

Faculté des sciences de la motricité

Biomechanical analysis and reproducibility of speed based on perception in overground and treadmill running

A cross sectional study

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ABSTRACT

Background : The popularity of running has risen in popularity globally due to its accessibility and health benefits. However, the high incidence of running-related injuries (RRIs) is worrying. Key factors influencing RRIs include training volume, previous injury history, and gender. Treatment often involves consultation with physiotherapists, emphasizing their crucial role in recovery. Recent studies explore the biomechanical differences between running on motorized treadmills (MT) and on land, bringing light on potential differences in running biomechanics and perceived exertion. This research aims to analyse data from Runscribe pods to identify biomechanical differences between MT and athletic track running, building upon previous findings with an additional sample.

Objectives : 1. Is the RPE scale reliable and reproducible for controlling exercise intensity in the same condition? 2. Are runners capable of reproducing the same speed at the same intensity in 2 different conditions: on overground and on motorized treadmill? 3. Is running on a motorized treadmill biomechanically comparable to overground running?

Study design : An observational cross sectional study

Methods : 55 healthy people were recruited. They were asked to run 6 times 1 km, 4 times at an intensity of 3/10 (2 times on treadmill and track) and 2 times at an intensity of 8/10 (1 time on treadmill and track). During the experiment, biomechanical data (via Runscribe pods) and physiological data (HR with heart rate monitor) were taken. Participants were also asked how they felt on an RPE scale after running.

Results : 1. ICC reported excellent reliability for 3/10 RPE running speed for both conditions with a high correlation of 0,97 (95% IC [0,945 ; 0,981]) on overground and 0,93 (95% IC [0,88 ; 0,959]) on treadmill.

2. Participants choose slower speed with lower heart rate and RPE on MT than on overground for the two levels of RPE. At 3 of RPE : There is a significant difference for speed of -2,18 km/h ($p < 0,001$, 95% IC [-2,5 ; -1,8], Cohen d: 1,11), for the perceived effort of -0,25 ($p < 0,001$, 95% IC [-0,38 ; -0,01], Cohen d: 5,52) and for the heart rate of -10,8 bpm ($p < 0,001$, 95% IC [-13,1 ; -8,5], Cohen d: 0,62). At 8 of RPE : There is a significant difference for speed of -1,58 km/h ($p < 0,001$, 95% IC [-2,08 ; -1,08], Cohen d: 0,61), for the perceived effort of -0,51 ($p < 0,001$, 95% IC [-0,76 ; -0,25], Cohen d: 0,80) and for the heart rate of -5,47 bpm ($p < 0,001$, 95% IC [-8,01 ; -2,93], Cohen d: 0,53). Runners feel less tired on MT but run slower than on overground.

3. For the first level of RPE (3/10), there are many biomechanical differences between MT and overground. There is a strong significant mean difference for the contact ratio with 79,32% for overground and 87,38% for MT ($p < 0,0001$, Cohen d: 0,81). There are significant mean differences for horizontal GRF of -1,43N ($p < 0,0001$, Cohen d: 0,93), for vertical GRF of -3,64N ($p < 0,0001$, Cohen d: 0,85), for step rate of -4 steps/min ($p = 0,0003$, Cohen d: 0,50), for step length of -0,22m ($p < 0,0001$, Cohen d: 0,89), for total steps of 224 steps/km ($p < 0,0001$, Cohen d:

0,84) and for ground shocks of -2,76 Gs ($p < 0,0001$, Cohen d: 1,09). Runners make more steps that are shorter and less stressful on a MT at low RPE.

Conclusion : RPE scales appear to be reliable tools for prescribing and controlling exercise intensity. The effort effectively perceived by runners is lower on MT than on overground for the two levels of RPE and MT running is characterized by a higher duty factor and a lower step length (At 3 of RPE) which decrease the risk of injury.

Key words : Runner, overground, motorized treadmill, rating of perceived exertion, biomechanics

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I. Introduction

Running is widely recognized as a prevalent and accessible sport globally, with the number of participants consistently increasing over the years. An examination of the New York Marathon participants from 1970 to 2019 demonstrates a significant rise from 25,299 to 344,126, reflecting this trend (1,2). The surge in popularity is attributed to the affordability and minimal equipment requirements of running, making it accessible to a diverse demographic. Moreover, running is celebrated for its health benefits, notably enhancing cardiovascular health and promoting longevity.

Despite its benefits, running is associated with a considerable incidence of injuries. Approximately 50% of runners experience injuries annually, with 25% suffering at any given time (3). The commonly endorsed 10% rule suggests that runners should not increase their training volume by more than 10% per week to mitigate injury risks (4). This high injury rate underscores the importance of prevention strategies in sports medicine. A meta-analysis highlighted several risk factors for running injuries, including high annual injury rates ranging from 19.4% to 79.3%, increased mileage as a risk factor among male runners, and the protective effect of gradual training volume increase against knee injuries (5). Moreover, a history of prior injuries was found to increase the risk of future incidents. Post-injury, many runners seek professional health services. A 2007 study by van Middelkoop et al. surveyed 165 recreational marathon runners who reported new pain post-Rotterdam Marathon; 16.4% consulted a general practitioner, and 24.2% sought physiotherapy (6). This indicates the critical role of physiotherapists in the rehabilitation of running injuries.

To facilitate rehabilitation and the return-to-sport process, clinicians often recommend that patients run on a treadmill. This controlled environment allows for the careful monitoring of pace and exertion, which is critical in preventing re-injury. Clinicians may utilize various indicators of effort to assist runners in finding their appropriate pace. These indicators often include heart rate, perceived exertion, and real-time biomechanical feedback, which are valuable in ensuring that the runner maintains a safe intensity level during recovery.

The American College of Sports Medicine has advocated the use of RPE scales as a way of monitoring the progression of an incremental test to exhaustion and to prescribe and monitor exercise intensity throughout the course of a workout (7). Previous studies have examined applying RPE to monitor exercise using self-paced time trials and self-selected RPE production trials in both cycle ergometry and treadmill running. They suggest that RPE is a viable alternative to physiological metrics like blood lactate levels or %VO₂ Peak when prescribing exercise (9,10).

Recent advancements have seen a growing interest in physiological tests among athletes and coaches. These tests are invaluable for monitoring health and training adaptations, assessing performance capacity, and guiding training prescriptions (11). A 2020 meta-analysis investigated the biomechanical similarities between running on motorized treadmills (MT) and overground.

Although the overall mechanics are quite similar, significant distinctions were noted in foot-ground angles, knee flexion, and pelvic movements. These differences are attributed to several factors, such as the stiffness of the treadmill and the runner's familiarity with the equipment (12).

