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Transient Postural Sway following Treadmill Walking

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ABSTRACT

Treadmill walking is widely used for assessment and treatment of medical and surgical conditions such as chronic pulmonary and heart disease. Transient increase in postural sway is often experienced by clients when they step off the treadmill on completion of their walking programme. In order to quantify this phenomenon 20 able-bodied college students with a mean (SD) age of 21.6 (2.3) years underwent 10, 20, and 30 minutes of treadmill walking followed by measurement of their centre (C) of pressure (P) while standing on a force platform. On commencement of measurement it was found that both the distance and area of C of P movement significantly increased for all of the groups immediately following walking on the treadmill when the participant commenced measurement. The largest change in the distance and area of C of P movement was obtained in the 30-minute walking group immediately after stepping off the treadmill on cessation of walking. These results demonstrate that a reasonably long artificially induced walking rhythm conflicts with the learned natural walking rhythm resulting in a transient increase in postural sway leading to a loss of balance. In conclusion, the findings of this study suggest that treadmill walking should be kept to approximately 20 minutes maximum, followed by a minimum rest period of 10 minutes.

KEY WORDS

centre of pressure, treadmill walking, postural sway

INTRODUCTION

Exercise therapy is used for a wide selection of clients with a variety of medical and surgical conditions, particularly medical conditions with cardiopulmonary disease with the aim of improving the respiratory and circulatory endurance. The treadmill is widely used in such clinical situations for assessment and treatment of these conditions. One side effect from this modality is that the client often experiences a temporary postural disturbance when he/she stands down from the treadmill onto the flat immobile surface immediately after their completion of walking, resulting in an impaired walking pattern. However, the postural sway is transient and disappears shortly afterwards. This phenomenon implies that the natural walking rhythm seems somehow impeded by the unnatural state of that which is enforced by the treadmill, and, because of this, the balance mechanism is possibly temporarily disturbed by it. To examine the balance mechanism a force platform is often employed, and this acts as a measure of postural sway and tells us if it is within its normal or abnormal limits[1].

Balance is a complex multi-system functioning dependent on intact sensory and neuromuscular systems[2]. The review of the literature on this subject revealed that a few studies have dealt with the malfunction of the balance mechanism following treadmill running and walking[3, 4] in relationship to disorientation of the

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righting reactions and postural disturbance. In a further study, closely related to this subject, Maruyama and his associates[5] state that there is no difference in the physiological reactions of indoor walking and treadmill walking. Regarding the relationship between exercise loading and balance function, there has only been one study where the roles of the righting reaction and nystagmus have been examined by Watanabe and his associates[6]. In addition, the movement of the centre (C) of pressure (P) has been analyzed by Tokita and his associates[5] in regard to any malfunction present in the balance mechanism, and also they quantified C of P movement and their study is generally accepted as scientifically valid.

Although Hashiba's study set the period of walking at seven minutes[3], in a clinical situation this may exceed 30 minutes or more. Further, the walking speed of seven kilometre per hour (km/h) in Hashiba's study[3] is, on occasion, too fast, i.e., for clients with chronic obstructive pulmonary disease during the regimen of their exercise tolerance training. Therefore, the purpose of this present study was to clarify the apparent transient increase in postural sway following varying set times of walking on the treadmill at relatively slow speed in terms of distance and area of C of P movement.

The significance of carrying out this experiment in scientific terms would be that, although the method of determining the quantity of exercise load for treadmill walking is well established[8], factors such as the dangers and adverse effects have not as yet been fully examined. It would, therefore, be possible, by quantifying C of P movement, to scientifically measure the condition which results in a disturbance in the function of the balance mechanism. Knowledge on the relationship between the length of time walking on the treadmill and changes which occur in the recovery of the balance mechanism following this could, then, be applied to clinical situations, and, consequently, a safer and more effective and efficient exercise therapy programme would be possible for the client.

