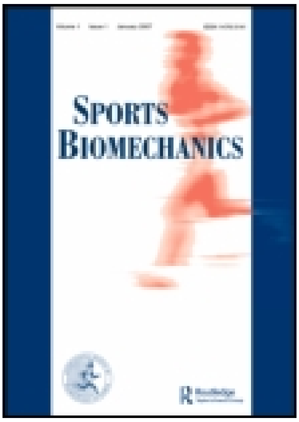

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The effect of chalk on the finger–hold friction coefficient in rock climbing

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Abstract
The main purpose of this study was to examine the effect of chalk on the friction coefficient between climber's fingers and two different rock types (sandstone and limestone). The secondary purpose was to investigate the effects of humidity and temperature on the friction coefficient and on the influence of chalk. Eleven experienced climbers took part in this study and 42 test sessions were performed. Participants hung from holds which were fixed on a specially designed hang board. The inclination of the hang board was progressively increased until the climber's hand slipped from the holds. The angle of the hang board was simultaneously recorded by using a gyroscopic sensor and the friction coefficient was calculated at the moment of slip. The results showed that there was a significant positive effect of chalk on the coefficient of friction (+18.7% on limestone and +21.6% on sandstone). Moreover sandstone had a higher coefficient of friction than limestone (+15.6% without chalk, +18.4% with chalk). These results confirmed climbers' belief that chalk enhances friction. However, no correlation with humidity/temperature and friction coefficient was noted which suggested that additional parameters should be considered in order to understand the effects of climate on finger friction in rock climbing.

Keywords: *Climber, hang board, humidity, temperature, magnesium carbonate*

Introduction

During the last decade, the popularity of rock climbing has grown rapidly and this sport is now pursued by many as a professional or recreational activity. In rock climbing, climbers maintain body equilibrium and evolve on vertical supports by applying high-intensity forces with the hands and fingers. The inability to maintain contact with the handholds is one of the main reasons for failure in rock climbing (Watts et al., 2000). Consequently, the capacity to exert high-intensity forces with the fingertips and the capability to resist finger muscle fatigue are recognized as characteristics of highly skilled climbers (Grant et al., 1996; Quaine et al., 2003). Moreover, the interaction between fingers and the hold surface is an important

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determinant of performance, especially on small holds with limited area available for finger placement (Bourne et al., 2011) and/or on sloper holds (i.e. holds with a flat inclined surface relative to the horizontal axis). The rock climbing community has recognized that this finger–hold interaction is highly influenced by transpiration, rock type, ambient temperature, and humidity. To increase the finger–hold friction coefficient, climbers use 'chalk' (mainly, magnesium carbonate or $MgCO_3$) to reduce moisture on the hands.

The skin friction coefficient has been investigated by several studies in both dynamic and static cases (Comaish & Bottoms, 1971; El-Shimi, 1977; Highley et al., 1977; Nacht et al., 1981; Adams et al., 2007; Derler et al., 2007, 2009a, 2009b; Savescu et al., 2008; André et al., 2009). Friction coefficients from different parts of the body were examined parallel to the effects of various probes (nylon, glass, teflon, steel, etc.) and/or conditions (hydration, lubricants, moisturizers, etc). Surprisingly, only one study has been conducted to analyse the effect of chalk on the friction coefficient of finger–rock contact (Li et al., 2001) in which three types of rock (sandstone, slate, and granite) and four different hand conditions (dry, dry plus chalk, wet, and wet plus chalk) were studied. Li et al. (2001) used a specially designed table and followed the 'beginning slip' method to measure the friction coefficient between the finger skin and rock samples. Thus different rock type surfaces were connected to a 3.5-kg load and subjects were asked to apply vertical fingertip forces on these surfaces to prevent slippage followed by reduction of normal force till slip. These authors reported that using chalk reduces the static coefficient of friction, which is in total contradiction with the climbers' belief. However, the design they used was not specific to rock climbing and the resistant force (3.5 kg hanging weight and 29 N tangential forces) was very small compared to real situations in rock climbing where forces could be as large as the body weight. This point is of importance since the skin and the pulp of human fingertips have viscoelastic material properties (Sivamani et al., 2003; Derler et al., 2009a). Depending on the applied load, the fingertips change their form and their characteristics, which directly influence the friction coefficient (André et al., 2009; Derler et al., 2009a; Warman & Ennos, 2009). In spite of the importance of these parameters, no design exists to investigate the finger friction in rock climbing and the precise effects of magnesium carbonate and ambient climate are still unknown.