Building on prior research, the first aim of this investigation was to report reproducibility measurements using RPE scale for runners at low pace in two conditions, overground and treadmill. Secondly, we tested if there was any pace difference between overground and treadmill conditions. Finally, we reported running biomechanical differences between conditions.

II. Methods

II.1 Study design

This cross-sectional study was conducted at the Catholic University of Louvain, Belgium. It has been submitted for approval to the "Comité d’Ethique Hospitalo-Facultaire N°: B403201523492." Each participant provided a written consent prior to enrolment.

II.2 Populations

Participants were recruited through a questionnaire distributed via social networks, email, and word of mouth. Out of the 85 individuals who responded to our participation questionnaire, 30 did not participate in the experiment due to not meeting the inclusion criteria, lack of time or availability, or failure to respond to our follow-up emails. Of those who responded, 55 individuals (36 males and 19 females) met the inclusion criteria and participated in the study. To be included in the study, participants were required to be recreational runners, defined as individuals who have been running at least once or twice a week for a minimum of six months and can comfortably run for 30 minutes without pain or the need to stop. Their level of physical activity was verified using the "Tegner Activity Scale" on the day of the experiment.

The study included individuals who were over 18 years old and fit the definition of a recreational runner. Participants were excluded if they had any heart, respiratory, pulmonary, or musculoskeletal pathologies less than six months old, were over 60 years old, were currently taking any medication, or were current or previous users of orthotics.

II.3 Outcomes

The primary outcomes of this study focus on assessing the reproducibility of speed under identical conditions, specifically the same RPE and running area. To this end, Intraclass correlation coefficient were used as well as Standard Error of the Measurement and Minimal detectable change.

The secondary outcomes investigated was pace of runners at differences RPE condition for two surfaces: overground and on a treadmill. In addition, the biomechanical parameters between these conditions, including contact ratio, shocks, step rate, step length, total steps, and ground reaction force (GRF) were assessed.

II.4 Procedure and materials

Participants were asked to wear their own running shoes for the experiment. The complete experience lasted about 1h30. Participants were free to stop it at any time. They were also free to ask questions if they felt the need. The experiment consisted of a warm-up about 750m on the athletic track and six runs of 1 km: 4 of them at 3 of RPE and two of them at 8 of RPE. Three of the six runs were on an athletic track and the three others on a MT. For each condition, participants ran two series of 1km at 3 of RPE and one at 8 of RPE. The order of the series has been randomized: participants were asked to pick papers corresponding to a run without knowing what it corresponded to.

Before the experiment, participants had to fill some documents in including a written consent form setting out the important information and objectives of the study, information about the participant such as age, weight, height, profession, other sports practised and past injuries (over 6 months) and the physical activity level with the Tegner Activity Scale (TAS) which is graded from 0 to 10 with a score of 0 corresponding to “sick leave or disability” and a score of 10 corresponding to “competitive sports at elite level” (13) (Figure 1).

Please indicate below the **HIGHEST** level of activity that you are able to participate in **CURRENTLY**.

- ☐ Level 10 Competitive sports-soccer, football, rugby (national elite)
- ☐ Level 9 Competitive sports-soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball
- ☐ Level 8 Competitive sports-racquetball, squash or badminton, track and field athletics (jumping, etc.), downhill skiing
- ☐ Level 7 Competitive sports-tennis, running, motorcars speedway, handball
Recreational sports-soccer, football, rugby, ice-hockey, basketball, squash, racquetball, running
- ☐ Level 6 Recreational sports-tennis and badminton, handball, racquetball, downhill skiing, jogging at least 5 x per week
- ☐ Level 5 Work-heavy labor (construction, etc.)
Competitive sports-cycling, cross-country skiing
Recreational sports-jogging on uneven ground at least twice weekly
- ☐ Level 4 Work-moderately heavy labor (e.g. truck driving, etc.)
Recreational sports-cycling, cross-country skiing, jogging on even ground at least twice weekly
- ☐ Level 3 Work-light labor (nursing, etc.)
Competitive and recreational sports-swimming, walking in forest possible
- ☐ Level 2 Walking on uneven ground possible, but impossible to back pack or hike
- ☐ Level 1 Work-sedentary (secretarial, etc.)
- ☐ Level 0 Sick leave or disability pension because of knee problems

Figure 1: Tegner activity scale

Investigators also gave an information document describing the entire study and also explained the concept of the Rating of Perceived Exertion (RPE) to the participants so that they could choose the right score after their effort depending on their feelings. It is known that RPE scales are useful in management of exercises or physical activities. They have lots of benefits such as relationships with physiological and performance parameters in a training session. They are also interesting in the regulation of exercise intensity and load when people want to reach or avoid a certain level of activity. These benefits are applicable to different populations and exercise modalities (14).

Rating of Perceived Exertion is used to quantify the subjective perception of an activity performed by an individual. Multiple tools exist to evaluate RPE such as the Borg scale (Figure 2) or the category-ratio scale named CR-10 (Figure 3). These two scales have shown validity and reliability in healthy, clinical and athletic adult populations (15).

As oxygen consumption and heart rate increase linearly with workload, RPE scales such as Borg scale should evolve similarly. Many studies have shown correlations between RPE scales and heart rates (0.8-0.9). The Borg scale range from 6 to 20 and can be directly compared to the heart rates ranging from 60 to 200. The category-ratio scale (CR-10) is a category scale combined with ratio properties. This scale is ranged from 0 to 10 and each number is associated with verbal expressions to make it easier to understand and use. CR-10 scale has a great relationship with the Borg scale and has been used for this experimentation (16).

Rating	Descriptor
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very Hard
18	
19	Extremely hard

Figure 2: Borg scale

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	.
7	Very Hard
8	.
9	.
10	Maximal

Figure 3: CR-10 scale

The MT (Figure 4) has been calibrated in order to standardize the data collected on this condition. Firstly, the length of the MT has been measured to calculate the real speed of it (333cm). Investigators counted the number of laps for three different speeds for one minute (5, 6 and 7 km/h). The number of laps multiplied by the length gave a speed in cm/min. After that, this speed was converted to km/h and a comparison with the referral speed was done. The difference between the two speeds has resulted in a coefficient. The average coefficient of the three referral speeds is 1,053. All the speeds calculated on the MT during the experiment were multiplied by this coefficient.



Figure 4: Technogym Treadmill Excite Run 600 LED

When these steps have been completed, the experiment could begin. At first, Runscribe pods (Figure 5) were fixed on participant's laces, one on the right foot and one on the left foot. Participants were asked to warm-up on 3 laps of a 250m athletic track with only one instruction: being able to talk while running. Investigators calibrated the Runscribe pods during this warm-up.

