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Modifications of anticipatory postural adjustments in a rock climbing task: The effect of supporting wall inclination

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Abstract

The aim of this study was to analyse the influence of initial postural constraint on the realisation of a leg release in a rock climbing task. Two conditions were tested: a vertical posture and an overhanging posture. The overhanging posture was characterised by a large sustentation base, which enhanced the mechanical possibilities of the system. Subjects had to release their right foot in both postural conditions. In the vertical posture, movement's effectuation was associated with anticipatory postural adjustments (APAs). In the overhanging posture, the movement was performed without APAs. The results indicated that APAs were modulated according to the possibilities of force creation of the system. Hence, the disappearance of APAs in the overhanging posture was explained by the efficiency of the system to create the impulse necessary to perform the task.

Keywords: Anticipatory postural adjustments; Rock climbing; Posture; Movement; Biomechanics; Equilibrium

1. Introduction

Rock climbing can be viewed as a complex motor activity, where the subject's motricity is highly constrained by the natural environment [3]. Indeed, rock climbing requires a fine balance control to preserve equilibrium when walls are vertical or overhanging. Nevertheless, vertical and overhanging walls represent two specific situations, associated with specific postural constraints [8]. In the case of a vertical wall, the sustentation base is represented by the holds' contact surface and the climber's centre of gravity (CG) is located outside this narrow sustentation base (Fig. 1(A)). The climbers have to apply additional horizontal forces to the hand holds in order to counteract the body weight moment (which tends to provoke a backwards imbalance) [12]. In the case of overhanging walls, the sustentation base grows larger since the vertical projection to the ground of hand holds and foot holds are not mixed up as in a vertical wall (Fig. 1(B)). Noé et al. [8] thus showed that this larger sustentation base induced supplementary lever arms in comparison with a vertical wall, which enhances the mechanical possibilities of the system. Indeed, both the vertical and horizontal components of the reaction force balance the body weight moment (Fig. 1(B)) and climbers have to exert less force to maintain balance since the horizontal supporting forces value is less important with overhanging walls [8].

The less displacement of one limb supporting a part of the body weight generates necessarily a re-distribution of forces on the three remaining holds. Rougier and Blanchi [14] and Quaine et al. [11] showed that forces were transferred onto the contralateral side to the moving limb. While using the principles of Newtonian mechanics in static conditions (i.e., $\sum F = 0$,

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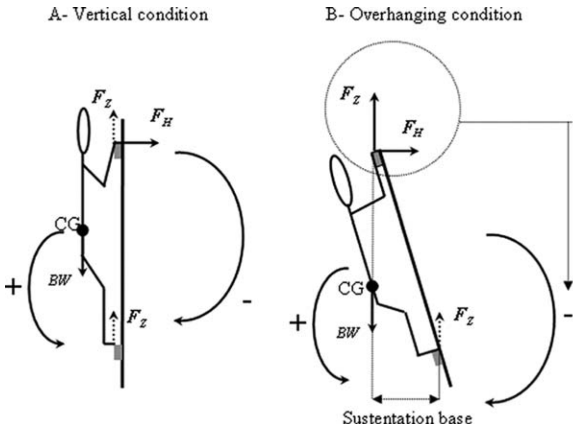

Fig. 1. Schematic representation of a rock-climber in A – a vertical posture and B – an overhanging posture. The climber is considered as a system being in rotation in reference to the foot supports. In the vertical posture, the vertical reaction forces (F_Z) balance the body weight (BW) applied to the centre of gravity (CG). The body weight creates a positive moment. In order to counteract this moment, horizontal forces (F_H) must be applied to the hand holds. These forces create a negative moment which balances the body weight moment. In the overhanging posture, the sustentation base induces supplementary lever arms: both the vertical (F_Z) and horizontal (F_H) components of the reaction force at the hand holds participate to create a negative moment which counterbalances the positive moment induced by the body weight.

