Journal of Sports Sciences, 2001, **19**, 427–432

Use of 'chalk' in rock climbing: *sine qua non* or myth?

F.-X. LI,* S. MARGETTS and I. FOWLER

Perception Action Laboratory, School of Sport and Exercise Sciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

Accepted 20 February 2001

Magnesium carbonate, or 'chalk', is used by rock climbers to dry their hands to increase the coefficient of friction, thereby improving the grip of the holds. To date, no scientific research supports this practice; indeed, some evidence suggests that magnesium carbonate could decrease the coefficient of friction. Fifteen participants were asked to apply a force with the tip of their fingers to hold a flattened rock (normal force), while a tangential force pulled the rock away. The coefficient of friction – that is, the ratio between the tangential force (pulling the rock) and the normal force (applied by the participants) – was calculated. Coating (chalk *vs* no chalk), dampness (water *vs* no water) and rock (sandstone, granite and slate) were manipulated. The results showed that chalk decreased the coefficient of friction. Sandstone was found to be less slippery than granite and slate. Finally, water had no significant effect on the coefficient of friction. The counter-intuitive effect of chalk appears to be caused by two independent factors. First, magnesium carbonate dries the skin, decreasing its compliance and hence reducing the coefficient of friction. Secondly, magnesium carbonate creates a slippery granular layer. We conclude that, to improve the coefficient of friction in rock climbing, an effort should be made to remove all particles of chalk; alternative methods for drying the fingers are preferable.

Keywords: chalk, coating, coefficient of friction, grip force, magnesium carbonate, rock climbing, rock surfaces.

Introduction

Although climbing has been practised since pre-historic times (Frison-Roche and Jouty, 1996), only recently has it become very popular; there are over 4 million climbers in the United States alone (Mermier *et al.*, 1997). The last 30 years has witnessed a boom in rock climbing, which is now a truly international sport. The essence of this sport is to lift the body against gravity to climb on rock faces or artificial structures using only bare feet and hands. To achieve this, climbers rely entirely on an efficient, coordinated contraction of muscles associated with fine balance and, of special interest here, friction of bare feet and hands on the support.

Various aspects of rock climbing have attracted the attention of sport scientists. These include the physiological (Hardy and Martindale, 1982; Billat *et al.*, 1995) and anthropometric (Watts *et al.*, 1997) characteristics of climbers, the energy (Rooks, 1997; Mermier *et al.*, 1997; Booth *et al.*, 1999) and attentional (e.g. Bourdin *et al.*, 1998a) demands of the sport, the biomechanical (Quaine *et al.*, 1997) and motor-control (e.g. Nougier *et al.*, 1993; Bourdin *et al.*, 1998 a,b, 1999) organization of the movements, and sport-specific injuries (Bollen and Gunson, 1990; Wyatt *et al.*, 1996; Jebson and Seyers, 1997; Rooks, 1997). Surprisingly, the grip of the hand on the rock, an essential aspect of the sport and a focal point for climbers, has not received any attention.

Magnesium carbonate, known by climbers as 'chalk', is traditionally carried in a bag attached to the climber's waist. Climbers dip their hands in it to cover the fingers and, in an attempt to remove any excess deposit, climbers blow on it. Chalk has been used for years by climbers in the belief that this will dry up sweat and improve grip on the holds. Indeed, chalk has been used unquestioningly in several scientific studies (e.g. Hardy and Martindale, 1982). Applying chalk to the fingers is widely perceived as a *sine qua non* for a good performance. However, to date, no scientific research supports this belief.