Runscribe pods are wearable sensors produced mainly for runners. This device contains two small pods (a right and left one) that are worn on runner's shoes and directly connected to the investigator's smartphone. These pods analyse kinetic, kinematic and spatiotemporal data of each step and don't hinder the runner. More specifically, Runscribe pods measure the Pace, Efficiency (Step rate, stride length, contact time, flight ratio, power), Shock (Impact Gs, Braking Gs), Motion (Footstrike type, pronation excursion, max pronation velocity), symmetry and many other metrics during running (17). This device has been used for each participant's run and all data were collected with it.



Figure 5: Runscribe

Due to many biomechanical parameters, some of them have been selected according to their relevance and their impact on musculoskeletal injuries. The current literature does not provide a precise definition of the spatiotemporal factors involved in the occurrence of running-related injuries. However, certain factors seem to be more relevant and have better associations with running injuries. The selected parameters are the following: Contact ratio, step rate, step length, total steps, GRF (Ground reaction force) and shocks.

The contact ratio corresponds to the stance-to-flight-time ratio and can be compared to the duty factor. It is calculated by dividing the stance time to twice the step time of the corresponding step. It is also defined as the contact time divided by the stride time (18). The duty factor is an important variable in running. A lower duty factor is more associated with performance or economy while a higher duty factor should decrease injury risk with a lower impact and muscular loading (19).

The step length refers to the distance measured along the direction of progression from the point of initial contact of one foot to the point of initial contact of the opposite foot during walking or running. In simpler terms, it represents the distance covered by a single step. Malisoux et al. (2022) observed a higher rate of injury for a greater step length. However, step rate is more debated, with some studies suggesting that a higher step frequency was source of reduction of risk injuries and others stating that there was no relationship between step rate and injury (18,20). Since steps should have an impact in the risk of injury, we also added the number of steps and shocks as parameter to be considered in our results.

The GRF or Ground Reaction Force, is an approximate measure of the loading of the lower-extremity musculoskeletal system (21). The vertical GRF consists of a first peak as heel landing and a second peak during pushing-off (22,23) and the ant-post GRF includes braking peak and propulsion peak (22,24). Many researchers agree that runners with a high LR (One of the vertical GRF parameters) are at greater risk of injury and that reducing the LR could be an effective method of reducing the development of injuries (25-28).

After the warm-up, participants picked up a paper corresponding to one of the six runs and had to do it. This system was used for a randomization of the races. Participants were free to adapt their speed at any time during the run and

were blind to the speed, time and heart rate (no electronic equipment allowed). The aim was to run as much as possible based on their own sensations. However, they had access to the distance already travelled. Each race was separated by a rest period of at least 5 minutes to make sure that parameters return to normal.

At the end of each run, investigators reported the time made and the heart rate in an excel table. They also asked how the participant had really felt his race with the score of Rating of Perceived Exertion to see if it corresponded to the score of RPE initially asked. These three data were always collected just after the race. Biomechanical parameters were automatically saved in the application Runscribe. The Garmin chest belt (Figure 6) has been used to measure the heart rate. It was fixed on the participant's chest and related to investigator's smartphone. The heart rate has been calculated to compare it with the rating of perceived exertion. The goal was to evaluate if RPE and HR evolve similarly together and if they were reproducible in the same condition.



Figure 6: Garmin chest belt

For the overground condition, participants had to run on an indoor athletic track of 250m. 4 laps were required to reach 1000m. For the MT condition, investigators started the race only when participants had found their speed corresponding to the RPE asked. In the two conditions, no encouragement was given.

In resume, 6 races of 1km were covered: 3 on an athletic track and 3 on MT. 4 of them were at 3 of RPE and 2 of them at 8 of RPE. Two races were repeated twice (3 of RPE on overground and 3 of RPE on MT) to evaluate the reproducibility of a speed based on perception. The second aim was to compare the speed in each condition when the same effort is asked. This comparison was done at 3 and 8 of RPE. Finally biomechanical parameters were analysed and compared in the two conditions with 3 of RPE (first and second run combined). Among all the Runscribe data, these have been selected: Contact ratio, step rate, step length, total steps, GRF and shocks. Each run was distributed randomly and separated by minimum 5 minutes of rest.

II.5 Data analysis

The data during the experimentation were collected on a computer and recorded on a standardized excel. All these information were secured by a password. Data analysis was performed using MedCalc® Statistical Software version 20.218 (MedCalc Software Ltd, Ostend, Belgium; <https://www.medcalc.org>; 2023). Descriptive data were presented in mean, standard deviation, minimal and maximal value. RPE level was verified used paired t test to ensure that participant ran at the level of perceived exhaustion required by the protocol. For reliability and reproductibility assessment, Intraclass correlation coefficients (2,1) was performed between trials for each RPE and conditions. Standard error of measurement (SEM) as well as worthwhile detectable change (WDC) were calculated. The SEM was calculated as followed: $SEM = SD * \sqrt{1 - ICC}$ with the SD representing the pooled standard deviation and the ICC of the corresponding analysis. The WDC was calculated as followed: $WDC = 1.96 * \sqrt{2 * SEM}$.

For the second objective, a paired t test was performed to compared treadmill and overground conditions for both 3 and 8 level of RPE for speed, RPE and heart rate. Lastly, biomechanical factors was compared for 3/10 of RPE between overground and treadmill conditions using paired t test. Level of significance was set at $\alpha = 0.05$.

III. Results

Data from 55 volunteers (males n=36 and females n=19) aged from 18 to 34 years old were retained for analysis in this study (Table 1).

Table 1. Descriptive data

	Mean	SD	Min	Max
Age (years)	22,33	2,98	18	34
Height (cm)	175,75	7,38	158	188
Weight (kg)	67,90	8,26	50	83
Tegner Activity Scale	5,70	1,57	2	9

SD = Standard Deviation

Participants were able to achieve the level of RPE imposed by the protocol on the track but ran at a lower reported RPE for the second trial on the treadmill (Table 2). Similarly, reported RPE were lower for treadmill conditions than overground at 8/10 of RPE (difference of 0.5 point of RPE, 95%CI [-0.76 to -0.25], pvalue <0.001, Cohen d= 0.79).

Table 2. Level of RPE between trial and conditions

	First trial (mean)	SD	Second trial (mean)	SD	pvalue
On track 3/10 of RPE	3,255	0,6997	3,145	0,4876	0,277
On Treadmill 3/10 of RPE	3,055	0,5906	2,855	0,4045	0,03
On track 8/10 of RPE	8,055	0,6212			
On Treadmill 8/10 of RPE	7,545	0,6616			

paired t-test pvalue.