$\sum M = 0$), Quaine and Martin [10] demonstrated that the contralateral force transfer represented the only mechanical principle to maintain mechanical equilibrium on vertical walls. Noé et al. [8] observed that this contralateral force transfer was less pronounced when the support was overhanging since force distribution remained more homogeneous on the three remaining supports. These authors demonstrated that the supplementary lever arms encountered with overhanging walls lead to an increase in the number of possible solutions available to maintain balance [8]. Focused on temporal aspects of force re-distributions for a climbing task on a vertical wall, Quaine et al. [13] and Testa et al. [18] thus showed that anticipatory postural adjustments (APAs) required a peculiar chronology of force variations. Nevertheless, no study has been performed in order to characterise the effects of supporting wall inclination on APAs in a rock climbing task. The present study has been conducted in order to specify the changes in APAs in relation to different initial postural conditions in rock climbing, when performing a limb release from a vertical and an overhanging posture. The displacement of a supporting limb requires to generate the initial impulse (the net effect of force acting over a period of time, i.e., a variation of momentum: $I = F \cdot \Delta t = \Delta P$) to increase the momentum of the CG (the product of body mass and CG velocity: $P = m \cdot v$) [9]. With supporting limb movements, APAs serve the purpose of generating this initial impulse [5,6]. Hence in the present work, APAs will be analysed while using a biomechanical model including the impulse–momentum relationship.

2. Methods

2.1. Subjects

Seven healthy male subjects (mean ± SD age 22.3 ± 0.4 years, body mass 67.6 ± 3.8 kg and height 174.8 ± 5.2 cm), without any neurological or motor disorders took part in the experiment as volunteers. They signed an informed consent in accordance to the University guideline. All subjects were competitors at an international level. The choice of expert subjects was due to the fact that is was impossible for recreational climbers to maintain balance on an overhanging wall.

2.2. Equipment

An artificial climbing frame was used for the experiment. This structure was equipped with climbing holds (Freestone$^{©}$, Argonnay, France). The holds were symmetrical and characterised by a 8 cm width and a 1 cm deep ridge, enabling a wedging type of support for the feet and a crimp grip position of the fingers [15]. The distance between holds was twice as wide as that of the shoulders and the distance between lower and upper supports equalled the height of the subjects. Each hold was firmly fixed (with a screw) to a 3D force transducer (Schlumberger, model CD 7501, Vélizy-Villacoubay, France), which measured the vertical (F_Z), lateral (F_Y) and antero/posterior (F_X) components of the hold reaction forces. The signals were amplified (PM instrumentation, ref 1965, Orgeval, France) and sampled at 100 Hz. Recording time was 10 s.

2.3. Experimental task

Two postural conditions were tested. In the first condition, the climbing structure was set vertically in the laboratory reference system (vertical condition). In the second condition, the climbing structure was adjusted so that the frame was inclined 10° to the vertical (overhanging condition), as previously tested by Bourdin et al. [2]. Both conditions were characterised by the same holds arrangement. The task consisted in maintaining a stable quadrupedal posture for 3 s and release of a specified hold upwards, without a jerk. The movement was performed in a self paced manner, without any constraint of velocity. In order to avoid a learning effect, the subjects were asked to perform five right foot and five left foot movements in a random sequence. Only data from trials involving the right foot releases were analysed. The release limb had thus to be kept 2 cm away from the hold, upwards. The subjects went from a steady quadrupedal posture to a steady tripedal posture which had to be maintained until the end of the trial.

2.4. Data processing

Force data were filtered with a low pass second order Butterworth filter (cut off frequency: 20 Hz). Filter characteristics were chosen after the application of a Fast Fourier transform to the raw signal, in sort of 95% of the raw signal content be conserved after the filtering processing [7]. Cut off frequencies presented are net cut off frequencies [19]. An automatic marking procedure was used in order to determine the onset of force variations on each hold. The mean baseline was calculated during 1 s following the beginning of the data recording, for each component of the reaction force, in order to characterise the initial stable state. The variation of force was considered significant when it exceeded two times the standard deviation computed over the duration of the initial stable state [16,17]. This time point was recorded as characterising the onset of the force variation. The moment at which the first variation began determined for the right foot t_0(i.e., the onset of voluntary movement). For the other limbs, when the force variations occurred before t_0, latencies were negative and termed APAs [1,18]. t_1 labelled the moment when the right foot lifted off from the hold.