What is the effect on grip of applying magnesium carbonate to the surface of the hands? The elements of response can be found in mechanics, tribology and neuroscience. The problem of grip is a problem of the coefficient of friction (μ). When a tangential force (F_t) is

* Author to whom all correspondence should be addressed. e-mail: f.x.li@bham.ac.uk

exerted on a surface, it will tend to move in the direction of the force applied. To prevent this movement, a friction force normal to the surface (F_n) can be applied. The ratio between tangential force and normal force defines the static coefficient of friction: $\mu = F_t/F_n$. The coefficient is roughly constant for any pair of surfaces. The coefficient of friction can be affected by the introduction of another substance between the two surfaces; this is the way lubrication works. For instance, a layer of oil is often used to reduce the coefficient of friction between two metallic surfaces. Conversely, removing any trace of grease or humidity can increase the coefficient of friction. This has been the basis for the rationale leading to the almost unchallenged use of chalk in climbing: dry skin grips better, chalk dries the skin, so by regular application of chalk one increases the coefficient of friction between the skin on the hands and the climbing surfaces. But is it that straightforward?

For solid surfaces, friction is proportional to the normal force applied and it is independent of the surface area. However, skin – or the stratum corneum, the outermost layer of skin – is a compliant material. It is about 10–15 μm thick. It behaves more like an elastomer or thermoplastic than a solid body (Johnson *et al.*, 1993). The properties of this biomaterial depend on many factors, including the percentage of water, pH and temperature. Interestingly, Johnson *et al.* (1993) showed that the addition of water increases the friction of dry skin. It would appear that the main effect of water is to increase the compliance of the surface asperities and hence the contact area. Frequent application of chalk may decrease the percentage of water in the skin and, therefore, decrease its compliance. Moreover, Wyatt *et al.* (1996) found that the splitting of the skin pads of the fingertips, a common injury among climbers, is due in part to the use of chalk and its desiccating effect. It appears that, at least from a tribological and medical point of view, the overuse of chalk can have the opposite effect to that intended.

Chalk is used to remove water and sweat. Sweat is produced naturally by more than 2.5 million subcutaneous sudoriferous glands. Sweat is a hypotonic solution with a content of 99% water (Marieb, 1992). Owing to the presence of sweat and the accumulation of various greasy substances collected during the manipulation of objects, the skin can be covered by a thin slippery deposit. Johansson and Westling (1984) have shown that, immediately after washing and drying the skin, the coefficient of friction increases. Therefore, there is an advantage in drying the hands. However, Cadoret and Smith (1996) showed that applying talcum powder to the skin can decrease the coefficient of friction. Magnesium carbonate could have the same effect, so that it may not be the best way to increase the coefficient of friction.

No scientific results directly support the use of chalk in rock climbing. Indeed, some studies (Johnson *et al.*, 1993; Cadoret and Smith, 1996; Wyatt *et al.*, 1996) cast doubt on its usefulness. The aim of this study was to determine the effect of magnesium carbonate on the coefficient of friction and its potential interaction with dampness and type of rock. We hypothesized that chalk would not improve the coefficient of friction for already dry hands and that applying water would decrease the coefficient of friction.

Methods

Participants

Fifteen students aged 20–22 years volunteered to participate in the experiment. They had no cuts or abrasions to the pads of the fingers and were all unaware of the hypotheses to be tested.

Apparatus

A purpose-built set-up was used in the experiment. A carriage moved freely on ball bearings and two parallel steel rods (Fig. 1). The rods were mounted on four strain gauges (RS 632-168, 5 mm). The strain gauges were calibrated and the total normal force applied by the carriage was calculated. A non-stretchable kevlar rope (diameter 4 mm) was attached to the carriage. A weight (3.5 kg) was suspended on the rope via a pulley. A strain gauge (RS 632-180, 5 mm), rigidly mounted between the rope and the carriage, was used to measure the force applied to the carriage by the weight. This tangential force was 29 N for all trials; this was sufficiently high to give accurate and meaningful results but did not result in the participants becoming too fatigued. The carriage was attached to a fixed potentiometer to measure linear displacements. Opposite to the rope and at the extremity of the rails, an armrest was mounted level with the carriage. The apparatus was mounted on a table and the participants were seated side-on to it so that the forearm and palm of the hand were placed on the armrest, with the fingers slightly above the carriage. A strap running over the back of each participant's hand was adjusted to prevent the hand being lifted.