III.1 First outcome: Reproducibility of running speed based on perception.

ICC reported excellent reliability for 3/10 RPE running speed for both on track and on the motorized treadmill conditions. Reproducibility measures were better for the on-track conditions (Table 3).

Table 3. Reproducibility of running speed at 3/10 on track and on motorized treadmill

	First trial (running speed in km h ⁻¹)	Second trial (running speed in km h ⁻¹)	ICC (2.1)	95%CI	SEM (in kmh-1)	WDC (in kmh-1)	Interpretation
On track at 3/10 RPE	11.05 (1.17)	11.09 (1.63)	0.968	0.945 to 0.981	0.3	0.7	Excellent
On motorized treadmill at 3/10 RPE	8.91 (2.32)	8.87 (2.13)	0.93	0.88 to 0.959	0.6	1.6	Excellent

RPE: Rate of perceived exhaustion, ICC: intraclass correlation coefficient, SEM: standard error of measurement, WDC: worthwhile detectable change

These results suggest that participants effectively used the Rating of Perceived Exertion (RPE) scale (CR10) to adjust their speed on both conditions (overground and MT) despite minor differences between them.

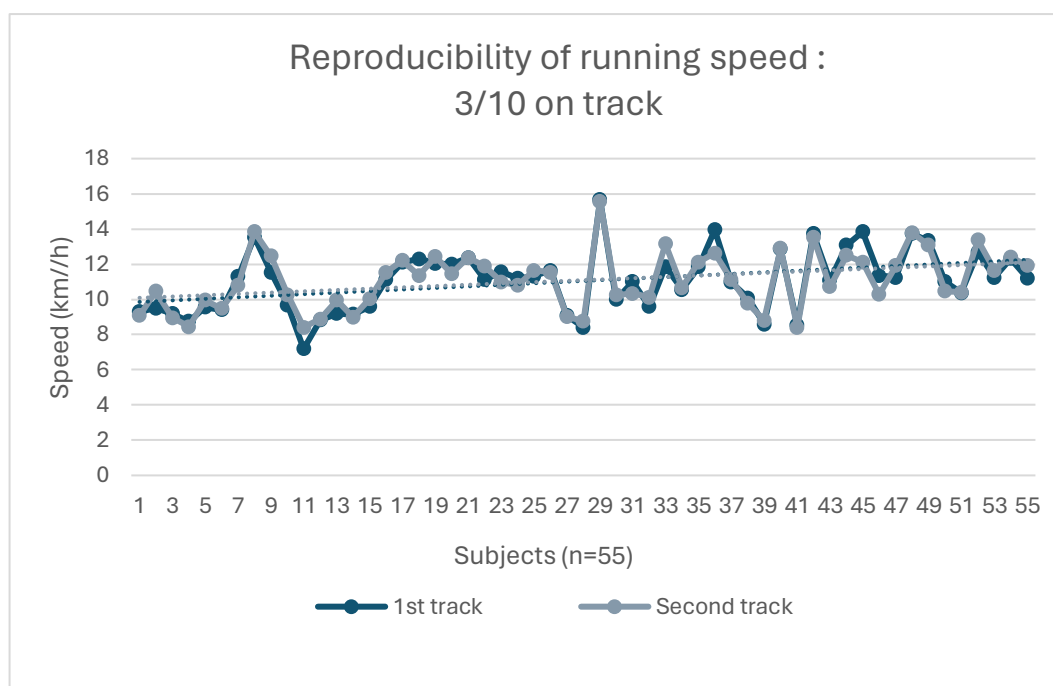


Figure 7 : Reproducibility of running speed based on perception (3/10 on track)

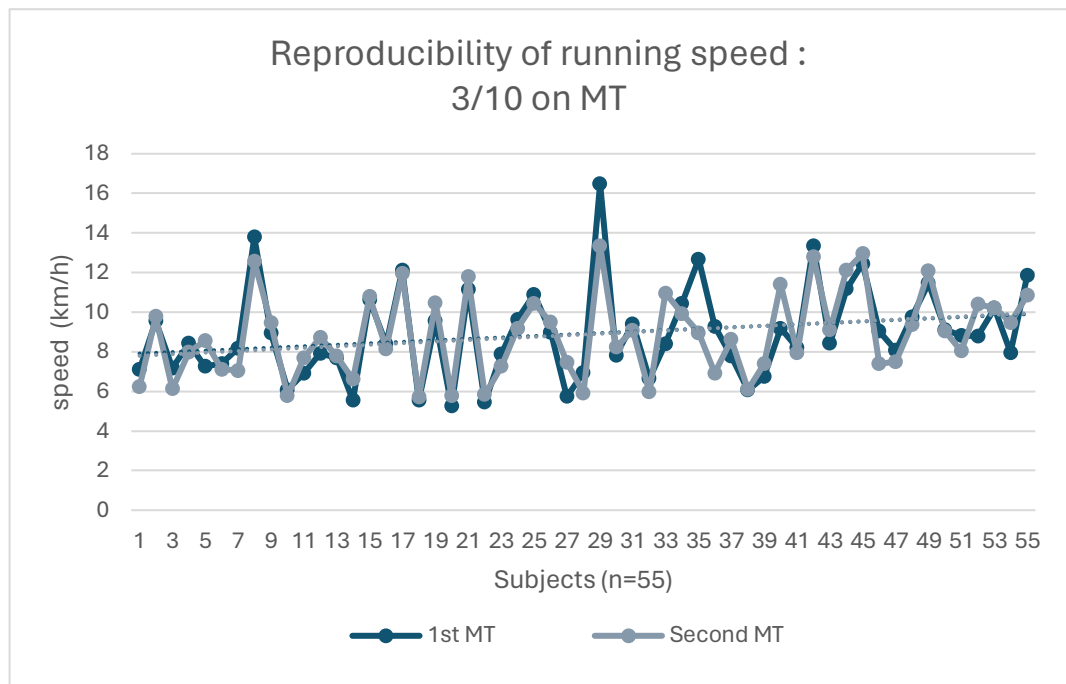


Figure 8 : Reproducibility of running speed based on perception (3/10 on MT)

III.2 Second outcome: Comparison of treadmill running and overground at different RPE level

Participants chose slower speeds with lower RPE and heart rate on MT than on overground for the first level of RPE (3 of 10). Similar results were obtained for the second level of RPE (8 of 10) with lower effect sizes compared to the first condition (Table 4).

