Measurement of the coefficient of friction and the centre of pressure of a curved surface of a climbing handhold

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Abstract

A smart climbing hold with variable inclination of the grip surface was developed, instrumented with two triaxial force transducers. The inclination of the cylindrical grip surface was varied by adding 10 mm panels to the wall, thereby confining the surface to larger inclinations. The difficulty of gripping the hold with variable surface inclination was reflected in the vertical and horizontal forces, which decreased as the inclination increased, and in the increasing angle of the average force vector.

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1. Introduction

Instrumentation of climbing holds is a standard method for evaluating and analysing performance parameters of climbing [1-8] and the experience of a climber [1, 3, 5]. Very few studies attempted to quantify the difficulty of gripping a hold [3, 4]. Fuss and Niegl used fractal dimensions of the force signals for measuring the grip difficulty, by comparing standard artificial holds [3], and by inclining an experimental hold [4]. In the latter experiment, the hold was mounted on a bouldering wall and the grip surface of the hold was tilted by inclining the wall gradually from 10 to 50 degrees. However, inclining the wall does not only change the grip difficulty of a hold but also affects the statics and dynamics of the move [4, 9].

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The aim of this study was to establish a method for increasing the difficulty of gripping a climbing hold by changing the inclination of its surface without having to tilt the wall, and for determining the centre of pressure and the coefficient of friction on a curved handhold surface.

Fig. 1. (a) Experimental hold instrumented with two triaxial force transducers; the cylindrical grip surface of the hold is confined to larger inclinations by adding wooden panels (1-5) to the wall; (b) climbing route; L / R: holds for left / right hands.

2. Experimental procedure

A handhold with a cylindrical grip surface (quarter cylinder; Figure 1(a)) and housing for two force transducers was designed in SolidWorks 2008 SP5.0 (Dassault Systèmes, Waltham MA, USA) and CNC machined from Ureal (Renshape BM 5460, Huntsman Advanced Materials, Everberg, Belgium). The hold was instrumented with two triaxial force transducers (9317B, Kistler, Winterthur, Switzerland). The extent of the hold’s grip surface was confined to larger inclinations by 10 mm thick wooden panels (Figure 1(a)). The more wooden panels attached to the wall, the more inclined is the surface, and thus the more difficult it is to keep a firm grip. The number of wooden panels therefore represents the increasing difficulty of moving up the wall. The instrumented hold was integrated in a climbing route shown in Figure 1(b). The charge of the piezoelectric force transducers was converted to voltage and amplified with three charge meters (5015A, Kistler, Winterthur, Switzerland) by combining the x-channels of the two transducers in line with the vertical direction (corresponding to the downward force in y-direction of the handhold’s coordinate system; Figure 1(a)) in a single channel in addition to two individual channels of the transducers’ z-channels (corresponding to the forces perpendicular to the wall). The data were sampled at 2 kHz, converted from analog to digital with a four channel USB DAQ module (USB-2404-10, Measurement Computing, Norton MA, USA; minimum data sampling frequency 1.8 kHz) and recorded with TracerDAQ Pro (Measurement Computing, Norton MA, USA).
The position of the centre of pressure (COP) on the cylindrical surface of the hold was calculated from the moment equilibrium and the equation of a circle. Due to the second order nature of the latter, two COPs resulted in x-direction, each of which had two associated y-coordinates. The right y-coordinates were determined from satisfying the moment equilibrium. The decision making for finding the right COP location was based on the following boundary conditions: the x-coordinate of the COP (COPx) must be real, and the COP must be located in the 2nd quadrant of the coordinate system (negative x- and positive y-coordinate). The coefficient of friction (COF) was calculated from the ratio of tangential to normal force components at each instantaneous COP. It has to be noted that the term COF refers merely to the force ratio and not to static or dynamic friction coefficients. Mean and standard deviation of COPx and COF were calculated from weighting them to the resultant reaction force at each instantaneous COP.

An experienced female mountaineer (red point UIAA VIII-, onsight UIAA VII) climbed the route 18 times, three times per panel number, the latter ranging from zero to five (Figure 1(a)). Grip-enhancing agents (e.g. chalk / MgCO₃) were not used in these experiments.

Fig. 2. Coefficient of friction (COF) against x-coordinate of the centre of pressure (COPx); (a): map of data distribution (0-5: number of wooden panels used for confining the surface of the hold); (b): mean values (black dots) and standard deviations of COPx and COF (the rectangles correspond to the boundaries of mean ± 1 standard deviation).

3. Results

The location of COPx against the COF is shown in Figure 2. The general trend matches the expected result: the further COPx off the wall, the higher is the COF (due to increasing inclination of the hold’s curved surface). However, when using all five wooden panels for confining the surface, the COF decreases instead of increasing. The COPx and COF average values are all significantly different, even the COF data at two and three panels (0.6628 ± 0.0805 and 0.6681 ± 0.0836, respectively), which is due to the large number of data per experiment (6300 - 7800).

The average resultant force of the three trials per panel decreased with the increasing inclination of the surface at the COP (Figure 3). The angle of the average resultant force vector at panels no. 4 and 5 was larger than 90 degrees, indicating the climber pushed slightly in the direction of the wall rather than
pulling on the hold as seen in the other four force vectors. The magnitude of the average resultant force correlated well with its position angle ($r^2 = 0.993$, parabolic fit; Figure 4b). In addition to that, the surface gradient at the average COP correlated linearly with the position angle of the average resultant force ($r^2 = 0.989$) and parabolically with the magnitude of the average resultant force ($r^2 = 0.994$).

![Figure 3](image.png)

Fig. 3. Average resultant forces; a: force vector diagram on hold surface, average resultant force vectors at different numbers of wooden panels confining the grip surface of the hold (0-5); b: magnitude of average resultant against angle of average resultant.

4. Discussion

The purpose of this study was to establish a method of measuring the difficulty of gripping a hold with variable surface inclinations without having to tilt the wall. The results presented in this study are based on a single climber only in order to evaluate and define the parameters representing the difficulty of the grip, before applying them to a larger cohort of test persons. The most apparent difficulty parameters turned out to be the average resultant force, and the position angle of the average resultant force. The climber reduced both the vertical (downward) as well as the horizontal (outward, off the wall) load on the hold with increasing inclination of the grip surface. Surprisingly, the COF did not serve for quantifying the grip difficulty, at least not in the climber examined, as the COF decreased from the second highest to maximal inclination of the grip surface, in contrast to the result of previous studies [4]. Further experiments are required to confirm this result.

5. Conclusions

The difficulty of gripping a climbing hold with variable surface inclination was reflected in the vertical and horizontal forces, which decreased as the inclination increased, and in the increasing angle of the average force vector.
References


