OLIVIER, S. 1997. Physiological, kinematic and psychophysical differences between overground and treadmill running. *South African journal of sports medicine* [online], 4(4), pages 17-20. Available from: https://doi.org/10.17159/2078-516X/1997/v4i4a913

Physiological, kinematic and psychophysical differences between overground and treadmill running.

OLIVIER, S.

1997

Physiological, Kinematic & Psychophysical differences between Overground and Treadmill running

S Olivier,
Dept of Human Movement Science, University of Zululand.

ABSTRACT

In order to simulate overground walking and running, the motordriven treadmill is only used in physiological, kinematic and psychophysical studies of human emotion. Primarily because of the convenience and control that it offers, the treadmill has played an important role in the development of sports science and allied disciplines. However, the results of studies utilising the treadmill can only be extrapolated to overground situations if there are no demonstrable, significant differences between the two modes of locomotion. This paper serves to examine the literature in order to clarify the issues involved for researchers. The review indicates that while the treadmill is a convenient tool to assess responses to physical work, some caution should be applied when extrapolating certain kinds of data obtained under certain kinds of conditions. These might include kinematic variables at speeds in excess of 5 m.s^{-1}, using a treadmill for shoe or orthotic assessment, and for obtaining psychophysical measures, which depend to some degree on cognitive appraisal. When workloads are matched, it seems that measures of oxygen consumption are equivalent for the two conditions. Finally, researchers need to consider the issue of sufficient habituation to treadmill locomotion, as this may reduce possible differences when comparing the two modes of locomotion. In conclusion, the treadmill is a valuable tool in research investigating responses to physical work. Much of this research is however concerned with extrapolation to "real world" environments, and researchers should be aware of possible differences between the two modes of locomotion under certain conditions.

INTRODUCTION

The vast majority of research investigating physiological, kinematic and psychophysical responses to work appears to have been conducted in the somewhat artificial ambience of the laboratory. More specifically, the motordriven treadmill is frequently used in biomechanical and exercise physiology studies of locomotion, as well as for training and rehabilitation purposes. The treadmill offers many advantages to studies in human locomotion, mainly because of the control and convenience it offers, particularly when doing tests that require maximal effort. Using the treadmill, a familiar human movement can be varied in intensity while the subject performs in close proximity to metabolic and cardiorespiratory recording instruments.[1,2,3] As a result, the treadmill has played a very important role in the study of human movement.

The treadmill is often used to simulate overground walking and running, but the literature indicates a wide difference of opinion about the validity of the extrapolation of treadmill information to the overground environment or vice-versa[4]. Wall and Charteris[2] state that even though differences between the two conditions may exist, these are probably outweighed by the convenience offered by the treadmill. If however, significant differences do exist between the two modes of locomotion, the extrapolation of information from one environment to the other could involve inherent inaccuracies.

Therefore, it is important to examine the results of specific studies before the results of treadmill studies can be generalised to the field.

Kinematic factors

Initially it was thought that through a basic analysis of fundamental mechanics, the results of treadmill studies could be directly applied to the overground situation. That is, in a system involving movement relative to a surface, there is no difference whether a person moves over the surface or whether the surface moves beneath the person (except for the effects of air resistance). Several investigators have however found differences in the kinematics between treadmill and overground locomotion.[1,3,5,6] Nelson et al.[1] hypothesised that meaningful differences would be observed between the two conditions, indicating that different mechanics are utilised when running on the treadmill than when running overground under similar conditions of slope and speed. Performance conditions for the two running surfaces were duplicated, and there were no differences between the matched velocities. At 6.4 m.s^{-1}, longer stride lengths and lower stride rates were observed for treadmill running. The treadmill condition produced greater times of support and corresponding decreases for non-support (Table I).

Table I:
Mean results for stride length (m), stride rate (strides.s^{-1}), support and non-support (s); for horizontal running at 6.4 m.s^{-1}. (Table from data presented by Nelson et al. 1972)

	Stride length	Stride Rate	Support	Non-support
Overground	1.92	3.32	.162	.14
Treadmill	2.01*	3.1 5*	.1 75*	1.43

*Significant (p<.01)

Although horizontal velocity was matched for the two conditions, vertical velocity was greater for the treadmill condition, indicating that running on a stationary surface requires greater vertical velocity than running on a treadmill. The authors concluded that the difference in velocity was most likely due to the acceleration-deceleration pattern in overground running which develops during the driving phase (acceleration) and during the touchdown and recovery phases (deceleration). They further report that two interrelated running