Table 4. Paired t-test comparison for overground and motorized treadmill speed, RPE and Heart rate

RPE 3/10						
	Overground	Treadmill	difference	95%CI	pvalue	effect size (Cohen d)
Speed (kmh-1)	11,07 (1,67)	8,89 (2,21)	-2,18	[-2,5 to -1,8]	<0,001	1,11
RPE (/10)	3,2 (0,05)	2,95 (0,04)	-0,25	[-0,38 to -0,01]	<0,001	5,52
Heartrate (bpm)	158,41 (17,47)	147,61 (17,13)	-10,8	[-13,1 to -8,5]	<0,001	0,62
RPE 8/10						
Speed (kmh-1)	15,76 (2,19)	14,17 (2,92)	-1,58	[-2,08 to -1,08]	<0,001	0,61
RPE (/10)	8,05 (0,62)	7,54 (0,66)	-0,51	[-0,76 to -0,25]	<0,001	0,80
Heartrate (bpm)	182,2 (9,61)	176,72 (10,91)	-5,47	[-8,01 to -2,93]	<0,001	0,53

III.3 Third outcome : Biomechanical analysis : Treadmill vs overground

After collecting data from the runscribe pods during the experiment, 5 parameters were selected for analysis: Contact ratio or duty factor, the GRF (ground reaction force), the step rate, the step length, the total numbers of steps and the number of ground shocks. This analysis was only carried out for the first level of RPE (3/10).

III.3.1 Contact ratio

For the contact ratio, there is a strong significant mean difference between the MT and overground with 79,32 % for overground and 87.38% for the MT ($p < 0,0001$; Cohen $D = 0,811035$). It means that runners have a higher contact time on MT (figure 7).

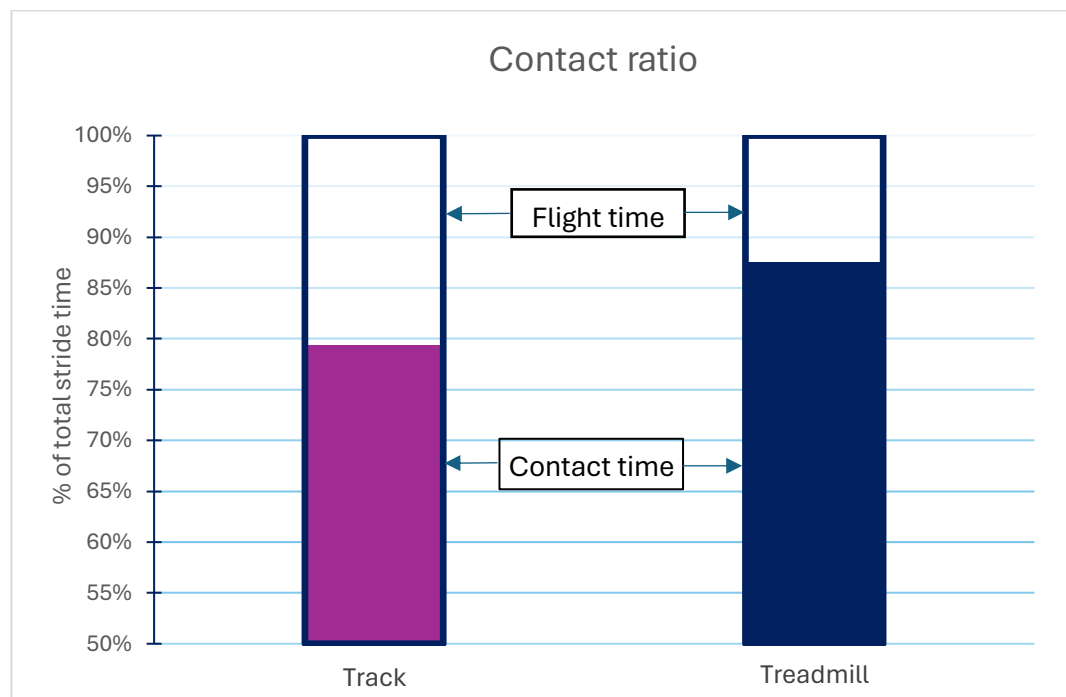


Figure 9: Contact ratio

III.3.2 GRF (Ground reaction force)

The horizontal and the vertical GRF show a strong significant mean difference between the MT and overground. There is a horizontal GRF mean of 4,93 N (Newton) on the MT and 6,36 N on overground ($p < 0.0001$; Cohen $d = 0,93341$), and a vertical GRF mean of 30,22 N on the MT and a 33,86 N on

overground ($p < 0.0001$; Cohen $d = 0,853109$). These results mean that the foot experiences less force when it strikes the ground during the stride on the MT than on the athletic track.

III.3.3 Step rate

There is a significant mean difference considered moderate between the MT and the track for step rate. The step rate mean for the MT have a value of 157,97 SPM (steps per minute) and 162 SPM for the track ($p = 0.000321$; Cohen $d = 0,498877$). That means runners make less steps per minute on the MT than on the track for the same RPE.

III.3.4 Step length

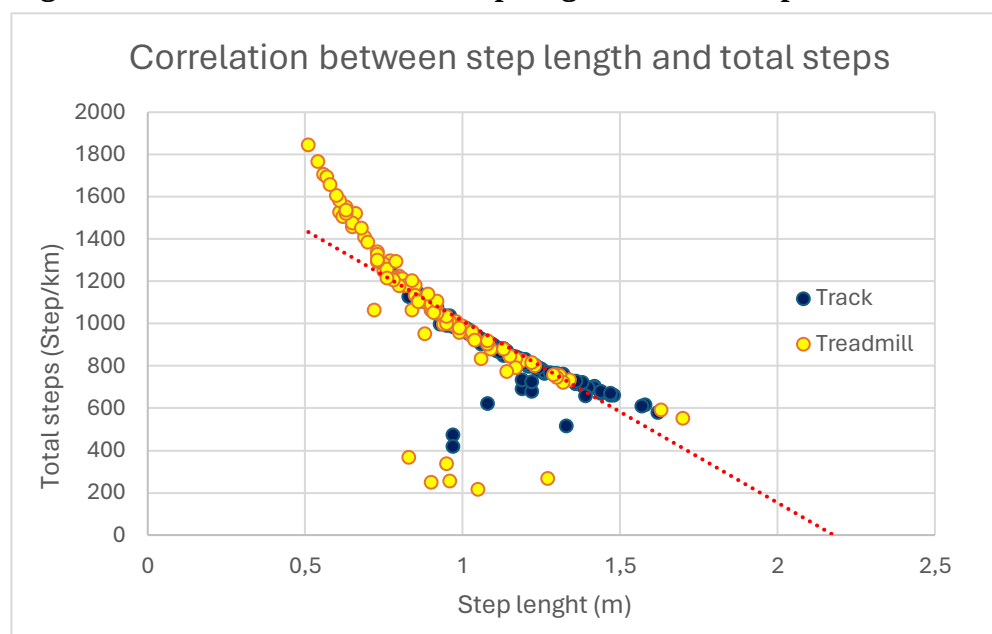
The comparison between the MT and the track for the step length shows a strong significant mean difference with 0,93 m (meter) for the MT and 1,15 m for the track ($p < 0.0001$; Cohen $d = 0,889723$). It means that runners have a shorter step length on the MT than on the track.