Three types of rock were used: sandstone, slate and granite. These rock samples do not have the same external structure or appearance. Sandstone is the roughest, while slate is the smoothest. The roughness has a strong influence on the ability to avoid slippage. However, the wide variability in the geological formation of rock in natural settings renders the reproduction of a real-life environment impractical. It would also be

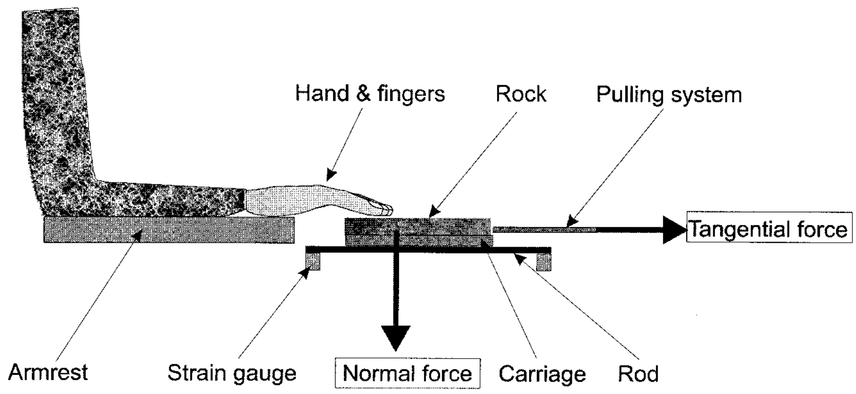

Fig. 1. Schematic side view of the set-up. The hand is on the armrest and the fingers apply a force normal to the rock while a tangential force pulls the rock away from the participant.

very difficult, if not impossible, to compare different types of rock samples. Therefore, to ensure that the surface texture of the rock samples was comparable, they were lapped using a vibrator machine and loose abrasive powder (Silicon Carbide of grit size 180). The abrasive powder removed the material by scratching the surface until an even surface was obtained. This treatment, classically used in geology (Allman and Lawrence, 1972), resulted in a rough but homogeneous surface across each rock sample, hence making comparisons between them possible. All rock samples were cut to the same dimensions (125×145 mm). They were mounted on the carriage and the participant's hand fell naturally on it. All signals from the transducers were recorded continuously at 1000 Hz on a personal computer using an A/D card (PCI-M10-16XE-10 NI) and a purpose-designed program under Labview.

Design and procedure

After reading the instructions and signing a consent form, the participants were required to clean and dry their hands. Then, they sat next to the apparatus with their left forearm on the armrest. The palm was placed on the support so that the matacarpophalangeal joint was the most proximal joint that could flex to apply pressure to the surface of the rock. The strap on the armrest was adjusted to restrain the hand. The carriage was moved to the back of the rails. The tangential force was applied and the participants fully extended their fingers and placed the pads of their index, middle and ring fingers on the surface of the rock. They were asked to apply sufficient force to the rock to prevent the carriage from sliding. They then gradually reduced this pressure until slippage occurred. At this instant, normal and tangential forces were measured and their ratio was calculated to obtain the coefficient of friction (for a review, see Turrell *et al.*, 2001). The participants were instructed not to try to stop the movement of the carriage once it had started to slip. They practised until they were familiar with the apparatus and the task.

