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REVIEW

Acute Effect of Uphill Running: Current Scenario and Future Hypotheses

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ABSTRACT

Strategies for metabolic adjustments are often considered by athletes throughout a running event. Planning for such events during training does not always include variations from level training, even though up/downhill exertion should definitely be a part of such planning. The differentiation of training stimuli, under adverse conditions of intensity and inclination, can generate differentiated benefits. However, uphill running raises expectations of deleterious effects. The imposition of different slope gradients throughout running could generate increased metabolic demands for sports performance. Thus, the present study aimed to answer questions mainly about the acute effects of uphill running, its relationship with aerobic performance, allowing us to introduce new hypotheses for future studies in the area on the subject. Gaps still need to be filled concerning the relevance of uphill running, and its determinants. Many of the points presently under scrutiny only lead to speculative explanations; for logical reasons, more studies should focus on the prescription of training at different slopes. This is the point at which specific conditioning is required, because the regulation of the effort and the energy cost resulting from the imposition of uphill running during competitive races depends heavily on previous experiences. This review will cover recently published research on the subject.

KEYWORDS: Uphill Running; Kinematic Analysis; Stretching-Shortening Cycle; VO_{2Max}.

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INTRODUCTION

Running performance is influenced by mechanical, physiological, anthropometric, neuromuscular, and environmental factors.[1,2] Therefore, in an already well established manner, gains in one or more of these categories promote greater aerobic competence and better sports performance.[3-7] It has also been reported that in race events, mainly in the middle to long distance range, experienced athletes consciously or unconsciously regulate their "pace" strategy in order to maintain a lower metabolic cost.[8,9] However, with the evolution of racing events, it is essential to re-examine models applicable to the competitive dimension of courses with variations of terrain, including variations positive or negative slopes. Athletes and coaches who once trained/prescribed more regular "pace" strategies have recently started to include in their programs variations in their own courses, or moved toward using specific training courses with varying inclinations, which would more adequately reflect real competitive scenarios. To achieve a much needed competence to minimize metabolic cost during running, differentiation of training stimuli has been introduced. Training in adverse conditions of positive/negative slopes, or on different surfaces (asphalt, grass, sand) can provide the needed conditions for adaptation and should have a special place in training prescription. Although empirical, these variables in turn can generate long-term differentiated metabolic and neuromuscular benefits.[10,11]

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Reports are beginning to delineate the acute effects of uphill running, pointing out singular differences relating to the variable inclinations required in training sessions.[12-16] Variable slope uphill running is capable of imposing different relationships between the application of concentric and eccentric forces during the running cycle.[13] In addition, there seems to be a significant association between concentric overload and the percentage increase of uphill running distances; consequently, more attention has been given to this modality. Sloniger et al[16] observed a 9% higher muscle activation at a 10% inclination running, compared to flat running. This increased muscle activation is in line (a) with the greater relative contribution of the concentric force observed during uphill activity, (b) with a significantly higher metabolic cost,[17,18] and (c) with a pattern of differentiated muscular recruitment.[16]

Positive chronotropic modifications and the heightened development of the slow component of oxygen consumption complete the list of significant physiological changes resulting from slope training.[17,19,20] It seems that the behavior of these variables shows greater amplitude during running long stretches at unusually intense slopes, when compared to running in the plane. Possibly such acute physiological changes can be attributed to excessive muscular overload coming from the major concentric component of muscle contraction.[13] The reduced use of the elastic power mechanisms and stretching-shortening reflexes could also partly explain this differentiated manifestation between concentric vs. eccentric moment, but some aspects still remain in the field of speculation.[20,21] Thus, the present study aimed mainly to answer questions about the acute effects of uphill running, its relation with aerobic performance, and the proposition of new possible hypotheses for future studies in the area.

METHOD

An search was performed ending September 2017. Articles with the key words "Uphill Running", "Aerobic Exercise", "Stretching-Shortening Cycle", "VO_{2Max}" were searched in the databases of PubMed and Web of Science. Within this context, articles that discussed the acute effects of uphill running, its relationship with aerobic performance, and new possible hypotheses for future studies on the subject were selected. Only articles in English and focused on the theme were included.

RESULTS AND DISCUSSION

Acute Physiological Changes and Their Perspectives

Pringle et al.[19] reported higher VO_{2Max} values in horizontal and uphill maximum progressive protocols (3.84 ± 0.57 L/min [0% slope] and 3.95 ± 0.60 L/min [10% slope], respectively). This had already been shown by Olesen et al.[14] and could be attributed to higher content of motor units being recruited during the uphill running. This assumption is based on the fact that in the horizontal plane the eccentric phase of the movement is enhanced, adequately activating stretch reflexes. This, coupled with an adequate elastic potential accumulation, leads to a lesser need for activation of motor units, resulting in a lower metabolic cost for force production.[22,23] In addition, during a maximal stress test the amplitude of the slow component at a 10% inclination VO_2 was 40% higher than the corresponding value for a flat exercise.[19]