PARTICIPANTS AND METHODS

Selection of the participants We selected ten healthy male and ten healthy female college students in their twenties with a mean (and standard deviation or SD) age of 22.4 (3.0) years for the males and 20.8 (0.6) years for the females. The mean (SD) age of all the participants was 21.6 (2.3) years. Young participants were chosen so that the effect of age on the balance mechanism would not be a major factor in affecting the experimental conditions.

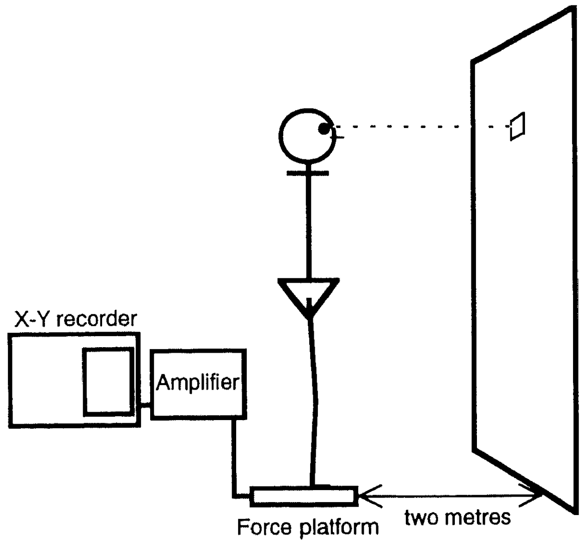


Fig. 1 Schematic illustration of the measurement of postural sway.

Measurement of C of P movement The participant rested on a couch for five minutes before the commencement of measurement in order to nullify the effect of fatigue. The investigator, then, asked the participant to stand on a force platform (type G1820, Anima Inc., Japan) with his/her feet close together (Fig. 1) with the upper limbs relaxed by their sides. While maintaining this erect posture a yellow, one-centimetre by one-centimetre plastic tape was placed two metres away in front of the participant, and he/she was asked to concentrate on it constantly. Initially, the participant was asked to remain still for five seconds in order to stabilize the posture in the erect position, then following this, the distance and area of C of P movement were measured for 20 seconds by a type G3850 length/area analyzer (Anima Inc., Japan) and this was recorded by a type WX1100 X-Y recorder (Watanabe Inc., Japan). Next, the participant underwent walking on a type STS-5200M treadmill (Nihon Kohden Inc., Japan) for 10 minutes on the first day, 20 minutes on the second day, and 30 minutes on the third day. The speed of the treadmill was set at 4.5 km/h and gradient at zero degrees

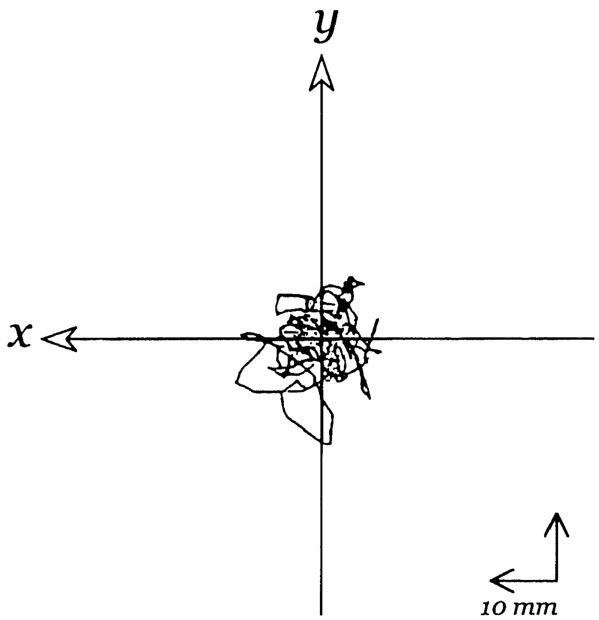


Fig. 2 One example of C of P movement.

in order to keep the effect of the load to a minimum, and also the participant walked without holding on to handrails.