Two hand dampness conditions (dry or wet) were crossed with two coating conditions (no chalk or chalk) and three types of rock (sandstone, granite and slate). This repeated-measure design resulted in four hand conditions:

- *Dry*: participants cleaned their hands with water and mild detergent to remove sweat and any other coating (grease, cream, etc.) that could have altered the surface of the skin. The detergent was then rinsed off and the hands were dried thoroughly with clean tissue.
- *Dry + chalk*: the same procedure was followed as for the dry condition. Then the pads of the fingers to be used were pressed into a bowl of loose, sieved magnesium carbonate powder. This powder is the standard chalk used in rock climbing. The back of the hand was then tapped to remove any excess. Rock climbers normally follow a similar procedure or blow on the hand.
- *Wet*: the same procedure was followed as for the dry condition. The pads of the fingers to be used were then pressed onto a damp sponge. This was aimed at reproducing the conditions encountered when the hands are sweating. An alternative could have been to expose the hands to heat until sweat appeared. However, this would have induced a change in the temperature of the skin and would, therefore, have been a confounding factor. Moreover, the quantity of sweat produced at a given temperature varies widely between individuals (e.g. Åstrand and Rodahl, 1986).
- *Wet + chalk*: the hand was prepared as for the wet condition. Following the same procedure as for the

dry + chalk condition, the pads of the fingers were then pressed into a separate bowl of magnesium carbonate powder and the excess removed by tapping.

Before testing began, the rock surfaces to be used were cleaned, rinsed and dried thoroughly. Owing to the roughness of the rock surfaces, a brush, clean tissue and hot air were used to clean and dry them. They were then left to rest and cool down to the ambient temperature.

For each trial, the coefficient of friction was calculated at the moment slip occurred by dividing the tangential force (F_t) by the force normal to the surface (F_n) exerted by the fingers: $\mu = F_t/F_n$. For each participant, five trials were performed in each experimental condition. A within-individual design, with repeated measures on rock (3), dampness (2) and coating (2), was used. The results were analysed with a three-way analysis of variance with repeated measures on all three factors. Alpha was set to 0.05. The order of each experimental condition was randomized across participants.

Results

Figure 2 depicts a typical example of a trial displaying, from top to bottom, load force, normal force and displacement of the carriage. During the first few seconds of the trial, the carriage was immobile and the load force was constant. Marginal fluctuations in the normal force were observed. Then, the participants reduced the normal force applied to the rock until the carriage first moved. At this instant, the coefficient of friction was calculated.

Figure 3 depicts the main effect of type of rock on the coefficient of friction. Sandstone had a higher coefficient than the two other types of rock. This was confirmed by the analysis of variance ($F_{2,28} = 9.98$; $P < 0.001$; $\eta^2 = 0.42$) and a pairwise comparison. The coefficient of friction of sandstone (mean = 3.25) was significantly higher than that of granite (mean = 2.49; $P < 0.01$) and slate (mean = 2.48; $P < 0.01$); those of granite and slate did not differ statistically ($P = 0.26$).

The analysis of variance revealed a significant main effect for coating ($F_{1,14} = 29.8$; $P < 0.001$; $\eta^2 = 0.68$). The coefficient of friction decreased (Fig. 4) with the application of magnesium carbonate (no-chalk = 3.00; chalk = 2.47). This result contradicts the climbers' belief that chalk increases the coefficient of friction.

There was no significant main effect for dampness ($F_{1,14} = 0.004$). Applying water to the fingers did not modify the coefficient of friction (Fig. 5). The interaction between coating and dampness was not significant ($F_{1,14} = 3.92$).

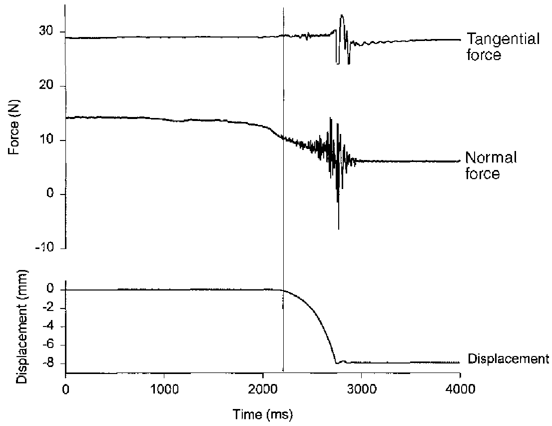

Fig. 2. A typical trial observed during the experiment. The tangential force, normal force and displacement of the carriage are shown. The vertical line indicates the moment the carriage first moved, the instant at which the coefficient of friction was calculated.