The components of the linear impulse at the CG (I_X,-I_Y, I_Z) correspond to the time integral of the net force acting at the CG [13,18]

$$I_X(t) = \int \sum_1^4 F_X(t)\,\mathrm{d}t,$$

$$I_Y(t) = \int \sum_1^4 F_Y(t)\,\mathrm{d}t, \quad I_Z(t) = \int \Delta F_Z(t)\,\mathrm{d}t, \text{ with}$$

$\Delta F_Z = \sum_1^4 F_Z - W$, W being the body weight. In order to fit the model proposed by Quaine et al. [13] and Testa et al. [18], the lateral and antero/posterior components of the linear impulse at the CG were analysed into a single horizontal CG impulse: $I_H(t) = I_X(t) + I_Y(t)$, the magnitude of I_H being $I_H = \|I_H(t)\| = \sqrt{\|I_X(t)\|^2 + \|I_Y(t)\|^2}$. This horizontal impulse represents the postural component of the CG impulse whereas the vertical impulse corresponds to the focal part of the CG impulse [13,18]. The Newton–Cote (order 2) numerical method was used for integrations.

The impulse at the CG was analysed at time t_1 (right foot take off). The values of CG impulse were obtained by averaging five trials per subjects ($n = 7$). The differences between the values corresponding to the postural conditions were tested by paired t-tests. Average values for force latencies were tested with a t-test with the null hypothesis mean = 0. The level of significance chosen was $P < 0.05$.

3. Results

Whatever the postural condition (vertical or overhanging), as the climber was in the process of releasing the right foot, force variations were observed at each support (Fig. 2). Following the limb release, a contralateral distribution of the reaction forces on the holds was observed in the vertical posture, since the three components of the force applied to the left holds were increased whereas the force applied to the right hand decreased down to zero. In the overhanging condition, the distribution of the forces was more homogeneous on the three remaining supports, since the decrease of the right hand force was not as drastic as in the vertical condition. The latencies of the vertical and the horizontal force changes at the same hold did not present any statistical difference. Similar results were observed for each hold in both postural conditions. Thus, the vertical and horizontal force changes were initiated in synchrony.

In the vertical condition, APAs were recorded since variation of the force at the manual supports always occurred prior to the first force variation at the right foot (right hand: mean ± SD latency -108 ± 23 ms; left hand: mean ± SD latency -102 ± 31 ms). Force variations at the left foot were concomitant to the focal movement variations at the right foot. In the overhanging condition, there was no significant difference between the latencies at the different supports. The variations of the forces occurred simultaneously with the onset of the focal movement.

Fig. 3 illustrates the evolution of CG impulse in both postural conditions. At t_1 (right foot lift-off), the value of the vertical CG impulse was not significantly different between both conditions (vertical condition: mean ± SD value 3.8 ± 2.9 N.s; overhanging condition: mean ± SD latency value 3.8 ± 0.3 N.s). Nevertheless, the value of the horizontal CG impulse was significantly different between both conditions ($T = 17.4$, $P < 0.0000$), with an higher value in the vertical posture (mean ± SD value 9.5 ± 4.5 N.s *VS* mean ± SD value 3.8 ± 0.7 N.s). The main difference between the overhanging and the vertical posture concerned the impulse value at t_0. As shown in Fig. 3, the impulse value at time t_0 was null in the overhanging posture, but not in the vertical one. With a vertical wall, the vertical and horizontal components of the CG impulse, respectively, amounted to 1.2 ± 2.3 N.s and 3.1 ± 2.7 N.s (mean ± SD) at t_0.

