending on the surface (e.g., continuously flat or uneven, altered with different height or width obstacles) and the number and type of obstacles (e.g., single or multiple subsequent obstacles, moving obstacles; da Silva et al., 2011; Krell & Patla, 2002; Patla & Rietdyk, 1993; Rhea & Rietdyk, 2011). Assuming the runner will continue past an obstacle, they can change direction to avoid it, but that may not be feasible or efficient. If the runner plans to progress forward and over the obstacle, they can increase ground clearance of the foot as well as adjust step length, flight time, and/or foot placement near the obstacle.

Previous running studies have mainly focused on elite athletes, with limited attention to the behavior of recreational runners and the effects of sex or habitual foot strike patterns on strategies for maintaining steady locomotion over an obstacle. Additionally, few studies have been conducted in urban settings commonly used by runners. This study expands on previous research by recording the kinematics of female and male recreational runners, across multiple step cycles, in the outdoors and across a relatively natural running surface, in which participants navigate a visual drop in surface height (a standard sidewalk curb) and continue through and beyond the surface alteration. We sought to observe if there were changes in lower limb mechanics in anticipation of an obstacle to better understand the potential avoidance strategies used by runners while navigating uneven terrain. Previous research has shown that adjustments made to factors such as step length, foot placement, and foot strike pattern to avoid an obstacle could decrease dynamic stability (thereby increasing risk of injury) and increase metabolic cost (Cavanagh & Williams, 1982; Kyrolainen, Belli, & Komi, 2001; Moore, Jones, & Dixon, 2012; Moraes, 2014; Voloshina & Ferris, 2015; Warren et al., 1986; Willems et al., 2006; Williams & Cavanagh, 1987).

With this previous research in mind, it is then possible to predict how runners might respond to a visible change in a running surface along a straight pathway. In our case, we developed predictions about how runners would alter their step lengths leading up to a sidewalk curb and where the final foot placement before the curb would be positioned. For this particular experimental setup, where there was a common and visible alteration to the running surface, there were several potential hypotheses. Borrowing from the strategies of targeted or pointed locomotion (Berg & Mark, 2005; Lee, Lishman, & Thomson, 1982; Rietdyk & Drifmeyer, 2009; Seyfarth, Friedrichs, Wank, & Blickhan, 1999; Warren et al., 1986), we recognized that runners might choose multiple step length alterations (either becoming shorter or longer or a combination of both) in response to a change in terrain. However, as a starting point, we established the null hypothesis that runners would prefer consistent step lengths across the run. We predicted that runners would favor placing their foot a particular distance from the curb; one that was close enough to easily clear the curb without changing step length. Specifically for this set of hypotheses, we predicted that runners would favor a last step that was about one half of a step length before the curb (near −0.50 or Zones 2 and 3) and that the first landing after clearing the curb would follow a similar pattern (near 0.50, Fig. 1A).

We then considered the predicted range at which we thought runners would feel "safe" to clear the curb and would not need to change step length. We assumed runners would want to avoid risking contact with the curb. Therefore, if foot placement were 3/4 of a step length or closer before the curb (−0.75 or less, or Zones 3, 2 or 1), the step length over the curb would stay the same (approximately one relative step length, solid bracket Fig. 1B) and the runners would land no less than 1/4 of a step length after the curb (at or greater than 0.25, or Zone 1 or 2; Fig. 1B). However, if foot placement were more than 3/4 of a step length (Zones 4 or 5) before the curb, the runner would choose to increase step length over the curb so that they could clear (and not land on) the curb (dotted bracket > 1.0 step length Fig. 1C). Alternatively, runners could shorten their step length before the curb and thus take an additional step before going over the curb (dotted bracket < 1.0 step length Fig. 1C). We recognized that additional factors including running velocity, sex of the runner, foot strike pattern, and experience of the runner could influence these predictions.