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Clinical gait analysis is a well-established tool for the objective assessment of gait, which allows one to identify specific gait deviations to better recommend treatment planning and monitor the treatment effect. Gait analysis was introduced as a clinical service for the treatment of children with cerebral palsy (CP). Treatment based on the recommendations of clinical gait analysis indeed reported greater improvements in clinical outcomes.[1,2] The use of clinical gait analysis has now extended to various patient groups, such as stroke survivors, people with spinal cord injury, and orthopedic patients.[3–5]

A case for treadmill-based gait analysis

Traditionally, gait analysis data was collected during overground walking using force plates, 3D motion capture, and electromyography (EMG). Although such analysis has proven to provide clinically useful information, walking with one single well-positioned step on a force plate is not likely to resemble walking during daily activities. To ensure a natural walking pattern, force plates are often embedded into the floor and hidden from the patient so they don't alter their gait to step on the plate. However, this greatly increases the number of trials needed, thus increasing the data collection time. A survey studying the current use of 28 gait labs indicated a turnaround time of almost 5 hours per subject, and only 30% of this time is actually used for data analysis. The remaining 70% is used for preparation of the laboratory and patient, data collection, data processing and communication with the specialist. The survey also showed that gait analysis is not a routine tool within the healthcare system yet. Despite its great potential to provide clinicians with useful information about different types of walking pathologies, gait analysis is often reserved for a select set of patients due to time constraints.

Using an instrumented treadmill for clinical gait analysis may help to overcome the limitations of overground testing. One of the advantages of treadmill-based gait analysis is that precise foot placement is no longer necessary since every step is recorded. Consecutive cycles with gait data can therefore be recorded in a short period of time, increasing data collection efficiency. This reduces the costs for a clinical gait analysis per patient and increases the number of patients who can be tested per day. Moreover, collecting multiple steps increases data reliability,[6] and allows the analysis of variability and changes over time. Also, a treadmill allows for the use of a safety harness or a body weight support system. Therefore, even patients who are more unstable can partake in the measurements. Another advantage of using a treadmill is that walking speed can be controlled and kept constant between sessions, which is crucial for monitoring progress over time. Lastly, a treadmill requires considerably less space; a limited and costly resource in hospital settings.

Comparison of overground and treadmill gait

Considering these benefits it is fair to say that treadmill-based gait analysis is more feasible and efficient than overground gait analysis. However, some limitations should also be recognized. Even though van Ingen Schenau (1980) stated that the fundamental biomechanics of overground and treadmill walking are the same, potential differences in biomechanical, electromyographic, and metabolic parameters have been a constant topic of discussion among researchers.[7] For example, people walk with a higher cadence, shorter stance time and reduced preferred walking speed on a treadmill compared with overground walking.[8–16] Moreover, treadmill walking artificially reduces natural variability and complexity thereby creating a more stable and predictable gait pattern.[10,17–19]

Kinematic and kinetic patterns are in general very similar between treadmill and overground walking, although some differences in the amplitude of the signals can be found.[20] For kinematics, these differences are typically very small (<2°) and below the minimal detectable change (see Table 1), suggesting that there are no clinically relevant differences in kinematics between overground and treadmill walking.[9,11,12,20] The differences in amplitude of kinetic profiles are slightly more pronounced (see Table 2). Smaller braking ground reaction force (backwards shear force) and hip flexor and knee extensor moments, and larger hip extensor and knee flexor moments, were reported.[12,13,20]

Also, muscle activation profiles are similar between treadmill and overground walking, shown by high correlation coefficients (>0.97) between the average EMG signals.[21] The only consistently reported difference is that hamstring muscles tend to show greater activation during late swing when walking on a treadmill.[9,13,15,21] This may be related to the shorter steps that people take during treadmill walking.[21]

Table 1. An overview of the changes from overground to treadmill gait in maximum joint angles. Age is presented as mean ± SD or range, depending on the given information. ext = extension; flex = flexion; ↑ = increased in treadmill gait; ↓ = decreased in treadmill gait

Author (year)	n Subjects	Age (y)	Joint angles (degrees)					
			Hip ext	Hip flex	Knee ext	Knee flex	Plantar flex	Dorsal flex
Alton (1998)	17	28 ± 5	=	4 ↑	=	=	=	=
Nymark (2005)	18	23–58	=	6 ↑		=	↑	↓
Gates (2012)	27	23 ± 6	=	=	0.9 ↑	0.7 ↑	=	=
Parvataneni (2009)	10	50–73	=	3.0 ↑	1.5 ↑	=	=	=
Riley (2006)	26	18–35	1.5 ↓	0.6 ↓	0.6 ↓	=	=	=
Lee (2007)	19	18–70	=	=		=	=	=
Watt (2010)	18	65–81	2.8 ↓	=		=	=	=