Address for correspondence:
Private Bag X1001, KwaDlangezwa, 3886,
South Africa.
Telephone: 0351 93916 (work & fax), 921963 (a/h),
082 4525761
E-mail: solivier@pan.uzulu.ac.za

modifications occur on the treadmill. The runner's foot is placed further in front of the centre of gravity, and the moving belt returns the foot beneath the runner. In overground running this would lead to a retardation of velocity. All this increases duration of the support phase and decreases that of the airborne phase at a given velocity. In order for an adequate stride rate to be maintained however, the runner must complete the recovery and touchdown phases more rapidly.

Given the variability in vertical velocity, it was concluded that the work done would be greater for overground than treadmill running, and that there were significant biomechanical differences between overground and treadmill running, but that this was particularly so in the case of temporal variables. However, whether the differences observed in this study are of practical import is still an unresolved question. Elliott and Blanksby[5] found kinematic differences between the two conditions, but also only at higher velocities (4.82 - 6.2 $m.s^{-1}$). For both males and females during treadmill running, stride length decreased and stride rate increased, while the period of non-support was significantly less. Although the results of these two studies were contradictory in that at a common velocity athletes modified their running style in different ways, both investigators indicate that at a velocity of approximately 5 $m.s^{-1}$ or faster on the treadmill, modifications in locomotion are likely to occur, and this should be taken into account when extrapolating data to field situations.

Nigg et al[6] attempted to determine whether a treadmill can validly be used as an instrument to simulate the kinematics of human locomotion during overground running. Specifically, leg kinematics were quantified for treadmill running by varying the treadmill gradient, the running velocity, the shoe, and the experience with treadmill running and were compared with the corresponding values for overground running. They found that most of the lower extremity kinematic variables showed inconsistent trends for individual subjects, with the differences being substantial. Contrary to expectations, they found that an increase in running speed tended to decrease the kinematic differences, and that a larger, more powerful treadmill increased the differences. It must however be remembered that the number of subjects used to assess these questions was small (n=22) and the variance associated with the variables was quite high. In stressing the importance of treadmill habituation before extrapolating to overground conditions, and noting particular adaptations to treadmill locomotion, the authors concluded that individual assessments of running kinematics on a treadmill for shoe or orthotic assessment may possibly lead to inadequate conclusions about overground running.

Physiological factors

Frishberg[3] examined selected kinematic variables during overground and treadmill sprinting to determine possible physiological differences, as well as differences in running technique due to altered kinematic variables. He found that O_2 debt for the overground condition was 36% greater than for the treadmill running condition. Pugh[7] has proposed that at running velocities above 6 $m.s^{-1}$, air resistance might be responsible for such differences. The reported 36% increase in O_2 debt however, far exceeds other reports of the percentage cost of air resistance to energy expenditure, and as such the large difference cannot be accounted for purely by the air resistance factor. Frishberg's[3] kinematic analysis revealed a possible standardisation of running form during treadmill locomotion, and he concluded that his data suggested that overground and treadmill locomotion at high sprinting speeds are biomechanically different, and that this resulted in the significant difference in O_2 debt. He hypothesised that the moving treadmill belt reduces the energy requirements of locomotion by moving the supporting foot and lower leg backward, which may contribute to the observed greater range of angular motion displayed by the lower leg, as well as the reduced angular motion of the thigh during the support phase. These changes, he concluded, would probably result in a reduced workload for the hip musculature, thus requiring less energy expenditure for the treadmill running condition. Thus, according to this study, treadmill sprinting is not as physiologically stressful as overground running. Methodological problems with speed-matching between the two sprinting conditions however indicate that Frishberg's[3] results should be interpreted with caution. The validity of using O_2 debt to measure total energy expenditure is also questionable. Furthermore, the velocity differences between his and other studies makes comparison difficult.