The objective of this study was to investigate the effect of chalk on the friction coefficient between the climber's fingers and climbing holds. As climbers practice in various climate conditions and on various rock types, the effect of chalk was tested in a wide range of temperature–humidity conditions and on two different rock characteristics. It was hypothesized that, in line with most climbers' perception, chalk would increase the finger–hold friction coefficient.

Methods

Eleven (10 males and 1 female) experienced climbers participated in this study: mass = 73.9 ± 6.3 kg, height = 178.7 ± 4.2 cm, and climbing experience = 9.6 ± 5.0 years. Prior to testing, they were informed about the testing procedure and signed a voluntary participation form according to the University Guidelines. Tests were performed on several different days and conducted outside in a wide range of weather conditions (temperature range: 11.9–28.0°C; relative humidity range: 28.5–75.9%; Table I) in order to incorporate the real weather conditions encountered during sport climbing. Temperature and humidity values were measured at each session by using a digital thermo-hygrometer (Temperature Station, Conrad Electronics, Barking, UK). A total of 42 sessions were recorded (one session is defined as tests for all conditions of chalk and rock type for a subject).

Experimental protocol

A specially designed hang board, consisting of a wooden plate hinged on a fixed frame and a fastened wooden step bar, was designed and used in this study (Figure 1). Two pairs of handholds (5.5 cm depth and 10.5 cm width) with flat surfaces were fixed on the wooden step bar about shoulder width apart. The holds were issue from the Mediterranean coast and they were representative of sandstone and limestone rock types. The hang board was articulated on its base in order to gradually change the angle of the holds using a pulley rope system.

Participants hung from the same pair of holds with straight arms as their natural position. They hung with only their four fingers (slope grip technique); the thumb was not used to apply a counter force. The inclination of the hang board was then increased continuously with a mean speed of 8.0 $\pm$ 4.0 deg/s until the subjects slipped from the holds. During this process participants were asked to hang on the holds as they do during rock climbing. They were required to maintain arm and body positions. This was controlled visually and trials were repeated if participants changed the test position. When they slipped from the hold, a short rest was given before they continued with the next tests and conditions. When participants released the hold voluntarily before the involuntary slip point the data were ignored and the trial was repeated. Participants were allowed to practice several times until they were accustomed with the task and the test design. Sandstone and limestone were tested and three trials were done for each rock type and chalk conditions (with and without chalk). The sequence of hold types and chalk conditions was randomized for each experimental session. Chalk was used by subjects as it is a common practice in climbing; by utilizing a

Table I. Temperature and humidity data ($N = 42$).

	Temperature (°C)	% Humidity
Mean	18.7	47.9
Standard deviation	5.1	11.5
Minimum	11.9	28.5
Maximum	28.0	75.9

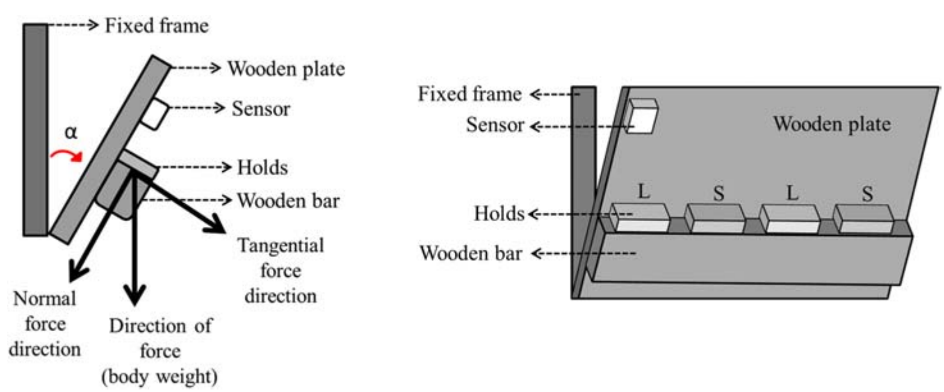

Figure 1. Side and front view of the designed hang board. A wooden bar screwed on the wooden plate and two pairs of sandstone (S) and limestone (L) handholds with flat surfaces were fixed on this wooden bar about shoulder width apart. Angle of the hang board was progressively increased until the climbers slipped from the holds.

chalk bag. Holds were cleaned with a brush after each session. Furthermore, the subjects' hands were cleaned with water and dried with a towel followed by shaking hands in the air before each test without chalk. A gyroscopic sensor (Animazoo IGS-190, Brighton, UK) was fixed on the moving plate to measure the angle of the hang board. The gyroscopic sensor was calibrated as zero for the starting vertical position, and angular displacement data were recorded with Animaview software (Animazoo) at a sample rate of 60 Hz.

