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Mini Review

The Walking Brain: Factors Influencing Human Gait

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Received: October 29, 2018; **Published:** November 16, 2018

Abstract

Human walking is a standardized, repeatable and rhythmic locomotor act, with biomechanical patterns reported as roughly common to all healthy individuals. However, some gait patterns could be affected by cognitive, social and cultural factors. This mini-review aims at investigating top-down related differences in walking healthy patterns due to the above factors. The reviewed literature reported that socio-economic factors are at the basis of differences in pedestrian walking speed, related to the pace of life: faster speed was found in industrialized countries than in developing ones. Furthermore, it was suggested that the ancient division between men and women in hunters and gatherers, respectively, could be at the basis of gender visual differences and, in turn, in upper body movements during walking, with women walking with a more stable head. Interestingly, changes in gait speed did not affect cortical resources needed for spatial cognition, whereas a cognitive task may affect the gait speed. The most reliable parameters, poorly affected by psycho-social factors, resulted the symmetry of limb movements and the ratio between stance and swing duration. The latter was found close to the irrational number called golden ratio, providing a fractal structure to human gait cycle. Both these parameters are at the basis of the harmony of human walking, a feature maintained also in presence of top-down driven gait modifications.

Keywords: *Psychology; Gait Analysis; Motor Control; Top-Down; Neuroscience*

Human walking is a standardized, repeatable, rhythmic locomotor act, with biomechanical patterns reported as common among all healthy subjects [1]. The initiation of walking is related to signals arising from either volitional processing in the cerebral cortex or emotional processing in the limbic system, but after that, the steady state of walking occurs as an automatically controlled movement [2]. In fact, premotor cortex has mainly been involved in successive intentional gait modifications requiring motor programming, such as for overcoming obstacles, for changing speed or for stopping [2].

The discovery of central pattern generators in mammalians furtherly supported the concept of an automatic steady state of walking [2,3]. Despite it, walking exploits a lot of sensorial integrations by locomotor system which simultaneously receives inputs from motor cortex, cerebellum and sub-cortical nuclei, and at the same time it embodies visual, vestibular and proprioceptive feedback, resulting in a multi-level neural control system that manages bottom-up and top-down stimuli and allows to perform a stable gait and a highly consistent walking patterns [3,4]. The central pattern generators are at the basis of these basic rhythmic patterns, while the higher-level centers are responsible for modulating these patterns according to environmental constraints [4].

The complexity of this integrative process emerges when bioengineers try to replicate human walking with anthropomorphic robots, that not yet fully achieves the features of the human gait [4]. Paradoxically, anthropomorphic passive-dynamic mechanical walkers, just built with springs and levers, showed a walking efficiency even higher than that of robots, confirming the idea that walking is an automatic act [5].

Despite this automatic mechanism is at the basis of the high similarity of walking patterns worldwide, there are some psycho-socio-cultural features that may influence walking parameters [6]. The aim of this mini-review is to analyze some of the most important factors affecting gait in healthy humans according to the findings reported in the scientific literature.

Socio-cultural factors

An in-depth study conducted in 31 countries [7] allowed to highlight how economic well-being, degree of industrialization, population size, climate and cultural values may influence the pace of life and, indirectly, the self-selected walking speed. In fact, higher industrialized Countries seem to request a higher pace of life and hence a higher walking speed, with a consequent variation of relevant spatio-temporal gait parameters [7]. People from Ireland, Netherlands, Switzerland, England and Germany resulted the most frenetic, with a pedestrian speed about 0.3m/s higher than that of Mexicans and 0.5m/s than that of Brazilians [7]. These results were then confirmed by the Pace of Life project, that also showed a successive increment of pedestrian speed in far eastern developing countries, such as Singapore.

Gender differences

Also some gender differences highlighted in walking seem to be most related to ancient cultural reasons than to gender differences in anatomical structures. During walking, head movements are smoother in women than in men, whereas pelvis accelerations are higher in women [8]. A possible cultural explanation was the control of poise required in previous centuries to women [8]. Another possible reason is the difference in visual ability, with men having significantly greater sensitivity for spatio-temporal changes and women with larger peripheral view. For men it is probably related to their ancient role of hunters, whereas for women to their role of children protectors (and hence able to control the presence of dangers in the surrounding environment) and fruit gatherers (also implying the ability of carrying baskets on their head) [9]. So, their larger peripheral view and their cultural poise leaded to a more stable head during walking.

Psychological factors

The perception of a walking distance seems to be even more affected by psychological factors. In particular, the judgment of distance can be affected by the position of a target, appearing greater when the target is near to the end of a hallway than when farther from its end [10], or when the pathway is ascending and hence requiring more effort to be travelled [11]. Furthermore, when a gap is present on the ground between subjects and target, they perceive the distance as longer than it really is [12]. Then, mental walking time increases systematically when subjects carry a weight on their back, despite actual walking time does not vary [13]. Surprisingly, motor imagery resulted more efficient outdoor than indoor, but it could be related to a role of the environment acting as a selective tuning between different predictive versus feedback based locomotor strategies [14]. Hence, the altered perception of distance and time to achieve the target, may in turn change the selected walking speed and related spatio-temporal patterns. Furthermore, these factors may also influence the subjective perception of environment as in the case in which an observer has to judge the most suitable path to reach a target placed at a certain distance [15].

It is surprisingly that during dual motor-cognitive task the influence is not reciprocal. By comparing the effects of interfering locomotor and cognitive tasks, it was found that differences in gait speed did not affect the cortical resources needed for a spatial memory task, whereas cognitive tasks may affect gait speed [16].

Steady physiological features of human gait

So, there is a number of psychosocial and cognitive factors that can affect the human gait, but, on the other hand, we must also dwell on a couple of quite invariant parameters [1]. The first one is symmetry of locomotion reflecting the symmetry of our body. The coordination between the two lower limbs, and also with the upper body, allows for synchronized, symmetric and rhythmic movements. It implies that the contralateral foot strike occurs at 50% of the gait cycle. This cycle is formed by a stance phase, in which the foot makes contact with the ground, and a swing phase, in which the foot advances in the air [1]. Several studies showed a low variability of contralateral foot strikes, and also of foot off timing among different walking conditions, suggesting that the proportion between stance and swing (60 - 62% versus 40 - 38%) is quite invariant in physiological comfortable human gait. Changing in 90% of walking speed leaded to a change in stance phase of only 4%, as well as changing in 40 degrees of ground slope leaded to a change in stance of about 2% [1]. It was noted that the proportion between stance and swing phase is close to the so called golden ratio, an irrational number (about 1.618034) already known in ancient Greece and used by artists as a paradigm of beauty and harmony of proportions [17]. So, what is often called comfortable speed of walking, could be related to comfortable harmony of walking, with a proportion found also in the game theory (in the psychological test called Ultimatum game) as a possible best optimum solution [5].

Conclusions

In conclusion, despite walking has often seen as an automatic locomotor act, the role of our brain during gait deserves more attention, with psychological, cognitive and cultural factors that may affect our way to walk. In particular, the modern pace of life seems to be a determinant of the preferred walking speed, whereas the ancient gender difference between hunters and gathers seems at the basis of the differences in trunk movements during walking between males and females. At the same time cognitive factors may play a role in locomotor imagery as well as in altering the performance of dual tasks. Some other factors resulted more steady, such as walking in golden ratio, but in turn this proportion may define the concept of comfortable walking even more than speed.

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Volume 7 Issue 12 December 2018