McMiken and Danieis[8] measured VO_2, in a discrete series of three speeds and at maximal effort during treadmill and track running. The aerobic requirement differences were evaluated, and none of the differences were found to be significant. The authors concluded that if real aerobic differences do exist between the two conditions, then they are probably very small. They concluded that treadmill determinations of O_2 uptake may be validly extrapolated to track running in calm air. However, the running speed of subjects in this study never exceeded 4.3 $m.s^{-1}$, and differences may occur at higher velocities. In support of these results, Bassett et al[9] state that there is general agreement that the oxygen demand of level running is similar for both the treadmill and overground situations at speeds under 4.5 $m.s^{-1}$. As stated earlier, Pugh[7] reported a greater energy cost for track running, but this was attributed to the effects of air resistance rather than to fundamental differences in the mechanics of overground and treadmill locomotion. The question of whether real aerobic differences do exist between the conditions remains unanswered, but at present the treadmill appears to be a valid instrument for the estimation of oxygen uptake when the data are to be applied to track running in calm air at running speeds below 4.5 $m.s^{-1}$.

Most of the above studies were, however, conducted on level surfaces, and the issue of grade locomotion is an ergonomic problem that is far from resolved[10]. According to ACSM[11] prediction formulae, the energy cost for overground running is greater than for running on the treadmill. At a speed of 3.3 $m.s^{-1}$ and at 7.5% grade, the difference would amount to 10.25 $ml.kg^{-1} min^{-1}$. Conversely, Van Ingen Schenau[4] used a theoretical physics approach and concluded that there should be no differences between the metabolic energy requirements of inclined treadmill running and overground hill running. If differences do exist, Van Ingen Schenau[4] feels that they can be attributed to visual, and to a lesser extent, auditory factors. Bassett et al[9] report date which support these assumptions. At 0% and 5.7% grades, no significant differences were observed between overground and treadmill running. These conclusions are supported by the research of Olivier and Scott[12] (Table II), who found no differences in VO_2 for a grade running task on the treadmill and overground. Minute ventilation (VE) and psychophysical differences between the two conditions were attributed to cognitive appraisal of the particular work task. Visual information may be important in maintaining equilibrium and stability, while the ambience of the treadmill and laboratory could prove to be an extremely stressful environment for a subject. These factors together with wind resistance could cause differences between the two situations, but it appears that measurements of VO_2 obtained during level and inclined treadmill are valid when applied to the overground situation.

Psychophysical factors

With regard to possible psychophysical differences, an examination of several studies indirectly related to the problem will be useful. Utilising a parallel-processing perspective, Pennebaker and Lightner[13] demonstrated that during exercise, external cues (e.g. terrain) do compete with internal cues e.g. ventilation) specifically, despite no differences in fatigue ratings, subjects were found to run faster on a cross-country course than on a track. As fatigue reports were comparable for the two courses, it was hypothesised that shifting attention to external cues led to diminished responsivity to internal states.[14] Put another way, as subjects were focusing on external cues to a high degree on the cross-country course, their processing of internal sensations was restricted.[15] An investigation by Stones[16] provides some support for the limited capacity position described by Rejeski.[17] Stones[16] states that physiological control systems undoubtedly contribute to judgement of pace and fatigue, and it would be surprising if the visual system did not contribute also, at least to pace judgement. Consequently, his research was designed to increase the demand on a runner's visual system by restricting field of vision through the use of specialised goggles. Attenuated visual input resulted in: a) enhancement of perceived pace relative to actual pace, b) lessening of fatigue relative to actual pace, and c) slowing of actual pace. These findings make it apparent that the visual system, in addition to other physiological control systems, contributes to various aspects of the running experience. This raises an interesting question with regard to running environment and fatigue perception; namely, might parallel observations be obtained under conditions where visual input was not attenuated artificially? In other words, would runners on a treadmill report different perceptions of fatigue than when running outdoors at a similar pace? It is worth noting that under conditions of unrestricted vision, the visual field is filled both with near and far objects. For a person in motion, the corresponding retinal projections will therefore be associated with varying degrees of change.[16] This may not be the case for treadmill running. Stones[16] thus found that visual impairment and the subsequent vigilance required for movement resulted in reduced awareness of fatigue-relevant physiological information. Thus, according to this particular investigation, it would appear that what is available in perception can be blocked from consciousness by flooding the lines of communication with distracting stimuli.