During submaximal running exercise sessions, Padulo et al[15] reported a reduced R-R interval for a running test for 5 min at 2% inclination, compared to that observed in the horizontal plane (0.388 ± 0.02 vs. 0.327 ± 0.05 ms, for 0% and 2% inclination respectively). This represented an increase of 5% in heart rate, associated with a 10% increase in VO_2. In steeper uphill running conditions (7% incline at 70% of V_{VO2Max}), the reduction in the R-R interval was more pronounced for the same 5 min run (0.388 ± 0.02 ms on the flat vs 0.280 ± 0.05 ms, for a 7% slope). This translates to 15.1% increase of heart rate with a 19% increase of submaximal VO_2.[15] Similar results were observed by Klein et al,[24] in high performance athletes submitted to a 35 min run at a 5% slope: they exhibited increases of heart rate (11%), VO_2 (18%), respiratory exchange rate (8%), and minute ventilation (24%). Other evidence corroborates this outcome, highlighting the amplitude of the physiological effects slope-dependent, or percentage-dependent procedures.[16,25]

Uphill Running and the Determinants of Performance

Intense acute effects on aerobic performance are observed in the running on the inclined plane. As already mentioned, the concentric contribution is proportional to the degree of inclination;[13] It is also associated with a reduction in the potentiating effects of the stretch-shortening cycle. Consequently, the metabolic energy spent to achieve the same velocity is higher in the uphill than in the horizontal plane. Reduced yield observed during uphill running can be explained in part by mechanical and kinematic alterations,[26] which are revealed as changes of the physiological profile. In fact, the are many determinants of aerobic performance, and perhaps the neuromuscular contribution is of greater importance when running up a slope than other factors. However, this still needs to be properly investigated.[27]

Swanson and Caldwell[28] have suggested an important role of running economy reflecting negatively on the uphill running performance. It seems that changes above or below the optimum kinematic pattern exerts deleterious influences, increasing metabolic cost and perceived exertion in uphill running.[28] Snyder and Farley[29] reported a U-shaped pattern in the frequency ratio of past metabolic cost, suggesting mechanical inefficiency at low pass frequencies, and higher cost associated with the production of force at high pass frequencies, hence a worsening which is ultimately detrimental to economy.

The decline in running performance is also notable in maximum progressive tests (V_{VO2Max} = 18.7 ± 1.9 km/h and 14.0 ± 1.6 km/h, respectively for 0% and 10% slope); running economy certainly influences the outcomes in such tests.[16] However, other factors such as (a) more pronounced and early activation of the anaerobic energy system, (b) a greater oxygen deficit, (c) a larger amplitude in the slow component of VO_2, and possibly (d) a precocious occurrence of the lactate threshold, would limit the total exercise time and the obtained VO_{2max}. Paradoxically, the highest values of VO_{2Max} are observed at high percentages of uphill running.[14,19] Finally, considering the well-known predictive value of VO_{2max} on medium and long-term aerobic performance,[4] it remains to be determined whether the same predictive behavior is observed in the VO_{2max} obtained in high slope condition.

Acute Deleterious Mechanisms in Uphill Running

During the initial phase of running in the horizontal plane, it is believed that only part of the work required is performed by the contractile elements,[30] while the remainder comes from the elastic elements and intrafusal reflexes of the musculature.[3] The stretch-shortening cycle is directly tied to the concept of energy conservation during running; however, it is possible that that the contribution of elastic elements and of yet unestablished reflexes on the inclined plane might be suppressed,[13,28] overloading the skeletal muscle structure. Therefore, the absorption of elastic energy at the moment of entry of the calcaneus and support phase, and consequently the transfer of this energy for the enhancement of movement does not occur satisfactorily. Kinematic changes partly explain the deleterious effect on running performance on the inclined plane, where significant increases of contact time are observed and are generally proportional to slope intensity.[26] Table 1 shows the main modifications in uphill running. Thus, part of the produced energy is lost in the form of heat. The degree of contribution of the reflex mechanisms is not clear enough, but it is also estimated that the energy requirement to move the center of mass vertically during uphill running is greater than on the horizontal plane and proportional to the degree of inclination imposed upon the practitioner.

Hypothetical Advantages of Uphill Running

Some advantages can be explored as functions of uphill running. Initially, it must be noted that if a high mechanical impact generated on the human body with each developed stride becomes a negative factor, it makes joints and muscles more vulnerable to the incidence of injury. However, the behavior of the ground reaction force in uphill running is inversely proportional to the required degree of elevation.[13] Thus, the muscular and articular requirement for absorption of mechanical loads is reduced and possibly keeps the contractile components and reflexes intact for longer. In another perspective, Roberts & Belliveau[31] have suggested that due to a preponderant concentric muscular solicitation, and because of the increased work load associated with uphill running, the overload on the knee joint is reduced, and in turn more work would occur on the hip and their extensors.[31] Perhaps the slope artifice

Table 1. Kinematic, postural, and performance variations in uphill running, and in different planes.