III.3.5 Total steps

There is a strong significant difference between the MT and overground for the total steps mean with 1074,9 steps per km on the MT and 850,95 steps per km on overground. ($p < 0.0001$; Cohen $d = 0,843451$). It means that runners make more steps over 1km on a MT than on the athletic track.

There is a strong negative correlation between the step length and total steps for each condition. The graph presented in figure 8 shows that the step length and the number of steps per km evolve significantly in inverse proportion to each other both on MT ($p < 0,001$; r Pearson = -0,754) and on track ($p < 0,001$; r Pearson = -0,821). The difference between MT and track is clearly observable : MT runners (yellow points) make more steps that are shorter than track runners (blue points).

Figure 10 : Correlation between step length and total steps



III.3.6 Ground shocks

There is a strong significant difference between the MT and overground for the shock mean with 10,45 Gs (=Shocks per footstrike) on the MT and 13,21 Gs on overground. ($p < 0.0001$; Cohen $d = 1,087674$). This means that the number of shocks for each step is higher on the athletic track than on the MT.

However, no significant difference has been observed for the total shock between the MT (11000G) and the track (11181G) ($p = 0,7557$; Cohen $d = 0,05695$).

Table 5. Summary of results Biomechanical analysis: Treadmill vs overground

Biomechanical parameter	Track	Treadmill	Cohen D	P-value	Test statistic
Contact Ratio mean (=Duty factor) (%)	79,31776	87,37963	0,811035	1,19E-08**	-5,9497
Horizontal GRF Rate mean (N)	6,35619	4,934615	0,93341	2,13E-10**	6,740585
Vertical GRF Rate mean (N)	33,85514	30,22222	0,853109	$P < 0,0001$ **	
Step Rate mean (Steps/min)	162,0093	157,9722	0,498877	0,000321**	3,658628
Step Length mean (M)	1,149159	0,9275	0,889723	6,62E-10**	6,529683
Total Steps mean (Steps/km)	850,9533	1074,907	0,843451	$P < 0,0001$ **	
Shock mean (Gs)	13,21215	10,49907	1,087674	9,26E-14**	7,974331

T-test value were set at $\alpha = 0,05$ significance test. * represents a significant difference between both conditions.

IV. Discussion

The primary objective of our study tried to evaluate the reproducibility of speed based on perception (3 of RPE) for two different conditions: MT and overground. The second objective was to compare the reliability of speed based on perception between the same conditions at low and high RPE. To achieve our goal, we applied various physiological and perceptual parameters to participant's runs. As it has been observed in the previous study realized in 2023 (29), runners are slower on a MT and their heart rate and sensation on CR10 are lower than on an athletic track for the same instruction (running at 3 or 8 of RPE). The last objective was to identify and analyse the various biomechanical parameters that could differentiate between running on a MT and overground to establish whether it can be useful in the rehabilitation of runners. To achieve this, we incorporated Runscribe pods on the participant's shoes into the training sessions to obtain the data needed for the analysis.

The first goal of this study was to evaluate the reproducibility of speed based on perception. We tried to determine if RPE scales can be used to manage exercise intensity. Results showed excellent correlations for the two conditions ($ICC > 0,8$). Other studies have shown similar results. Doherty et al. showed in 2003, that the RPE displays a reliable and positive linear response during the first 2 minutes of constant-load, short-term, high-intensity MT running ($ICC = 0,78-0,87$) (30). They proposed that the RPE could be used to determine subjective and perceptual effort during short-term exercise. Regarding the track, Garcin et al. carried out in 2001, a study aimed at evaluating the scales of perceived effort during progressive and maximal effort on an indoor track. They concluded that HR values, RPE and ETL (Estimated Time Limit) scales are reliable during progressive and constant load exercise until exhaustion ($r = 0,96-0,99$; $r = 0,95-1$; $r = 0,94-1$). Their data, varying from 10 to 20 km/h, also showed that the RPE scale is reliable at low speeds (31). These results led us to say that RPE scales appear to be reliable tools for prescribing and controlling exercise intensity which is relevant clinically to guide patients through reliable paces for running analysis or running rehabilitation. In their study, Billat et al. showed in 2022 that the RPE scale could be used to find one's optimal pace during a marathon and that athletes learning to pace themselves according to sensation or feeling, which is the RPE, combined with running, could be a more advantageous and realistic experience (32).

Physiological, perceptual and performance parameters should be considered for our second outcome: Reliability of speed based on perception. In our study, these three parameters correspond respectively to the heart rate, the effort perceived after each run (RPE) and the speed. As it has been observed previously, runners feel less tired and choose lower speed on MT than on overground when it is asked to run at low intensity (3 of RPE). Their heart rate is also lower at the end of each run. These results are the same at high intensity (8 of RPE).

The difference of speed between MT and overground for the same RPE has already been observed by Ceci et al. in 1991 (33). In their study, they found significant speed differences between MT and overground for three levels of RPE (11, 13 and 15 out of 20). Miller et al. published a systematic review and meta-analysis in 2019 comparing physiological, perceptual and performance measures between MT and overground running. They reported that running on a MT is perceived as requiring more effort especially for faster speeds because of a lack of comfort. The anxiety of falling or an increased body temperature due to a lack of air movement might cause increases in heart rate and perceived effort. MT running has no extra attentional requirements in opposition with overground running and this may affect running economy or running technique (34). These factors may explain our results concerning speed. Runners may perceive their effort harder on a MT so they tend to reach lower speed when they have to run at a given level of perceived exertion.

Our study shows a moderate difference in heart rate between MT and overground for high level of perceived exertion (8/10). Even if this difference is considered statistically significative, it represents an absolute difference of 5,5 bpm which doesn't mean much in clinical terms. Miller et al. suggested that HR and RPE differences between the two conditions are nearly insignificant at very high speeds because runners reach their bodily limits (34). This explanation may justify the similar heart rates at 8 of RPE. In opposition, lower heart rates are observable on MT for 3 of RPE. Miller et al. obtained same results for slower speeds but there was low-to-moderate evidence, and the difference was non-significative. In our study, the difference may be explained by the reduced speed on MT.