The distance and area of C of P movement were recorded four times ; namely, immediately after, five minutes after, 10 minutes after, and 15 minutes after the completion of treadmill walking. The participant was asked to rest on the couch except during the post-treadmill measurements. All the participants acted as their own control by being randomly asked to undergo walking on the treadmill on three separate occasions. In this way three groups were created ; 10-minute (min), 20-min, and 30-min groups.

The optimum time of day for the experiment was chosen to eliminate any hunger or sign of fatigue which may have had adverse affects, and also the ambient room temperature was maintained at 18 to 24 degrees Celsius during the experiment. The procedures and risks of the study were explained to the participants before the experiment took place, and they were asked to sign an informed consent sheet.

Data analysis The change in distance and area of C of P movement was calculated for each group using the Student's t test with the level of significance at 0.05. Also calculated were regression equations to examine the temporal change in C of P movement during the post-treadmill walking period.

RESULTS

One example of C of P movement is shown in Figure 2.

Temporal change in the distance of C of P movement (Fig. 3) The distance of C of P movement significantly increased immediately after the completion of treadmill walking for all the groups when compared to those of the pre-treadmill walking period (10-min group $p<0.05$, 20-min $p<0.01$, and 30-min groups $p<0.001$, respectively). The post-treadmill period showed that the distance of C of P movement decreased as time elapsed following completion of the walking period on the treadmill, except for a temporary increase 10 minutes following the treadmill walk-

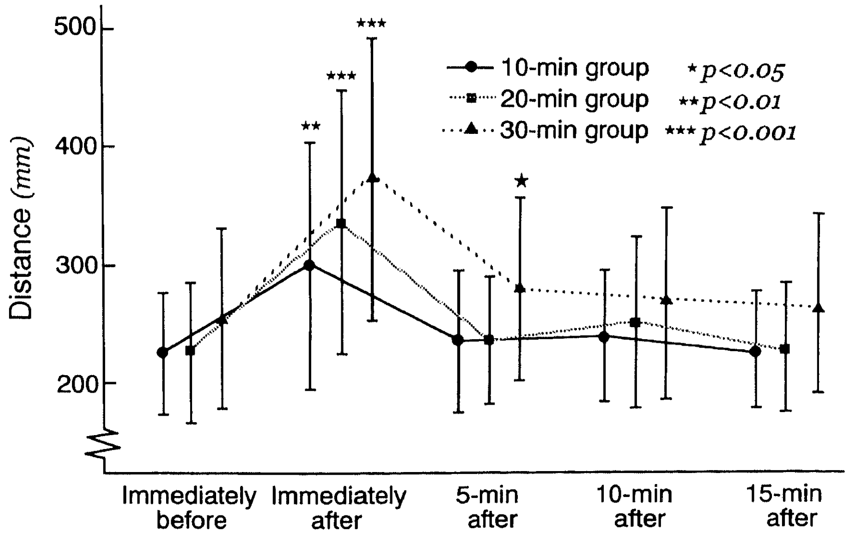


Fig. 3 Temporal change in the distance of C of P movement.

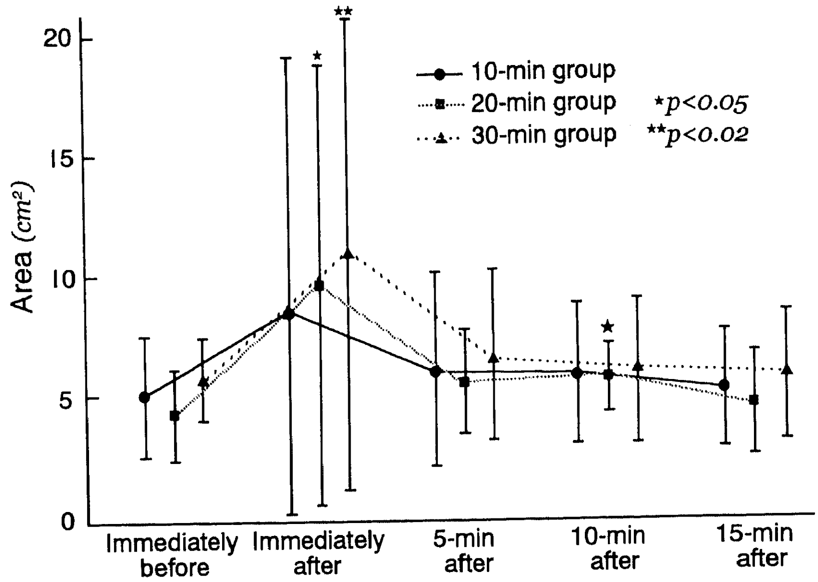


Fig. 4 Temporal change in the area of C of P movement.

