

# **Fight Gravity- Rock climbing biomechanics**

Quaine, Franck

Univ. Grenoble Alpes Grenoble INP, Gipsa-Lab, France. [Franck.Quaine@gipsa-lab.grenoble-inp.fr](mailto:Franck.Quaine@gipsa-lab.grenoble-inp.fr)

## **Abstract**

This paper reports on rock climbing biomechanical adjustments. Different rock climbing devices used to assess the forces at the supports are first presented. Data are obtained with the climbing walls at Grenoble University equipped with 1D and 3D-force sensors or throughout numerical optimization schemes associated with biomechanical models to draw relevant constraints. Rock climbing experiments are described and supporting forces are discussed in the frame of Newton's Laws of motion. In conclusion, most recent biomechanical simulations based on numerical optimization are proposed.

**Keywords** : Rock climbing; Biomechanics; Newton's Laws of motion; numerical optimization

**Résumé :**

Cet article s'intéresse aux ajustements biomécaniques réalisés en escalade. Pour cela, différents dispositifs d'enregistrement des forces aux appuis sont présentés. Les principes de la mécanique Newtonienne sont retenus pour analyser et discuter les changements de forces aux appuis observés dans diverses situations d'escalade. Les premiers résultats présentés correspondent aux enregistrements des forces d'appui en 1D ou 3D qui ont été réalisés avec les 'ergomètres d'escalade' développés à l'Université de Grenoble. Enfin, une approche théorique plus récente combinant optimisation numérique sous contraintes et modélisation biomécanique est proposée.

**Mots clés :** Escalade sportive; Biomécanique ; Lois de Newton, optimisation numérique

What is common between a young beginner in rock climbing and the best world rock climber? Both are subjected to the same external mechanical constraints induced by the gravity force, and both have to adapt their supporting forces respective to Newton's Laws of motion to success for climbing. During ascent the climber has to manage the supporting forces according to Newton's Laws of motion in order to catch next holds while maintaining balance.

Rock climbing can be described as a physical activity performed against gravity, in which the contact forces at the holds are tested during the ascent. Analysis of biomechanics of postures mimicking climbing situations is a useful approach to help us to understand balance control in rock climbers.

One specificity of rock climbing balance is that it does not need that the body's centre of mass lies in the base of support as it is the case in most common situations encountered during our daily life. This situation is totally unusual and it implies that dedicated supporting forces are applied at the holds in order to achieve Newton's Laws of motion. Hence, analysis of these forces provides one unique opportunity to better understand balance control in human in general, and in rock climber in particular. In static equilibrium, supporting forces applied at the holds must succeed two purposes: (1) avoid vertical collapsing against gravity force, and (2) balance the backwards body weight torques. According to these simple observations, several experimentations have been performed at the Grenoble University in the last decades in order to characterize the postural behaviour of rock climbers. Pioneer researches from Rougier *et al.* (1991) have focussed on the level of expertise of climbers. They aimed at evaluating the expertise of climbers through the analysis of the forces applied at the holds. To do that, they had built an artificial climbing wall equipped with force sensors mounted onto the holds to characterize the supporting forces. They used 1D-vertical force sensors at each hold (Fig. 1).



Figure 1 –Patrice Rougier at work on the first equipped climbing wall in Grenoble University. Each hold was equipped with 1D-vertical force sensor

They intended to characterize the variation of the vertical forces at the holds when the subject was in process of moving from four limb holds to three limbs holds. Rougier *et al.* (1991) were strongly influenced by the studies

concerning balance control and neurophysiology in animals (Gahery *et al.*, 1980). A huge literature describes postural regulation when cats release one limb from a stable posture. Specific postural indexes based on the analysis of the vertical force transfer on the remaining supports are used to characterize the postural strategy. These indexes reflect some parts of the “centre of pressure” shifts. They can be instantaneous or differential and they are used to discriminate from a pure mechanical strategy observed with a rigid table to a physiological one observed with a cat trained to release a limb. The postural indexes were tuned by Rougier *et al.* (1991) in order to be adapted to the vertical support configuration as in rock climbing. They proposed new indexes reflecting the dynamics of a resultant point labelled “hanging centre” instead of centre of pressure. Great research activity was performed in the way to understand how the climbers share their body weight on the holds. Different initial experimental conditions were tested. Main results indicated that a strong lateral pattern of vertical force transfer was observed with beginner climbers, while a more diagonal one was typical in skilled climbers. This means that expert climbers share their body weight on three remaining supports, whereas beginner do not. On the contrary, beginners transfer the body weight preferentially towards two lateral holds with the straight effect to overload these supports, increasing as well the physiological demand on them.