Table 2. An overview of the changes from overground to treadmill walking in braking ground reaction force (GRF) and maximum joint moments. ext = extension; flex = flexion; ↑ = increased in treadmill gait; ↓ = decreased in treadmill gait

Author (year)	n Subjects	Age (y)	Braking GRF	Joint moments (Nm/kg)					
				Hip ext	Hip flex	Knee ext	Knee flex	Plantar flex	Dorsal flex
Riley (2006)	26	18-35	↓	0.05 ↑	0.15 ↓	0.09 ↓	0.11 ↑	=	=
Lee (2007)	19	18-70	↓	0.17 ↑	0.13 ↓	0.24 ↓	0.05 ↑	=	0.09 ↓
Watt (2010)	18	65-81	↓	=	0.12 ↓	=		=	=

Several research groups have investigated the differences between treadmill and overground walking in patient groups, such as children with CP,[22–25] stroke patients,[15] and transtibial amputees.[11] In general, gait deviations seem to be more pronounced in treadmill walking, making it a valid and maybe even superior method to detect motor control deficits.[15,23] However, systematic differences between treadmill and overground walking do necessitate the use of treadmill-specific normative data.[24]

Understanding and minimizing potential differences

In summary, it seems that the biomechanics of walking on a treadmill vs overground are comparable with some minor differences that are most pronounced in kinetic measures. These differences can be attributed to four underlying principles regarding treadmill walking:

1. During treadmill walking there is a mismatch between the visual perception of the subject and his movement pattern, as there is no visual flow. This causes changes in the visuomotor or other sensory expectancies involved in locomotion.[26] Use of a virtual reality system could provide a solution to this problem. By showing an immersive virtual reality environment synchronized with treadmill speed, the visual flow and perception of movement of the subject correspond. Although gait parameters actually do not seem to differ much between walking with or without virtual reality, subjects do rate walking with virtual reality as more similar to overground walking.[11,22,27]
2. Treadmill walking enforces walking direction and speed, thus restricting subjects to walking in a straight line without speed variations. This may explain the reduced variation seen in spatiotemporal parameters.[10,17–19] A larger treadmill and walking surface would allow for more natural drift,[11] and, moreover, a self-paced mode can be used, in which the speed of the treadmill is controlled automatically by the walking speed of the subject, as recorded by a 3D motion-capture system.[28] This allows for natural walking speed variations. Indeed, self-paced walking compared with fixed-speed walking showed greater long-term walking speed variability[29] and improved kinematic and kinetic gait patterns.[30]
3. During treadmill walking there are intra-stride variations in belt speed, which can explain the reduced braking ground reaction forces and therefore the reduced ankle dorsal flexion and knee extension moments.[13,20] Indeed, walking kinetics and kinematics differ between walking on a low power or high power treadmill, with respectively high (6%) or low (3%) belt-speed variations.[31] Current treadmills minimize the intra-stride variations in belt speed by using a strong motor and appropriate control software, and by reducing possible belt slip over the rollers.
4. Most people are not as familiar with treadmill walking as with overground walking. Therefore, a major limitation of most of the above-mentioned studies is that they included only a short period (two minutes) of familiarization with the treadmill. It has been shown that after six minutes of treadmill walking, spatiotemporal parameters and knee kinematics are no longer different from overground walking.[32] It is therefore recommended to implement a six-minute familiarization period.

It can thus be concluded that there are various ways to minimize the differences between treadmill and overground walking, and thus optimize the generalizability to everyday life. Ideally, treadmill-based gait analysis should be done on a large treadmill with a strong motor and control software, while using a self-paced mode, and a virtual reality environment.

Functional gait analysis

Although for many patients and clinical users steady state gait analysis will be sufficient, recent studies indicated the benefit of more challenging environments to examine functional gait.[33–36] During functional gait analysis, real-life challenges are simulated, such as avoiding an obstacle, dual-tasking, or responding to a near slip or trip situation. This may be a more sensitive and revealing way to assess movement pathologies and fall risk. Treadmill-based gait analysis allows the addition of a virtual reality system and a movement platform to facilitate various types of visual, mechanical and cognitive perturbations during gait. Also, by giving real-time feedback on gait parameters, the ability of patients to adapt their gait can be assessed, providing information on compensatory mechanisms.[37] The use of a treadmill thus expands the possibilities of gait analysis, allowing for a more functional and, likely, more sensitive assessment.

Conclusion

To conclude, differences between treadmill and overground walking are small and typically not clinically relevant. Potential differences can be further minimized by using a familiarization period, self-paced mode, and a virtual environment. Therefore, the advantages of treadmill-based gait analysis, such as increased efficiency and functionality, seem to outweigh potential limitations. If we are prepared to accept the small differences from overground walking, treadmill-based gait analysis opens up a variety of new possibilities, including functional gait analysis. This may strengthen the position of clinical gait analysis in the field of rehabilitation, and expand its use to neurology, orthopedics and geriatrics.

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