Birk and Birk[18] contend that the use of Ratings of Perceived Exertion (RPE), estimated during exercise testing, to control intensity during training by reproduction of similar efforts, may be inappropriate. They feel that environment influences would render direct perceptual translations from the laboratory to the field invalid. Jackson et al[19] have demonstrated that the physiological and psychological correlates of exercise performance are different in a field setting than in the laboratory. On the other hand, ratings of perceived exertion were not affected by auditory input such as music and mechanical noise, e.g. treadmill operation.[20] It is worth noting that studies of this nature are difficult to control, and may not validly discriminate between the effects of physiological and psychological stress indicators, as has been inferred.[20] Nevertheless, in the field, where a myriad of social physiological forces impinge on the performer, the role of physiological feedback to RPE may well be reduced. The potential role that motivational and informational factors may play in the subjective assessment of physical work is thus increased.[14] This is supported by Olivier & Scott[12] (Table II), who investigated physiological (HR, VO_2, VE), perceptual (RPE) and attitudinal (Semantic Differential) responses to identically matched workloads (70% of VO_2 Max) under treadmill and overground conditions. There were no differences in VO_2 and HR responses, whereas VE and RPE responses were significantly elevated for the treadmill condition, and attitudes were more favourable towards the overground condition. In support of the literature cited above, the authors concluded that the differences were, at least in part, due to the perceptual and cognitive interpretations of the particular characteristics inherent in the two environments.

Table II:
Mean physiological, RPE and attitudinal responses to uphill (5.72%) overground and treadmill running at 2.94 m.s-¹. (Table from data presented by Olivier & Scott, 1993).

Variable	Overground	Treadmill
Physiological		
HR ($b.min^{-1}$)	157	156
VO_2 ($ml.kg^{-1}.min^{-1}$)	47.59	48.45
VE ($l.min^{-1}$)	69.05	75.13*
RPE		
Local	11.07	11.96*
Central	10.86	11.36
Overall	10.89	11.82*
Attitudes		
Evaluation	26.53	16.73*
Potency	16.64	13.91
Activity	18.27	16.81
Overall	61.46	46.82*

*Significant ($p<.05$)

Treadmill accommodation

Treadmill accommodation has been defined as the state obtained when a subject has had sufficient training on the treadmill, such that no significant within-day or between day kinematic or temporal differences are evident from stride-to-stride. The process involves the gradual establishment of a stable and essentially normal gait showing no significant variations in averaged kinematic patterns from stride-to-stride or trial-to-trial over days or weeks. Accommodation is contingent upon initial adjustment and subsequent long-term conditioning.[21]

Wall and Charteris[21] have demonstrated that the kinematics of treadmill locomotion alter as the novice learns how to walk on the moving belt surface. Although accommodation to the surface may initially be rapid, kinematic changes continue towards a stable gait pattern with distributed practice over a period of 1 hour.[2]

These authors have also suggested that there may be metabolic correlates of these progressive changes, and that changes in skill level may result in a lowering of the energy cost of gait as the novice becomes an accomplished treadmill walker. Furthermore, they recommend that when studies to investigate the subtle differences between overground and treadmill locomotion are contemplated, it would be inappropriate to employ subjects habituated for anything less than 1 hour, in several distributed practice sessions, and that measurements should not be taken during the first 2 minutes of performance.

Schieb[22] states that the actual time required before the individual feels comfortable with the treadmill seems to depend on factors such as length of time into the treadmill run and overground running experience, while Van Ingen Schenau[4] feels that psychological factors such as apprehension may retard accommodation. Therefore when the treadmill is used to derive cardiovascular measures in order to assign a subject's workload to the overground situation, it is important to expose the subject to an adequate amount of treadmill locomotion,[22] otherwise inaccurate or misleading information may result.

Investigating the problem of treadmill accommodation, Schleb[22] found that significant between-day kinematic adjustments were made by novice treadmill runners, but only between days 1-2 of a 10-day (15 min per day) training programme. Further, significant within-day adjustments were only evident between minutes 1 & 8 on any day's run, and not after minute 8. Within day differences were not found beyond the third day, indicating fairly rapid accommodation to treadmill locomotion.

From this he concluded that one 15 min training session is inadequate for a novice treadmill subject to accommodate fully, but that after the 8th min of a second habituation session a subject should be accommodated to the treadmill. Wall & Charteris[22] however suggest that where measurements are to be made of gait patterns for the purpose of application to overground situations, subjects should be previously habituated in distributed practice sessions for 1 hr, and no measurements should be made within the first 2 min of performance. Further, in studies investigating subtle differences between treadmill and overground conditions, it is inappropriate to utilise subjects habituated for anything less than 1 hr in several distributed practice sessions. However, when fine measures of gait are not collected, random speed and grade habituation of 10 min should suffice.[2]

Conclusion

In conclusion, the treadmill is a convenient tool to assess responses to physical work. In terms of its practical application as a research tool, it is widely used to extrapolate to overground locomotion contexts. The research reviewed above however indicates that some caution should be applied when extrapolating certain kinds of data obtained under certain kinds of conditions. These might include kinematic variables at running speeds in excess of 5 $m.s^{-1}$, using a treadmill for shoe or orthotic assessment, and psychophysical measures such as RPE and attitudinal responses, which depend to some degree on cognitive appraisal. There seems to be general agreement that measures of oxygen consumption are equivalent for both conditions when workloads are matched. Sufficient habituation to treadmill locomotion on the part of research participants may reduce the kinematic and psychophysical differences between the two conditions, with a consequent increase in the validity of applying the data to field situations.