Data analysis

The slip angle was determined by processing the recorded angle data for each trial (Figure 2). The coefficient of friction was defined as the ratio between tangential force and normal force at the moment of slip (i.e. the tangent of slip angle; Sivamani et al., 2003). The results of each trial were analyzed individually in order to determine the coefficient of friction. All computation procedures were performed in MATLAB (The Math Works, Inc., Natick, MA, USA).

Statistics

The average value of the three trials of a subject in a condition was considered for statistical analysis. All results were reported as means and standard deviations. Normality of the collected data was verified. A two-way repeated measures ANOVA was used to analyse the effect of *hold type* and *chalk condition* on maximal slip angle. A Tukey post hoc test was used to identify differences when ANOVA showed a significant effect ($p < 0.05$). A multiple regression model was used to analyse the relationship between the temperature, humidity, and the friction coefficient for each condition (*hold type* and *chalk condition*). Statistical analyses were performed using Statistica (StatSoft, Inc., Tulsa, Oklahoma, USA).

Results

In all the measurements, the coefficient of friction ranged from 0.47 to 1.14 (Figure 3). The mean coefficients of friction value on limestone were 0.64 ± 0.10 without chalk and 0.76 ± 0.09 with chalk. The sandstone coefficients were 0.74 ± 0.10 and 0.90 ± 0.10, respectively. There was a significant effect of chalk on the coefficient of friction ($F_{1,41} = 85.2$; $p < 0.001$). The positive effect of chalk was 18.7% and 21.6% for limestone and sandstone, respectively. The coefficient of friction also differed significantly according to the hold type ($F_{1,41} = 447.5$; $p < 0.001$). The mean coefficient of friction increased by 15.6% without

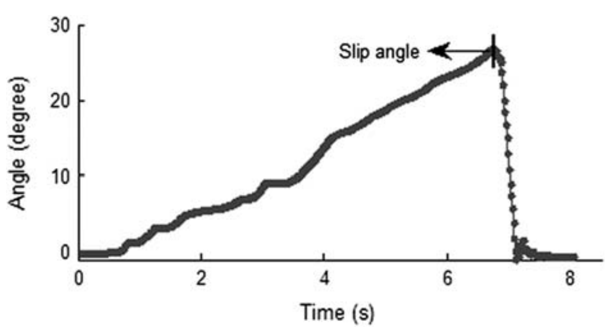

Figure 2. Typical recording of the angle data for one representative test. Slip angle was determined as the maximum angle of the trial.

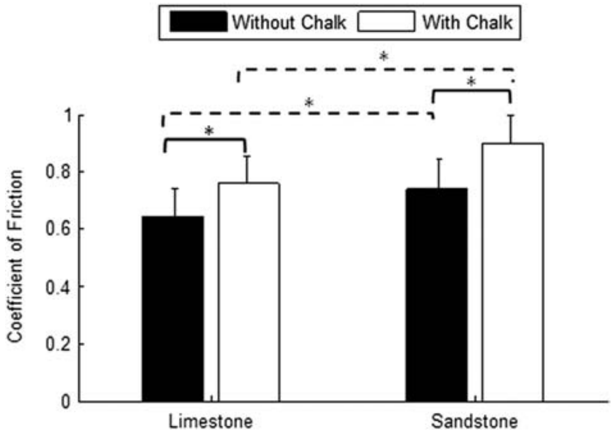

Figure 3. Mean coefficient of friction values and standard deviations for both rock and chalk conditions.

chalk and 18.4% with chalk between limestone and sandstone. Also a significant interaction between *hold type* and *chalk condition* was found ($F_{1,41} = 20.6$; $p < 0.001$).

The multiple regression models showed no significant correlation between humidity, temperature and friction coefficient ($p > 0.05$ and $r^2 < 0.3$).