4. Discussion

The current study was interested in a rock climbing task and showed that APAs were modulated when the inclination of the supporting wall was modified. The vertical posture can be considered as a specific case.

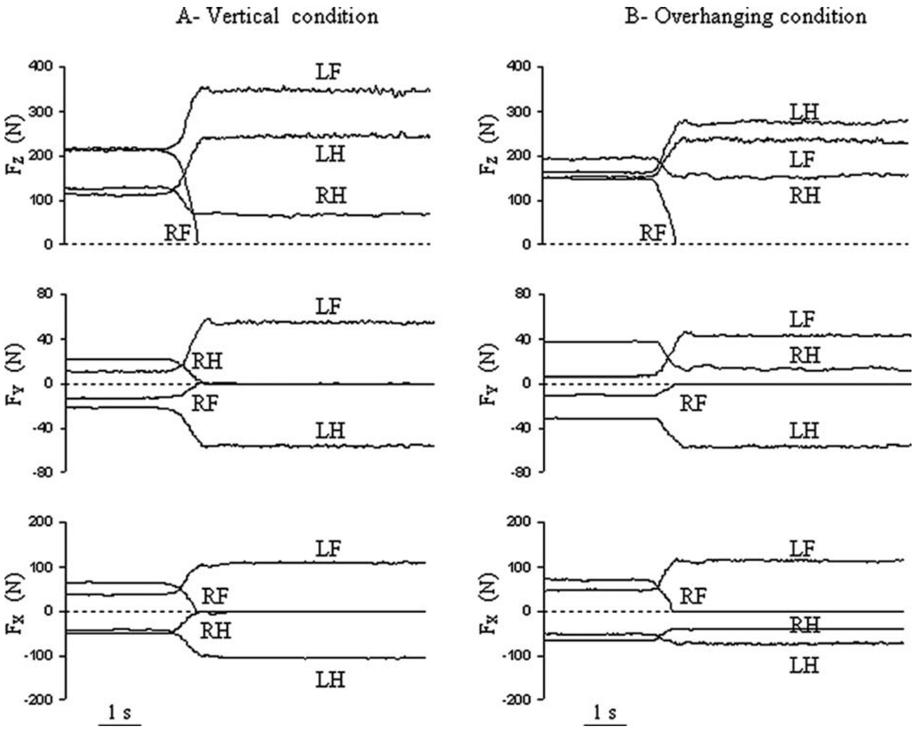

Fig. 2. Single trial recording showing typical forces variations (N) along the vertical (O_Z), medio/lateral (O_Y) and antero/posterior (O_X) axis associated with a right foot release in A – the vertical condition and B – the overhanging condition. RH and LH correspond to the right and left hand, RF and LF to the right and left foot.

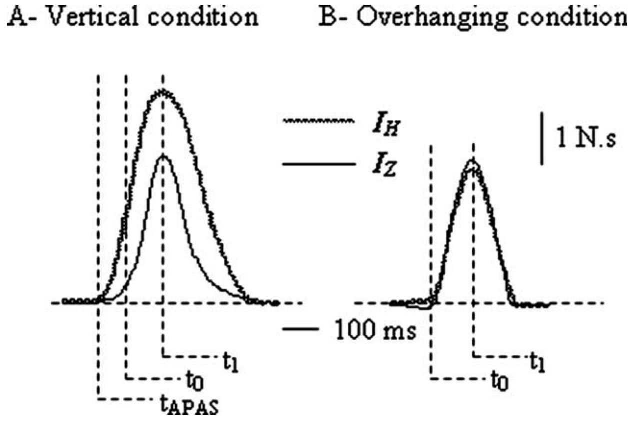

Fig. 3. Evolution of the vertical (I_Z) and horizontal (I_H) components of CG linear impulse (N.s) when a right foot release was performed from (A) a vertical and (B) an overhanging rock climbing posture. t_{APAS} represents the time of first force changes, t_0 the onset of focal movement and t_1 the time of right foot lift-off.