The effort effectively perceived by runners is lower on MT than on overground for the two levels of RPE. Same results were observed for slower speeds by Miller et al. (very low-to-moderate evidence). However, RPE was similar between MT and overground at near-maximal speeds (low evidence). It is important to notice that these results were mainly based on speeds whereas our results were only based on perception. Miller et al. analysed studies using a MT grade with some methods very different from ours. Moreover, their results were not always significant with moderate to high heterogeneity and low to moderate quality of evidence (34). In our study, lower RPE's are more explained by the fact that runners choose slower speeds on MT for a given level of perceived exertion.

Our third outcome was to identify biomechanical differences between MT and overground condition. At a level of 3 of RPE, runners have a slightly different running technique on MT than athletic tracks. At low intensity, runners have a shorter step length and a higher total number of steps on MT than on the track. However, the step rate seems to be approximately equal for the two conditions. This may be explained by the fact that participants are running at a slower speed on MT. They need more time to reach 1km so this could explain the higher total number of steps.

The number of steps per run has an impact on the amount of shock on the runner. Although we know that there is less shock per footstrike on MT, we also

know that runners make more steps per km. The total amount of shock received by runners seems finally to be the same in the two conditions. In our study, shocks are similar for one km on overground or on MT. However, for the same number of steps, MT should be less stressful.

Regarding the GRF parameters, these have shown a significant difference with lower horizontal and vertical GRF rates for the MT. Although these differences are statistically proven, it is difficult to know if they have a real clinical impact. The absolute differences are effectively small: 1,42N for the horizontal GRF rate and 3,63N for the vertical GRF rate. However, these differences must be considered even if they are low. These results suggest that running on a MT should be less stressful.

The contact ratio is higher for the MT than for the track. Running on a MT tend to increase the contact time and decrease the flight time. The contact ratio and duty factor are very similar. According to Nijs et al., a higher duty factor reduces the risk of injury due to a decreased impact and muscular loading. However, a lower duty factor is more interesting for performance or running economy (19). This study combined with our results suggests that running on a MT could be a good way to prevent injuries and to start a rehabilitation with runners. It seems to be interesting to start running again on a MT after an injury because of less loading due to a higher duty factor. The MT should be interesting to load progressively the injured runner.

According to our results, there are many biomechanical differences between the MT and the trackfield. Some parameters seemed to be more influenced by the MT than others. However, it is difficult to find clear explanations to these differences. Van Hooren et al. published a systematic review and a meta-analysis of a biomechanical comparison between MT and overground running in 2020. In their study, they found no differences for spatiotemporal outcome measures (stride time, length and frequency) which goes against our results. There was only a small difference of 5-ms for the ground contact time but it was considered smaller than the minimum detectable change. However, these results had a very low to low grade quality evidence and there was inconsistency across the studies which found sometimes differences between the two conditions (12). One reason of this inconsistency may be explained by a lack of familiarity with MT running which results to a higher stride frequency and a shorter stride length and contact time (35).

Other studies reported the influence of perception on a MT. It has been shown that runners feel faster on a MT and this higher perceived speed may increase stride frequencies and decrease stride lengths (12). Surface stiffness can also influence biomechanical parameters because of the differences between MT and overground. Intra-belt speed variations are mainly caused by inadequate motor power, low belt speed update frequency or slip of the belt and are influenced by weight and running speeds. These variations represent another contributing factor for biomechanical differences between MT and overground (36). Van Hooren et al. also talked about an absence of air resistance, a lack of comfort and a lack of sweat evaporation that take part in biomechanical

differences. Other factors can affect biomechanics such as visual focus, belt dimensions and mechanical treadmill model (12).

In summary, lots of factors may contribute to biomechanical differences between MT and overground condition. These factors are the following :

1. Lack of familiarity with MT
2. Perception of speed on a MT
3. Surface stiffness differences between MT and overground
4. Intra-belt speed variations
5. Absence of air resistance, lack of comfort and lack of sweat evaporation
6. Visual focus, belt dimensions and mechanical treadmill model

In summary, MT running may have lots of clinical benefits. Our study has shown that MT running is characterized by a higher contact ratio and a lower step length (At 3 of RPE) which decrease the risk of injury. A higher duty factor (similar to contact ratio) decreases impact and muscular loading (19) while a higher step length, a longer flight time and a shorter contact time are associated with a greater injury risk (18). Bonnaerens et al. showed that grounded running (GR) compared to slow aerial running (SAR) decreased impact loading by up to 35% and muscular loading to 34% which reflects on a higher duty factor (37). MT running seems to be less stressful with a lower shock mean and lower horizontal and vertical GRF rates and this should again be explained by a higher duty factor. MT running compared to overground running is perceived less tiring with lower heart rates at a same level of RPE. Van Hooren et al. reported that biomechanical differences in MT running should be useful for training and rehabilitation. For example, less stiff surface reduces vertical loading rates compared to stiff surfaces such as concrete (12). Based on literature and our results, MT may be useful to start rehabilitation or training for runners at low intensity. MT running seems to be a good way for preventing injuries thanks to a higher duty factor and lower step length. Moreover, using a MT in rehabilitation gives the opportunity to monitor the patient in a controlled environment (12).

However, even if the MT has quite a few advantages, certain points must be considered. As previously stated, a higher duty factor reduces the risk of injury due to reduced impact and muscle loading. However, a lower duty factor is more attractive for performance or running economy. MT may be less relevant for uninjured elite runners with performance perspective (19). According to our results, participants tend effectively to run slower on MT. One of the factors that could have an influence on the biomechanical differences between MT and overground running is the lack of familiarity with MT. Being less accustomed to running on a MT can be a hindrance to well-managed rehabilitation. Studies have shown that it takes around 6 to 8 minutes to get used to running on a MT (35,38). A physiotherapy session in Belgium lasts an average of 30 minutes and it is therefore difficult to sacrifice a third of a session so that a patient can run in good condition. Nevertheless, arrangements can be made with the patient (coming earlier before the session, having a MT at home, etc.). Regarding the practical side, a MT is an expensive device, ranging from 500€ to more than 2000€ in

terms of purchase. The space taken up by the MT can also be a problem, as it's usually quite large and requires a space that's not possible for everyone.

IV.1 Limitations

There are several limitations to this review that should be considered when interpreting these findings. Firstly, the experiment was carried out indoors on a 250m track which is different from running outdoors on concrete because of the perception via the wind. The circular shape of the track can also influence the results because runners always must run to the left, which is not the case in reality.