Discussion

The aim of this study was to examine the effect of chalk on the friction coefficient between climber's fingers and two commonly encountered rock types during rock climbing. In addition, various temperature and humidity conditions were investigated to observe their combined effects on the friction coefficient. In this study, a new experimental design was proposed to measure the friction coefficient of the fingers as encountered during rock climbing. This design was close to the real rock climbing conditions and it enabled us to measure the friction coefficient of hold–fingers contact under loads resulting from full body weight.

The main result of our study indicated that there was a significant positive effect of chalk on the friction coefficient for both rock types. This result was in contradiction with the previous results of Li et al. (2001) which might have been caused by the used load intensity. Li et al. (2001) used a constant tangential force around 29 N and participants applied normal forces around 12 N at the moment of slip, while in the present study the contact forces corresponded to the participants' body weights (725.3 ± 62.2 N). The influence of the normal force on the friction coefficient of skin has been studied by several authors (Comaish & Bottoms, 1971; Savescu et al., 2008; Warman & Ennos, 2009). These studies have shown that the friction coefficient is not constant for fingertips and is modified according to the applied normal force. This result has also been confirmed for different body parts by several subsequent studies (El-Shimi, 1977; Derler et al., 2007; André et al., 2009). Derler et al. (2009b) concluded that the friction coefficient of bare foot skin systematically decreased with the normal load applied onto the foot (in the range from 50 to 700 N). This behavior of skin results from its viscoelastic nature and that the actual contact area changes as a function of normal load (Derler et al., 2009a; Warman & Ennos, 2009). All these results confirm the importance of studying the friction coefficient of fingers under force intensities equivalent to those encountered during rock climbing and explain the differences between conclusions of the present study and Li et al. (2001). Moreover, the granular layer effect hypothesized by

Li et al. (2001) is probably cancelled out by the force intensities encountered during rock climbing.

While it was shown that the hold–finger contact was improved by chalk, the present study did not aim to investigate the actual factors which led to these results. Better performance observed with chalk can be explained by several possible reasons: modifications of the skin roughness, modification of skin elasticity which enables the fingers to best adapt to the hold shape and changes in water/sudation elimination behavior. Climbers indeed recognize that chalk eliminates perspiration and keeps the hands dry. Thus this effect is fundamental to explaining our results. However, in the literature, it was shown that highly wet or highly dry skin showed relatively low friction (Highley et al., 1977; Dawson, 1997; Derler et al., 2007; André et al., 2009). Therefore an optimal use of the chalk is important in order to keep the hand in the ideal moisture range.

The rock type effect was also shown in the present study. In accordance with the climbers' testimonies, it was found that sandstone displayed a higher friction coefficient than limestone. Also, no cross interaction between rock types and chalk usage was observed; chalk had a positive effect for both rock types. It appeared that the higher friction coefficient on sandstone was due to the rougher contact surface compared with limestone. This result was in accordance with Li et al. (2001) who concluded that sandstone produced a higher coefficient of friction than granite and slate. They found that the normalized performance of granite and slate was 0.77 and 0.76, respectively, compared with the performance of sandstone. Granite and slate were not studied in the current study, but the normalized limestone performance (0.86) indicated that limestone might have a higher coefficient of friction than slate and granite. Further studies are required to clarify this result and investigate the coefficient of friction on other rock types.

The positive effect of chalk and the influence of rock type were verified for a wide range of outdoor climate conditions. While the correlation among air temperature, humidity, and friction was investigated, no evidence of linear relationships was found. Absence of significant correlation could be due to the fact that extremely low or high temperature and humidity values were not assessed. Moreover, these parameters could not be controlled independently since the tests were conducted outdoors. The effects of these parameters could be further investigated by controlling them independently in a climate-controlled room. In addition, the temperature and humidity of rock and/or skin also need to be controlled in future studies. As mentioned by Tang and Bhushan (2010), temperature and humidity conditions affect the water in the skin, which leads to changes of the tribological and mechanical properties of the skin surface. Thus, the effects of temperature and humidity on the friction properties of finger skin need to be studied in detail to determine optimum performance conditions.