Indeed, Quaine and Martin [10] demonstrated that the contralateral forces transfer observed with vertical walls was the only method for a climber to restore balance following a limb release. The overhanging posture is characterised by a large sustentation base, which induces supplementary lever arms and supplementary moment components. These supplementary moment components enable equilibrium to be maintained with supplementary solutions and subjects can use different combinations of force variations in order to restore balance following a limb release [8]. Hence, the contralateral force transfer is less extensive with an overhanging wall and the distribution of the forces onto the three remaining supports is more homogeneous. Such a difference between vertical and overhanging postures engenders changes of postural adjustments associated with the realisation of the limb release.

The analysis of latencies of force variations revealed the presence of APAs in the vertical condition. Anterior studies reported similar findings [11,14,18]. There were no APAs in the overhanging condition since force variations were concomitant. This difference in the timing of APAs can be explained when analysing CG impulse. With limb releases performed from rock climbing postures, Quaine et al. [13] and Testa et al. [18] attributed a focal role to the vertical component of the impulse at the CG and a postural role to the horizontal CG impulse. The results of the present study showed that the vertical component of the impulse at the CG peaked at right foot take off (t_1) in both vertical and overhanging conditions. The amplitude of the peak thus did not present significant difference between both conditions. Consequently, the constraint linked to movement's effectuation was the same between both conditions because subjects had to create the same vertical momentum in order to displace their right foot upwards [9,18]. Hence one can't attribute APAs' disappearance in the overhanging posture to the movement's performance, what support the idea of a cause linked to postural conditions. When considering the model proposed by Quaine et al. [13] and Testa et al. [18], the higher horizontal CG impulse observed at t_1 in the vertical posture thus brought an additional element confirming a postural cause. In the vertical posture, APAs thus participated to generate the initial CG impulse, as observed with sit-to-stand movements [5,6,9]. A different result was observed in the overhanging condition since the impulse was generated without APAs. APAs' disappearance in the overhanging posture can be attributed to the mechanical properties associated with this postural condition. In order to preserve equilibrium from a vertical or an overhanging posture, subjects must counteract the body weight moment around the lateral axis which creates a positive angular acceleration and induces a backwards imbalance (Fig. 1). With a vertical wall, subjects must apply horizontal forces to the hand holds in order to create two negative moments (one moment at each hand) which counteract the positive body weight moment (Fig. 1) [12]. Quaine and Martin [10] thus showed that the maintenance of equilibrium during the tripedal state induced by the release of a limb required the horizontal force at the right hand to drop to zero. Consequently, only the increase of the horizontal forces applied to the left holds participates to the creation of the horizontal component of the impulse at the CG during movement's effectuation. To perform the release of a supporting limb, subjects must generate the initial CG impulse in order to increase the momentum of the CG [9]. The creation of the impulse required the exertion of a force over a period of time ($\mathrm{I} = F \cdot \Delta t$). Consequently, with a vertical wall, possibilities of force creation (the F term in the impulse formula) are limited and APAs served the purpose of increasing the duration of force appliance (the Δt term in the impulse formula) in order to generate the impulse. With an overhanging wall, our results showed that equilibrium maintenance did not require a dramatic decrease of the right hand horizontal force. Indeed, additional lever arms were at work and four negative moments, induced by the antero/posterior and vertical components of the reaction forces at the right and left hand, balanced the positive body weight moment around the lateral axis (Fig. 2). When the limb was released, all these moments counteracted the body weight moment, whereas only one moment was acting against the body weight moment with a vertical posture [8,10]. With an overhanging wall, right and left hands created the impulse at the CG. With such a system, the possibilities of force creation (the F term in the impulse formula) are enhanced and the time required to generate the CG impulse (the Δt term in the impulse formula) is shorter. The disappearance of the APAs reflects this reduction of the time window of force application.