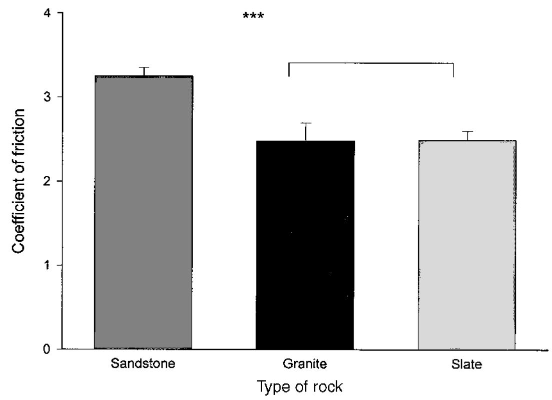

Fig. 3. Effect of rock type on the coefficient of friction. The interaction between sandstone and hand, regardless of coating or dampness, generated a high coefficient of friction. Error bars represent the standard error.

The absence of a significant interaction between rock and coating ($F_{2,28} = 0.12$) suggests that the effects of these two factors are independent. Finally, there was no significant interaction between rock and dampness ($F_{2,28} = 1.71$) or rock, dampness and coating ($F_{2,28} = 0.15$).

Discussion

The aim of this experiment was to test the belief that applying magnesium carbonate, or 'chalk', to the fingers dries them and increases the coefficient of friction, therefore facilitating rock-climbing performance. The

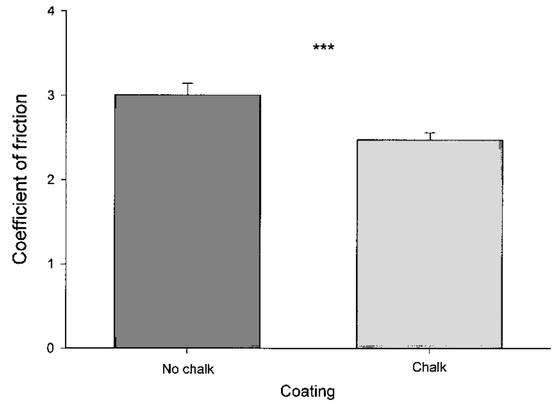

Fig. 4. Effect of coating on the coefficient of friction. The highest coefficient of friction was obtained without the application of chalk. Error bars represent the standard error.

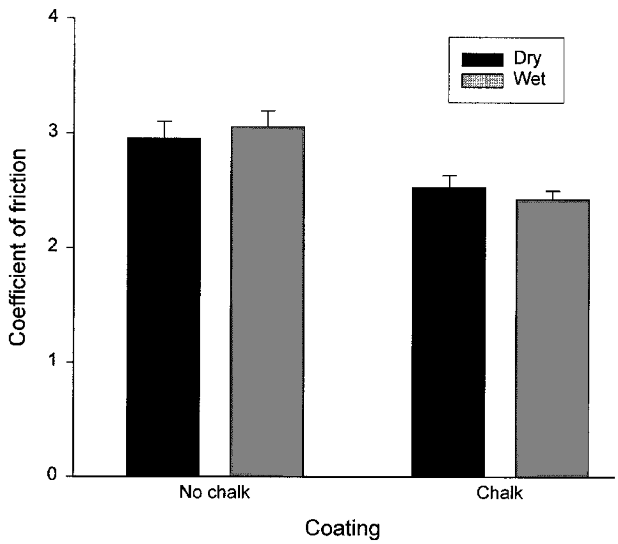

Fig. 5. Effects of coating and dampness.