In summary, this study is the first to demonstrate the positive effect of chalk for rock climbing, but some limitations need to be considered: the most important of which concerns the angular speed of the hang board which varied between trials. Since a large number of trials were tested randomly it was expected that the different velocities were homogenously distributed across the conditions and this limit did not affect the conclusions of the study. The angular speed, however, needs to be controlled in further studies. Another limitation concerns psychological bias: the participants knew when magnesium chalk was used. Magnesium chalk has a specific color (white) and a specific consistency which makes a blind test difficult to perform. Another important point concerns the mechanical characteristics (rough, polished) and elasticity (compliance) of the climbers' skin which were shown to be modified with practice and expertise. These characteristics could change over time and vary from one individual to another, no attempt was made to control them. It is important to further investigate the influence of skin characteristics and to determine how the climbers should prepare their skin to obtain optimal characteristics.

References

Adams, M. J., Briscoe, B. J., & Johnson, S. A. (2007). Friction and lubrication of human skin. *Tribology Letters*, *26*, 239–253.

André, T., Lefevre, P., & Thonnard, J. -L. (2009). A continuous measure of fingertip friction during precision grip. *Journal of Neuroscience Methods*, *179*, 224–229.

Bourne, R., Halaki, M., Vanwanseele, B., & Clarke, J. (2011). Measuring lifting forces in rock climbing: Effect of hold size and fingertip structure. *Journal of Applied Biomechanics*, *27*, 40–46.

Comaish, S., & Bottoms, E. (1971). The skin and friction: Deviations from Amonton's laws, and the effects of hydration and lubrication. *British Journal of Dermatology*, *84*, 37–43.

Dawson, D. (1997). Tribology and the skin surface. In K. -P. Wilhelm, P. Elsner, E. Berardesca, and H. Maibach (Eds.), *Bioengineering of the skin: Skin surface imaging and analysis* (pp. 159–179). Boca Raton, FL: CRC Press.

Derler, S., Gerhardt, L. -C., Lenz, A., Bertaux, E., & Hadad, M. (2009a). Friction of human skin against smooth and rough glass as a function of the contact pressure. *Tribology International*, *42*, 1565–1574.

Derler, S., Huber, R., Feuz, H. P., & Hadad, M. (2009b). Influence of surface microstructure on the sliding friction of plantar skin against hard substrates. *Wear*, *267*, 1281–1288.

Derler, S., Schrade, U., & Gerhardt, L. C. (2007). Tribology of human skin and mechanical skin equivalents in contact with textiles. *Wear*, *263*, 1112–1116.

El-Shimi, A. F. (1977). *In vivo* skin friction measurements. *Journal of the Society of Cosmetic Chemists*, *28*, 37–51.

Grant, S., Hynes, V., Whittaker, A., & Aitchison, T. (1996). Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. *Journal of Sports Sciences*, *14*, 301–309.

Highley, D. R., Coomey, M., DenBeste, M., & Wolfram, L. J. (1977). Frictional properties of skin. *The Journal of Investigative Dermatology*, *69*, 303–305.

Li, F. -X., Margetts, S., & Fowler, I. (2001). Use of chalk in rock climbing: Sine qua non or myth? *Journal of Sports Sciences*, *19*, 427–432.

Nacht, S., Close, J., Yeung, D., & Gans, E. H. (1981). Skin friction coefficient: Changes induced by skin hydration and emollient application and correlation with perceived skin feel. *Journal of the Society of Cosmetic Chemists*, *32*, 55–65.

Quaine, F., Vigouroux, L., & Martin, L. (2003). Finger flexors fatigue in trained rock climbers and untrained sedentary subjects. *International Journal of Sports Medicine*, *24*, 424–427.

Savescu, A. V., Latash, M. L., & Zatsiorsky, V. M. (2008). A technique to determine friction at the finger tips. *Journal of Applied Biomechanics*, *24*, 43–50.

Sivamani, R. K., Goodman, J., Gitis, N., & Maibach, H. I. (2003). Coefficient of friction: Tribological studies in man—an overview. *Skin Research and Technology*, *9*, 227–234.

Tang, W., & Bhushan, B. (2010). Adhesion, friction and wear characterization of skin and skin cream using atomic force microscope. *Colloids and Surfaces B: Biointerfaces*, *76*, 1–15.

Warman, P. H., & Ennos, A. R. (2009). Fingerprints are unlikely to increase the friction of primate fingerpads. *The Journal of Experimental Biology*, *212*, 2016–2022.

Watts, P. B., Daggett, M., Gallagher, P., & Wilkins, B. (2000). Metabolic response during sport rock climbing and the effects of active versus passive recovery. *International Journal of Sport Medicine*, *21*, 185–190.