5. Conclusion

The present study showed that APAs were modulated according to the mechanical possibilities associated with the initial conditions of posture, as previously observed by Cordo and Nashner [4]. Our results suggest that the nervous central system would modulate APAs on the basis of a physical coupling between the mechanical properties of the initial postural set (force creation possibilities) and the voluntary movement's constraints (impulse to create, under the dependence of velocity) and inertia.

References

[1] S. Bouisset, M. Zattara, Biomechanical study of the programming of anticipatory postural adjustments associated with voluntary movement, Journal of Biomechanics 20 (1987) 735–742.

[2] C. Bourdin, N. Teasdale, V. Nougier, Attentional demands and the organization of reaching movements in rock clilmbing, Research Quarterly for Exercise and Sport 69 (4) (1998) 1–5.

[3] P. Cordier, G. Dietrich, J. Pailhous, Harmonic analysis of a complex behavior, Human Movement Science 15 (1996) 789–807.

[4] P.J. Cordo, L.M. Nashner, Properties of postural adjustments associated with rapid arm movements, Journal of Neurophysiology 47 (1982) 287–303.

[5] T.A. Hanke, Y.C. Pai, M.W. Rogers, Reliability of measurements of body center-of-mass momentum during sit-to-stand in healthy adults, Physical Therapy 75 (2) (1995) 105–113.

[6] H. Hirschfeld, M. Thorsteindottir, E. Olsson, Coordinated ground reaction forces exerted by buttocks and feet areadequately programmed for weight transfer during sit to stand, Journal of Neurophysiology 82 (6) (1999) 3021–3029.

[7] K.M. Jackson, Fitting and mathematical functions to biomechanical data, IEEE Transactions of Biomedical Engineering 26 (2) (1979) 122–124.

[8] F. Noé, F. Quaine, L. Martin, Influence of steep gradient supporting wall in rock climbing: biomechanical analysis, Gait and Posture 13 (2001) 86–94.

[9] Y.C. Pai, W.A. Lee, Effect of a terminal constraint on control of balance during sit-to-stand, Journal of Motor Behaviour 26 (3) (1994) 247–256.

[10] F. Quaine, L. Martin, A biomechanical study of equilibrium in sport rock climbing, Gait and Posture 10 (1999) 233–239.

[11] F. Quaine, L. Martin, J.P. Blanchi, Effect of initial posture on biomechanical adjustments associated with a voluntary leg movement in rock climbers, Archives of Physiology and Biochemistry 104 (1996) 192–199.

[12] F. Quaine, L. Martin, J.P. Blanchi, The effect of body position and number of supports on wall reaction forces in rock climbing, Journal of Applied Biomechanics 13 (1997) 14–23.

[13] F. Quaine, L. Martin, J.P. Blanchi, Effect of a leg movement on the organisation of the forces in a climbing position: 3D kinetic analysis, Human Movement Science 16 (1997) 337–346.

[14] P. Rougier, J.P. Blanchi, Evaluation objective de la difficulté en escalade par la relation posturo-cinétique, STAPS 26 (1991) 61–77.

[15] A. Schweizer, Biomechanical properties of the crimp grip position in rock climbers, Journal of Biomechanics 34 (2003) 217–223.

[16] P. Stapley, T. Pozzo, A. Grishin, C. Papaxanthis, Investigating centre of mass stabilisation as the goal of posture and movement coordination during human whole body reaching, Biological Cybernetics 82 (2000) 161–172.

[17] G.E. Stelmach, J. Phillips, R.P. DiFabio, N. Teasdale, Age, functional postural reflexes and voluntary sway, Journal of Gerontology 44 (4) (1989) 100–106.

[18] M. Testa, L. Martin, B. Debû, Effects of type of holds and movement amplitude on postural control associated with a climbing task, Gait and Posture 9 (1999) 57–64.

[19] D.A. Winter, Biomechanics and motor control of human movement, second ed., Wiley, New York, 1990.

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