				Outcomes										
				Performance	Postural Angular Variation (°)					Kinematic Variation				
Authors	n	Running	Gradient (°)	Maximal Speed ($km.h^{-1}$)	Trunk (T/O)	Hip (T/O)	knees (T/O)	Thighs (T/O)	Ankles and Ground (T/O)	Time Contact (ms)	Flight Time (ms)	Frequency of Stride (Hz)	Time to Stride (ms)	Lenght of Stride (m)
28	8	Sprint	+3	28* (-3%)	(73*/74,0*) (-9%/10%)	(129/196)	(144/158*) (-4%)	(31*/101,0) (74%)	(88*/37,0*) (-5%/-14%)	133	124	3.90	257'	2.00* (-5%)
			-3	31.6* (9%)	(82/82)	(136*/200) (4%)	(155*/155*) (6%/-6%)	(40*/99,0) (35%)	(100*/37*) (8%/16%)	131	127	3.88	258	2.26* (7%)
			0	29	(80/82)	(131/204.0)	(145/165)	(54/99)	(92/43)	138	127	3.79	265	2.11
33	9	Sprint	+3	22.6* (-20%)	NM	(47.1/95.8)	(143.4* /159.4) (4%)	NM	(96.2/103.9)	137.0* (15%)	132.0	3.90* (7%)	NM	1.82* (-16%)
			0	27.2	NM	(55.3/95.9)	(149.4/151.6)	NM	(102/ 104.5)	117.0	128.0	3.61	NM	2.12
13	10	Submax Running	+3/+6°/+9	NM	NM	NM	NM	NM	NM	23/23/23	NM	1.46/1.49/ 1.51* (5%)	NM	2.07/2.02/1.99* (-4%)
			-3/-6/-9	NM	NM	NM	NM	NM	NM	23/22/22	NM	1.43/1.42/1.42	NM	2.10/2.12/2.12
			0	NM	NM	NM	NM	NM	NM	23	NM	1.45	NM	2.07

(T/O) – ground touch phase / ground output phase; (º) – unit in degrees; (ms) – milliseconds; NM – not measured; * - significantly different from running in the horizontal plane.

can be visualized as a functional mode of knee joint post-injury re-conditioning.[31] As a final point, considering the contemporary demands of performing race tests, it is clear that there is a need for specific conditioning in different inclinations. In this way, it is possible to speculate about the existence of some mechanism of a transfer of adaptations resulting from uphill running to flat race performance.[10,11] Such effects could be beneficial to sports performance and deserve to be properly investigated.

FINAL CONSIDERATION

The acute effects of uphill running are already reasonably delineated in the literature. However, the deleterious physiological and mechanical mechanisms that directly influence the determination of putative influences upon aerobic performance are not well understood. Many of the present-day questions have only received explanations of a speculative nature. Logical reasoning suggests that more studies should focus upon the prescription of uphill training, before different percentages of inclination are embarked upon. In spite of these findings, the need for specific conditioning is obvious: the regulation of effort and energy cost in uphill running depends heavily on previous experiences.

CONFLICT OF INTEREST

The authors have not conflicts of interest.

AUTHOR PARTICIPATION

Sá-Filho AS and Machado S developed the project, discussed the data, reviewed the literature and approved the final version of the article.

EFEITO AGUDO DA CORRIDA ASCENDENTE: CENÁRIO ATUAL E FUTURAS HIPÓTESES

RESUMO

Estratégias para ajustes metabólicos são frequentemente consideradas por atletas ao longo de um evento de corrida. O planejamento de tais eventos durante o treinamento nem sempre inclui treinamento em planos inclinados, que deveriam compor esse planejamento. A diferenciação dos estímulos de treinamento, em condições adversas de intensidade e inclinação, pode gerar benefícios diferenciados. No entanto, a corrida ascendente aumenta as expectativas de efeitos deletérios. Portanto, a imposição de diferentes gradientes de inclinação ao longo da corrida poderia gerar demandas metabólicas aumentadas para desempenho esportivo. Assim, o presente estudo teve como objetivo responder questões principalmente sobre os efeitos agudos da corrida ascendente, sua relação com o desempenho aeróbio e a proposição de novas possíveis hipóteses para estudos futuros sobre o assunto. Muitas lacunas ainda precisam ser preenchidas sobre a relevância da corrida ascendente e seus determinantes. Muitas das questões apresentadas apenas levam a explicações especulativas; por razões lógicas, mais estudos devem se concentrar na prescrição de treinamento em face de diferentes porcentagens de inclinação. Este é o ponto em que o condicionamento específico é necessário, porque a regulação do esforço e do custo de energia resultante da imposição de corrida ascendente durante corridas competitivas depende fortemente das experiências anteriores.

PALAVRAS CHAVE: Corrida em Inclinação; Análise Cinemática; Ciclo Alongamento Encurtamento; $VO_{2Máx}$.

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