main finding is that the inverse effect was observed: applying a coating of chalk reduces the coefficient of friction. This contradicts the general belief and this result is counter-intuitive for most rock climbers. Cadoret and Smith (1996) showed that coating a surface with talcum powder reduces the coefficient of friction. It is probable that chalk, as talc, creates a granular layer. The small smooth particles roll on each other, creating a slippery surface. Physics experiments have shown that, with quite thin layers, such an effect can occur (e.g. Nasuno *et al.*, 1998). The particles also fill the asperities of the skin, creating a smoother and slippery surface. Further research using other methods (e.g. Johnson *et al.*, 1993) is required to identify precisely the mechanics of the phenomenon. Nevertheless, the effect is clear enough to conclude that dry hands produce a higher coefficient of friction than when magnesium carbonate is applied to them. The effect would probably be amplified by the regular application of chalk, which desiccates the skin, reducing further the coefficient of friction. Finally, it is probable that, in natural settings, each climber leaves a small amount of chalk on the rock, contributing to the deposit of a slippery layer of magnesium carbonate. Applying more chalk to the fingers would only amplify this effect. All of this evidence strongly suggests that rock climbers should not use chalk when the fingers are already reasonably dry; if chalk is used to dry the hands, all traces of it should be removed before climing. As this is particularly difficult when rock climbing, an alternative method of drying the hands (e.g. using a towel) is preferable.

The manipulation of dampness did not yield any significant effect. We expected that the application of water to the fingers would decrease the coefficient of friction. Several reasons could have contributed to this lack of effect. The composition of the liquid used may have played a role. Virtually no trace of grease can be found in water, whereas sweat includes various components, including salt, antibodies, traces of metabolic wastes, lactic acid and vitamin C (Marieb, 1992). Therefore, the water on the fingers may have been slightly less slippery than real sweat. However, as sweat is 99% water, the difference should be minimal. As the participants pressed the humid sponge only once for each series of five trials, it is possible that the rock surfaces rapidly absorbed the limited amount of liquid, decreasing further its lubricating effect. However, this effect should have been stronger for the sandstone than for the slate. It would be interesting to replicate this experiment with repeated applications of real sweat or a liquid similar in its chemical composition, although very small differences are expected. Finally, applying water to the skin may have increased its compliance (Johnson *et al.*, 1993) and compensated the lubricating effect of liquid.

The effect of rock type shows that, with similar texture, sandstone produces a higher coefficient of friction than granite or slate. This is not surprising considering the differing nature of the fine structure of these rocks. More interestingly, that there was no interaction between rock and either coating or dampness suggests that the negative effect of chalk is independent of the type of rock. Although not all rock types and artificial structures were tested in this study, there is no reason to believe that the results could not be generalized; further work would help to clarify this. It would also be interesting to determine the effect of a rise in temperature on the coefficient of friction. The temperature of the environment was kept constant, and the few trials plus the relatively small forces applied suggests that body temperature did not play an important role in the experiment. However, in natural settings, ambient temperature and body temperature vary. Although body temperature has been studied extensively, the exact effect of body temperature on the skin's coefficient of friction remains to be addressed. As skin temperature rises, its pliability increases, since the lipid bilayer of the cell wall becomes more fluid. This increase in compliance will lead to an increase in the coefficient of friction.

Is chalk a myth or an absolute requirement of the sport? Chalk can help to dry wet, sweaty or greasy hands and, therefore, can potentially improve a climber's grip. However, any trace of the chalk will decrease the coefficient of friction. Therefore, chalk is not a *sine qua non* for a good performance in rock climbing. Is it a myth? For the coefficient of friction, largely it is. Is it useless? Possibly not, as a psychological support, although the exact magnitude of this support remains to be evaluated.

Acknowledgements

We thank Paul Hands for his patience and help in grounding the stones and Martin Lansley for his useful comments on an earlier draft of the manuscript.

References

Allman, M. and Lawrence, D.F. (1972). *Geological Laboratory Techniques*. London: Blandford Press.