Table 1 Quantitative change in the distance of C of P movement in millimetres.
(Parentheses denote standard deviation.) NS : non-significant

	Immediately after	5-min after	10-min after	15-min after
10-min group	80.4 (123.9)	9.6 (45.1)	13.6 (45.5)	1.5 (44.3)
20-min group	109.4 (121.4)	11.5 (59.2)	25.0 (65.5)	1.5 (54.3)
30-min group	119.8 (102.2)	25.3 (52.9)	17.9 (52.4)	14.0 (60.8)
Significance between 10- & 20-min groups	*NS*	*NS*	*NS*	*NS*
Significance between 10- & 30-min groups	$p<0.05$	*NS*	*NS*	*NS*

ing period of the 10- and 20-min groups. However, the distance of C of P movement in the 30-min group was significantly larger both at cessation of and five-min after treadmill walking ($p<0.05$), which demonstrated that this group showed less decrease in the distance of C of P movement than the other groups on cessation of treadmill walking.

Temporal change in the area of C of P movement (Fig. 4) The area of C of P movement increased for all the groups immediately after the completion of treadmill walking, and all were significant but it was especially evident in the 20- and 30-min groups (the former $p<0.05$ and the latter $p<0.02$, respectively). However, the area of C of P movement decreased as time elapsed following treadmill walking except in the 15-min group for which there was a temporary but significant increase in the movement of C of P during the 10-min period following the treadmill walking ($p<0.05$). The 30-min group showed a more moderate decrease in the area of C of P movement during the five- and 15-min periods following treadmill walking than the other groups.

Quantitative change in the distance of C of P movement (Table 1). The quantitative change in the distance of C of P movement immediately following treadmill walking and the five-min periods following treadmill walking increased linearly, and this was dependent on the amount of increase in walking time. The 20-min group showed the highest rate of change during the 10-min period following treadmill walking and, again, during the 15-min period following treadmill walking with the 30-min group showing almost ten times the quantitative change in distance of C of P movement and the 10- and 20-min groups showing similar changes. A significant change in the distance of C of P movement occurred only in the 10- and

Table 2 Quantitative change in the area of C of P movement in square centimetres.
(Parentheses denote standard deviation.) NS : non-significant.

	Immediately after	5-min after	10-min after	15-min after
10-min group	3.7 (11.0)	1.1 (2.5)	0.9 (2.5)	0.1 (1.8)
20-min group	5.1 (9.9)	1.0 (3.0)	1.2 (2.2)	0.2 (2.1)
30-min group	5.6 (9.8)	1.1 (4.0)	0.6 (2.8)	0.5 (1.8)
Significance between 10- & 20-min groups	*NS*	*NS*	*NS*	*NS*
Significance between 10- & 30-min groups	*NS*	*NS*	*NS*	*NS*

Fig. 5 Relationship between the distance of C of P movement following treadmill walking.