References

1. Nelson RC, Dillman CJ, Lagasse P & Bricket P (1972) *Biomechanics of overground versus treadmill running. Medicine & Science in Sports 4(4), 233-240.*
2. Wall JC & Charteris J (1981) *A kinematic study of long-term habituation to treadmill walking. Ergonomics 24(7), 531-542.*
3. Frishberg BA (1983) *An analysis of overground and treadmill sprinting. Medicine & Science in Sports & Exercise 15(6), 478-485.*
4. Van Ingen Schenau GJ (1980) *Some fundamental aspects of the biomechanics of overground versus treadmill locomotion. Medicine & Science in Sports & Exercise 12(4), 257-261.*
5. Elliott BC & Blanksby BA (1 976) *A cinematographic analysis of overground and treadmill running by males and females. Medicine & Science in Sports 8(2), 84-87.*
6. Nigg BM, De Boer RW & Fisher V (1995) *A kinematic comparison of overground and treadmill running. Medicine & Science in Sports & Exercise 27(1), 98-105.*
7. Pugh LGCE (1971) *The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. Journal of Physiology 213, 255-276.*
8. McMiken DF & Daniels JT (1 976) *Aerobic requirements and maximum aerobic power in treadmill and track running. Medicine & Science in Sports 8(8), 14-17.*
9. Bassett DR, Giese MD, Nagle FJ, Ward A, Raab DM & Balke B (1 985) *Aerobic requirements of overground versus treadmill running. Medicine & Science in Sports & Exercise 17(4), 477-481.*
10. Charteris J (1986) *Pedestrian adaptations to differences in the slopes of walking surfaces. Proceedings of the Second Annual Conference of the Ergonomics Society of Southern Africa, University of Cape Town.*
11. American College of Sports Medicine (1980) *Guidelines for Exercise Testing and Prescription. 2nd Edition, Lea & Febiger, Philadelphia.*
12. Olivier S & Scott PA (1993) *Physiological, perceptual and attitudinal responses to identically matched workloads in field and laboratory testing conditions. SA Journal for Research in Sport, Physical Education & Recreation 16(1), 63-72.*
13. Pennebaker JW & Lightner JM (1980) *Competition of internal and external information in an exercise setting. Journal of Personality & Social Psychology 39, 165-174.*
14. Rejeski WJ (1981) *The perception of exertion: a social psychophysiological integration. Journal of Sport Psychology 1981(4), 305-320.*
15. Hardy CJ, Hall EG & Prestholdt PH (1986) *The mediational role of social influence in the perception of exertion. Journal of Sport Psychology 8, 88-104.*
16. Stones A (1980) *Running under conditions of visual input attenuation. International Journal of Sport Psychology 11(3), 172-179.*
17. Rejeski WJ (1985) *Perceived exertion: an active or passive process? Journal of Sport Psychology 1985, (7), 371-378.*
18. Birk TJ & Birk CA (1987) *Use of ratings of perceived exertion for exercise prescription. Sports Medicine 4, 1 -8.*
19. Jackson A, Dishman RK, La Croix S, Patton R & Weinberg R (1981) *The heart rate, perceived exertion and pace of a 1.5 mile run. Medicine & Science in Sports & Exercise 13, 224-228.*
20. Carton RL & Rhodes EC (1985) *A critical review of the literature on ratings scales for perceived exertion. Sports Medicine 2, 198-222.*
21. Wall JC & Charteris J (1 980) *The process of habituation to treadmill walking at different velocities. Ergonomics 23(5), 425-435.*
22. Schieb DA (1986) *Kinematic accommodation of novice treadmill runners. Research Quarterly for Exercise & Sport, 57(1), 1 -7.*
23. Charteris J (1987) *Personal communication. Rhodes University, Grahamstown, South Africa.* □