Åstrand, P.-O. and Rodahl, K. (1986). *Textbook of Work Physiology: Physiological Bases of Exercise*, 3rd edn. London: McGraw-Hill.

Billat, V., Palleja, P., Charlaix, T., Rizzardo, P. and Janel, N. (1995). Energy specificity of rock climbing and aerobic capacity in competitive sport rock climbers. *British Journal of Sports Medicine*, **35**, 20–24.

Bollen, S.R. and Gunson, C.K. (1990). Hand injuries in competition climbers. *British Journal of Sports Medicine*, **24**, 16–18.

Booth, J., Marino, F., Hill, C. and Gwinn, T. (1999). Energy cost of sport rock climbing in elite performers. *British Journal of Sports Medicine*, **33**, 14–18.

Bourdin, C., Teasdale, N. and Nougier, V. (1998a). Attentional demands and the organization of reaching movements in rock climbing. *Research Quarterly for Exercise and Sport*, **69**, 406–410.

Bourdin, C., Teasdale, N. and Nougier, V. (1998b). High postural constraints affect the organization of reaching and grasping movements. *Experimental Brain Research*, **122**, 253–259.

Bourdin, C., Teasdale, N., Nougier, V., Bard, C. and Fleury, M. (1999). Postural constraints modify the organization of grasping movements. *Human Movement Science*, **18**, 87–102.

Cadoret, G. and Smith, A. (1996). Friction, not texture, dictates grip forces used during object manipulation. *Journal of Neurophysiology*, **75**, 1963–1969.

Frison-Roche, R. and Jouty, S. (1996). *A History of Mountain Climbing*. Paris: Flammarion.

Hardy, L. and Martindale, K. (1982). Some physiological parameters in rock-climbing. *Physical Education Review*, **5**, 41–44.

Jebson, P.J.L. and Seyers, C.M. (1997). Hand injuries in rock climbing. *The Physician and Sportsmedicine*, **25**, 54–63.

Johansson, R.S. and Westling, C. (1984). Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects. *Experimental Brain Research*, **56**, 550–564.

Johnson, S.A., Gorman, D.M., Adams, M.J. and Briscoe, B.J. (1993). The friction and lubrication of human stratum corneum. In *Thin Films in Tribology* (edited by D. Dowson, C.M. Taylor, T.H.C. Childs, M. Godet and G. Dalmaz), pp. 663–672. Amsterdam: Elsevier.

Marieb, E. (1992). *Human Anatomy and Physiology*, 2nd edn. Redwood, CA: Benjamin Cummings.

Mermier, C.M., Robergs, R.A., McMinn, S.M. and Heyward, V.H. (1997). Energy expenditure and physiological responses during indoor rock climbing. *British Journal of Sports Medicine*, **31**, 224–228.

Nasuno, S., Kudrolli, A., Bak, A. and Gollub, J.P. (1998). Time-resolved studies of stick-slip friction in sheared granular layers. *Physical Review E*, **58**, 2161–2171.

Nougier, V., Orliaguet, J.P. and Martin, O. (1993). Kinematic modifications of manual reaching in climbing – effects of environmental and corporal constraints. *International Journal of Sport Psychology*, **24**, 379–390.

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

Rooks, M.D. (1997). Rock climbing injuries. *Sports Medicine*, **23**, 261–270.

Turrell, Y.N., Li, F.-X. and Wing, A.M. (2001). Estimating the minimum grip force required when grasping objects under impulsive loading conditions. *Behavior Research Methods, Instruments and Computers*, **33**, 38–45.

Watts, P.B., Martin, D.T. and Duratschi, S. (1997). Anthropometric profiles of elite male and female competitive sport rock climbers. *Journal of Sports Sciences*, **11**, 113–117.

Wyatt, J.P., McNaughton, G.W. and Grant, P.T. (1996). A prospective study of rock climbing injuries. *British Journal of Sports Medicine*, **30**, 151–155.