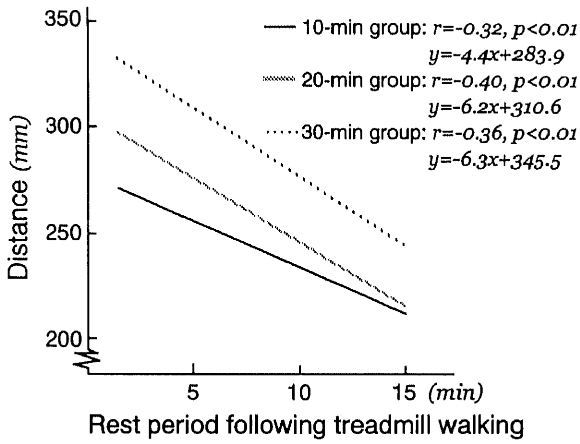
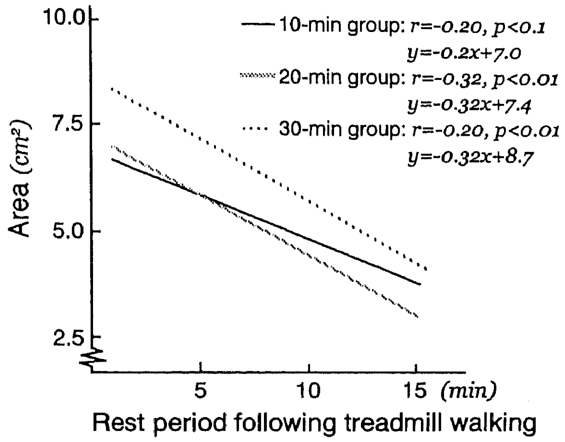


Fig. 6 Relationship between the area of C of P movement following treadmill walking.



30-min groups immediately after the completion of treadmill walking ($p<0.05$).

Quantitative change in the area of C of P movement (Table 2). The quantitative change in the area of C of P movement during the immediate and 15-min periods following treadmill walking increased with the increase in the length of the walking time. There was no relationship between the length of the walking time and either the five- or 10-min rest period following treadmill walking. A significant change occurred only in the 10- and 30-min groups immediately following treadmill walking ($p<0.1$).

Relationship between the distance of C of P movement following treadmill walking and length of treadmill walking time (Fig. 5). The relationship between the distance of C of P movement and the rest periods in each group was almost proportional ; specifically, 10-min group $r=-0.32$, 20-min group $r=-0.40$, and 30-min group $r=-0.36$, respectively, with $p<0.01$ for all the groups. In each group, both the gradients and intercepts of regression lines increased as the length of treadmill walking time increased. Especially, a large difference could be seen in the intercept between the 20- and 30-min groups, but the change in the gradient between these two groups was small.

Relationship between the area of C of P movement following treadmill walking and length of the treadmill walking time (Fig. 6). The relationship between the area of C of P movement and post-treadmill periods in each group was almost proportional ; specifically, 10-min group $r=-0.20$, $p<0.1$; 20-min group $r=-0.30$, $p<0.01$; and 30-min group $r=-0.20$, $p<0.1$, respectively. In each group, the intercepts of the regression lines increased as the length of treadmill walking time increased, but the gradient remained constant for both the 20- and 30-min groups and are seen to be only slightly larger than those for the 10-min group.

DISCUSSION

The results of this study demonstrated that the movement of the C of P was greatest immediately after treadmill walking, and the movement tended to decrease progressively as the resting time elapsed. Further, the longer the length of walking time, the greater were the above effects. It was, therefore, evident that treadmill walking disturbed the participants' balance mechanism. The increased movement of C of P immediately after treadmill walking may have been due to a sudden change in motion of stepping off the treadmill, so that the balance mechanism could not adjust itself promptly to the changing environment of the immobile floor on which the body stood. Another reason for the increased movement of C of P immediately after treadmill walking may be explained by the fact that the gait patterns on the treadmill, compared to the normal gait patterns, resemble a stepping-like motion due to a delay in synchronizing the landing of the foot[9]. Further, walking without holding on to handrails could possibly have disturbed the natural balance mechanism. Because of the enforced artificial rhythm of treadmill walking, the legs, but not the trunk, become loaded, and this disproportion during walking possibly acts as a disrupter of one's balance mechanism. However, a distinction of the effect of fatigue due to treadmill walking cannot be drawn in relationship to the length of walking time, and it would, therefore, be necessary to compare this under the same conditions with normal gait in order to clarify this question.