Secondly, the heterogeneity of the group of participants could be a problem when it comes to running. Indeed, as mentioned above, the biomechanics of running differ according to the participant's level of running. Zhang et al. studied how the effect of training experience could impact running biomechanics (39). The results suggested that elite runners apply greater force to the ground than recreational runners. This higher ground reaction force results in a longer airtime during the race which could be beneficial for the economics of running. In the same way, if experience plays a role in running technique, the type of sport does the same. A runner, whether a recreational or elite runner, will have more experience and therefore a different running technique to a practitioner of another sport. The phenomena of familiarisation and habituation must also be considered. In her study, Lavcanska found that young adults in good health, unexperienced on a MT, needed 6 minutes to become familiar with MT running during a training session (38). The results of Schieb's study suggested a similar result: an experienced field runner, but novice on the MT, can adapt to the MT machine after 8 minutes of MT running. However, the process of full habituation may require a minimum of three 5-minute training sessions or a combination of training sessions lasting a total of around 45 min (35). In our study, no categorization of runners has been made and our sample may therefore result on many differences between participants (sports practised, type of runner, etc).

Thirdly, the MT also has a few limitations, the room in which the MT is located is warmer than outside, which can accentuate the effect of heat and sweat. During the experiment, participants had to control the intensity by using a button, and there was a delay between the moment they increased the speed and the moment the MT really accelerated. In addition, the MT makes noise, and it increases with speed which can influence participants' perception of their choice of speed. Moreover, the MT used during the measurements has a speed limit of 20 km/h which can be problematic in certain cases when the runner reaches his limit. This was the case only once during our experiment.

Finally, the data collected were carried out by 2 different examiners adding an extra variable to the measurement which can be a source of error. Furthermore, the biomechanical analyses only covered runs at low RPE (3/10). It means that runs at high RPE (8/10) were not taken into consideration. In addition, other parameters could have been considered during our study. We have selected 6 parameters that we consider to be the most relevant according to the literature, but it is clear that other parameters have also influence on the results.

IV.2 Clinical perspective

The MT is a crucial tool, whether for rehabilitating injured patients, conducting research experiments, training athletes or programming exercises for coaches. Knowledge of the parameters that can differ from those of a conventional ground is therefore essential for understanding the MT. Our results identified some parameters, such as the contact ratio, which is higher on the MT than on the track and may reduce the risk of injury due to the reduction of impact and muscle load. Other parameters, such as GRF and number of steps, suggest that running on a MT should be less stressful. All this, combined with the physiological, perception and performance results, shows that the MT has a place in the rehabilitation of pathologies.

This leads us to future issues. It would be interesting to identify the pathologies that are most responsive to MT rehabilitation. Van Hooren et al. suggested that MT running is best suited to the rehabilitation of lower-limb stress fractures, but not to Achilles tendinopathy, Achilles ruptures or calf muscle strains because of the higher muscle forces in the gastrocnemius and soleus during MT running (12). Once the most responsive pathologies have been identified, it would be interesting to test rehabilitation programmes based on the results of this study in future experiments.

It would also be interesting to continue the experiment under other conditions, for example by including a warm-up of at least 8 minutes to ensure sufficient familiarity with the MT (35), taking measurements outdoors to reduce the heat effect and increase the wind perception, carrying out biomechanical analyses at higher speeds, taking a different reference than the RPE during running, evaluating the influence of shoes on running biomechanics or selecting different populations of runners ranging from recreational to experienced runners or from sprinters to marathon runners.

V. Conclusion

Results over the reliability of RPE scale, showed excellent correlations for the two conditions ($ICC > 0,8$). This led us to say that RPE scales appear to be reliable and reproducible tools for prescribing and controlling exercise intensity.

The effort effectively perceived by runners is lower on MT than on overground for the two levels of RPE. Same results have been shown for heart rates. Lower RPE's are more explained by the fact that runners choose slower speeds on MT for a given level of perceived exertion.

The current study provided knowledge on biomechanical differences between overground and MT running. MT running is characterized by a higher duty factor and a lower step length (At 3 of RPE) which decrease the risk of injury. A higher duty factor decreases impact and muscular loading while a higher step length, a longer flight time and a shorter contact time are associated with a greater injury risk.

Based on this study, MT may be a good tool for rehabilitation after injury for runners, both for biomechanical aspects and perceptual levels. MT running is an effective way of transitioning back to outside running. It would also be interesting to continue the experiment under other conditions by carrying out biomechanical analyses at higher speeds, taking different references than the RPE during running, evaluating the influence of shoes on running biomechanics or selecting different populations of runners ranging from recreational to experienced runners or from sprinters to marathon runners.

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Background : The popularity of running has risen in popularity globally due to its accessibility and health benefits. However, the high incidence of running-related injuries (RRIs) is worrying. Key factors influencing RRIs include training volume, previous injury history, and gender. Treatment often involves consultation with physiotherapists, emphasizing their crucial role in recovery. Recent studies explore the biomechanical differences between running on motorized treadmills (MT) and on land, bringing light on potential differences in running biomechanics and perceived exertion. This research aims to analyse data from Runscribe pods to identify biomechanical differences between MT and athletic track running, building upon previous findings with an additional sample.

Objectives : 1. Is the RPE scale reliable and reproducible for controlling exercise intensity in the same condition? 2. Are runners capable of reproducing the same speed at the same intensity in 2 different conditions: on overground and on motorized treadmill? 3. Is running on a motorized treadmill biomechanically comparable to overground running?

Study design : An observational cross sectional study

Methods : 55 healthy people were recruited. They were asked to run 6 times 1 km, 4 times at an intensity of 3/10 (2 times on treadmill and track) and 2 times at an intensity of 8/10 (1 time on treadmill and track). During the experiment, biomechanical data (via Runscribe pods) and physiological data (HR with heart rate monitor) were taken. Participants were also asked how they felt on an RPE scale after running.

Results : There is a high correlation when using the RPE as a reproducible tool to manage exercise intensity. Participants choose slower speed with lower heart rate and RPE on MT than on overground for the two levels of RPE. Runners feel less tired on MT but run slower than on overground. There are many biomechanical differences between MT and overground at low intensity (3 of RPE). Runners tend to make more steps that are shorter and less stressful on a MT.

Conclusion : RPE scales appear to be reliable tools for prescribing and controlling exercise intensity. The effort effectively perceived by runners is lower on MT than on overground for the two levels of RPE and MT running is characterized by a higher duty factor and a lower step length (At 3 of RPE) which decrease the risk of injury.

Key words : Runner, overground, motorized treadmill, rating of perceived exertion, biomechanics