This first series of results was very interesting since it confirmed that the analysis of vertical supporting forces was reliable to characterize balance control in rock climber. Many experiments were performed according to this methodology in order to test the effect of the age, the type of hold, the gender or the level of expertise...

However, analysing 1D-vertical force appears non fully appropriated to characterize the postural strategy since it does not allow to characterize how the climber adapt the forces at he holds to counterbalance the destabilising body weight moments. In order to overcome this limitation, it is necessary to measure 3D forces at the holds. Hence, a second generation of artificial climbing wall was assembled in Grenoble University by replacing 1D-vertical force sensors by 3D-force sensors. The use of 3D-force sensors gave the possibility to discriminate the mechanical actions performed to avoid gravity collapsing with vertical forces and to balance the moments due to body weight with tangential forces. Theoretical models clearly demonstrated that tangential forces at the holds are directly dependant upon the distance between the body and the wall. More precisely, antero-posterior supporting forces are proportional to the distance between the projection of the centre of mass and the contact area of the supports. Analysis of 3D-force data showed that expert rock climbers used this relationship to adapt the position with the lower physiological demand. The more skilled the climber, the closest the posture to the contact area of the supports (Quaine *et al.*, 1996). Tangential forces analysis showed that the function of the arms in rock climbing is to control the body posture and the proximity to the support, while the leg have to support the main part of the body weight.

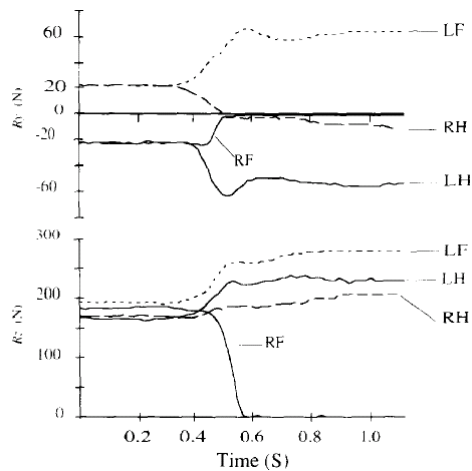


Figure 2 – Typical vertical ( $R_z$ ) and antero-posterior ( $R_y$ ) force variations after a right-foot hold release. RH, LH, RF and LF correspond to the right/left foot/hand hold.

One conclusion concerns the quantitative analysis of the limb support. In a posture closed to the wall, the transfer of the forces is less extensive than in a posture with the trunk far from the supporting wall, so that the forces were exerted primarily on the remaining holds (Fig.2). It appears that the force transfers differ according to the difficulty of the position: the contralateral distribution of the reaction forces was observed for a position far from the wall support, while a more homogeneous distribution occurred during a close position to the wall. Concordant results were observed by Noe *et al.*, (2001) for overhanging positions.

These results imply that expert climbers are capable to organize the tangential forces and the vertical forces in a specific way on the holds. Despite no obvious link between the vertical and the tangential forces applied on the same hold can be noted, a link between the tangential forces, the body weight and the position of the climber is observed at the whole.

Rock climbing biomechanical understanding requires this type of experiment and this kind of experimental device. However, this rises difficulties of two types. First, from a practical point of view, this requires a climbing wall equipped with 3D-force sensors at each hold. This precludes analysis of difficulty routes of several meters. Second, from a fundamental mechanical point of view, rock climbing poses a huge, interesting and difficult problem for solving supporting force for equilibrium. In fact there is no one unique force sharing pattern for balancing the whole body. Conversely, an infinity of solutions can be proposed since equilibrium in rock climbing represents an under-determinate problem with more unknowns than we can write equations. Then solving this kind of system is a complex problem in biomechanics and no straight method can be proposed. One solution to go further is to elaborate an optimization scheme with biomechanical model constraints to simulate the forces sharing pattern on the holds. This implies to identify an optimal criterion for optimization relevant to the rules used by the climbers to share the 3D forces between the feet and hand holds. Currently, such understanding is far away our knowledge and this optimal criterion remains to be clarified. However, one relevant and promising approach may consist to use the minimal torque change criterion with the minimization of the external forces under the biomechanical model constraints (Robert *et al.*, 2013). This approach has already

been proposed in Courtemanche (2014) to simulate the forces at the holds without the need to use a climbing wall equipped with 3D force sensors.

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