The movement of C of P and length of walking time demonstrated a close relationship, especially between the 10- and 30-min groups. This finding suggests that the balance mechanism becomes significantly impaired between 20 and 30 minutes of treadmill walking. This statement can be further supported by the fact that the quantitative change in the movement of C of P after 15 minutes of rest was greater for the 30-min group compared to that for the 10- and 20-min groups. Therefore, an optimal length of time for walking on the treadmill is approximately 20 minutes during which movement of C of P is at a minimum. However, these findings cannot be extrapolated directly to clients, because participants in this study were all healthy young men and women, so that a shorter length of treadmill walking may be applicable in the elderly and client with cardiopulmonary conditions.

It is a known fact that there is no relationship between the length of walking time and heart rate following treadmill walking[8]. However, because of a direct proportional relationship to the movement of C of P shown in our study, we assume that the recovery of C of P displacement takes place in proportion to the lapse in the time following treadmill walking.

The relationship between the rest period required following treadmill walking and maximum oxygen uptake has not been examined in detail[6]. But our study somewhat clarified this relationship by demonstrating full recovery of C of P displacement after five minutes following 10 and 20 minutes of treadmill walking and after ten minutes following 30 minutes of treadmill walking. Therefore, approximately 10 minutes of rest should possibly be provided following 20 to 30 minutes of treadmill walking.

Contrary to normal walking, energy for the propulsion of the body on the treadmill during the gait cycle is at an absolute minimum due to the nature of the movement of the apparatus. This may result in an imbalance between the plantarflexors of the foot and other muscles of the leg in terms of fatigue and readyness for contraction, leading to relationship between postural sway and non-requirement of push-off phase.

Future studies on this subject should address how the balance mechanism is affected by changes in the joint angles produced by variations in gradient while walking on the treadmill. Also to be addressed, measurement of elderly population's postural sway during and following treadmill exercise would be of value in today's escalating ageing society.

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トレッドミル歩行による平衡機能の一時的低下

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山崎　俊明，三秋　泰一，武村　啓住，横川　正美

要　旨

心疾患や慢性呼吸器疾患などの内科的疾患を有する患者の評価および治療においてトレッドミルは広く利用されている。しかし，トレッドミル歩行の直後に平地に起立すると身体動揺を経験することが多い。本実験では，トレッドミル歩行により平衡機能が一時的に低下することを重心動揺の距離と面積から明確にすることを試みた。健常な20歳代の大学生20名（平均年齢：21.6±2.3歳）に毎時4.5km，勾配は０°でトレッドミル歩行を10分間（第１群），20分間（第２群），および30分間（第３群）課した。歩行終了の直後，５分後，10分後，および15分後の４回，歩行前と同様にピドスコープ上で重心動揺の距離と面積を測定した。重心動揺の距離および面積は，各群ともに歩行前に比較すると歩行直後は有意に増加し，とくに第３群で大きかった。歩行後の経過は，第１群と第２群で歩行後10分で一時的に増加したことを除くと，重心動揺の距離は経時的に減少したが，第３群においては減少の程度が他群に比べて小さかった。重心動揺の面積も経時的に減少したが，第２群では歩行後10分で一時的に有意に増大した。第３群においては歩行後５分から15分までの経過は他群に比べて緩やかであった。歩行後の重心動揺の距離の変化量は，歩行時間が長くなるにつれ概ね増大したが，第３群では変化量が他群に比べて大きいままであった。歩行後の重心動揺の面積の変化量も，歩行時間が長くなるにつれ概ね増大した。歩行後の重心動揺の距離と時間との関係については，各群ともにほぼ比例関係を示した。また各群ともに回帰直線は歩行時間が長引くにしたがって勾配・切片ともに増大した。歩行後の重心動揺の面積と歩行後の時間との関係については，各群ともにほぼ比例関係を示した。また各群とも回帰直線は歩行時間に従い切片は大きくなったが，勾配は第２群と第３群においてほぼ同値を示し，且つ第１群よりも僅かに大きかった。以上の所見により，トレッドミル歩行は20分間程度で，しかも歩行後には10分間休息することが適切であると思われる。