Measuring fluidity in climbing

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Experts in motor tasks as diverse as sports, music, and surgery produce rapid, smooth, precise movements that appear almost effortless. Skilled climbers are no exception; they ascend smoothly (without excessively jerky movement) and are able to link together different sections of a climb without unnecessary stoppages (Seifert et al., 2014). Quantifying the spatio-temporal path of the climber over time allows us to assess learning and compare climbers of different skill.

The fluency of a curve can be assessed using a ratio of the path length relative to the size of the shape that encapsulates the path, which is often measured as geometric entropy (Cordier, Mendes France, Pailhous, & Bolon, 1994). The entropy of a system is a measure of the amount of order vs. chaos of that system; the higher the entropy, the higher the disorder of the system. The geometric entropy is computed by taking the natural logarithm of two times the length of the pattern travelled by the body centre of mass divided by the perimeter of the convex hull around that path (Cordier et al., 1994). A low entropy value is associated with low energy expenditure and probably with a more effective route finding skill (Cordier et al., 1994).

However, this approach has certain limitations: 1) calculations based on the path of body don't consider the way that the path was achieved – i.e. how displacement varied over time. Lots of small oscillations could create the same path length as a fewer number of larger oscillations. And, if I climber stops during the ascent, the reason for the stoppage is unknown. Stopping to decide upon the route is indistinguishable from rests due to fatigue; 2) it assumes best route is linear, and if the climb includes traverses and vertical parts the convex hull wraps the perimeter of the path (Figure 3); 3) the path is usually defined by the pelvis because it's easier to track than the centre of mass. A single marker can be placed on the sacrum and tracked with a camera facing the wall. Calculation of the centre of mass requires tracking of each body segment, knowledge of the moment of inertia (mass and radius of gyration). The difference between the centre of mass (CoM) and a single point on the pelvis (the mid-point between the Posterior Superior Iliac Spines; mPSIS) can be seen in Figure 1. The offset between the mPSIS and CoM were adjusted to start at the same point.

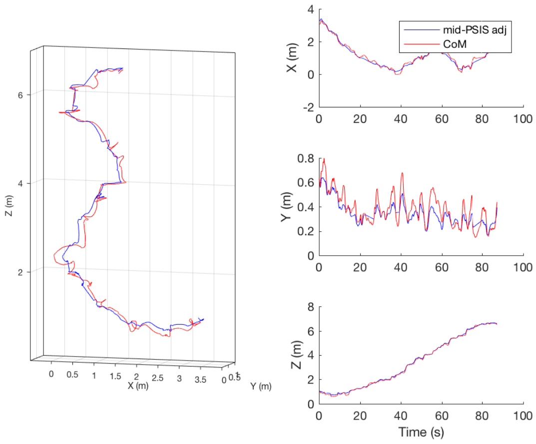

Figure 1: Left - Path of centre of mass (red) and a single point of the pelvis (mid Posterior Superior Iliac Spine; blue) during a climb. Right – Difference between the centre of mass and the pelvis in each direction.

Some of these problems can be overcome. If the route includes changes of direction, such as traverses and vertical sections, the route can be divided into subsections so that the convex hull encapsulates a subsection of the path. Figure 2 shows an example of two ascents up such a route and the division into subsections.

An alternative (or additional) solution is to change the way in which the boundary is calculated. Traditionally a convex hull - the smallest convex region enclosing all points in the set – has been used, but we can also create a boundary of a set of points (i.e. a path) that is nonconvex. If you allow concave vertices the boundary looks like it's been "vacuum packed", Figure 3. This could create a more realistic boundary around a smooth path that is required in sections of a route that requires a non-linear path.

Temporal measures

The temporal dynamics of the path can be quantified by the percentage of time in motion (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Seifert et al., 2014). However, this fails for the same reason as discussed above - if I climber stops during the ascent, the reason for the stoppage is unknown when only the pelvis or CoM are considered. Additional parameters such as limb actions must be considered (Boulanger, Seifert, Herault, & Coeurjolly, 2016; Pijpers, Oudejans, Bakker, & Beek, 2006; Seifert et al., 2018).

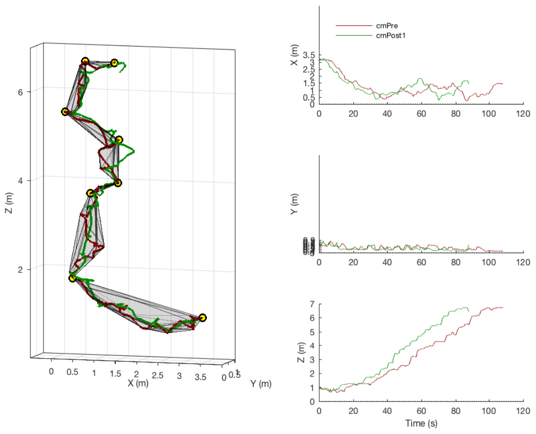

Figure 2: : Left – Path of centre of mass during two ascents (red-unfatigued; green-fatigued). The route is divided into sections based on spatial characteristics of the route. The start/end of each section is indicated by the yellow circle. The grey area is the convex hull for that section. Right – centre of mass position in each direction.

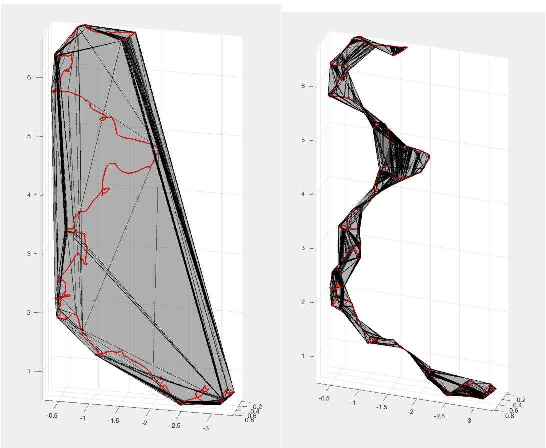

Figure 3: Left - convex hull. Right - "shrink-wrapped" boundary.

Spatiotemporal measures

Various derivatives of displacement have been used to quantify the spatiotemporal dynamics of the climber: the absolute velocity (the magnitude of the velocity vector), absolute acceleration, and jerk (the derivative of acceleration) (Seifert et al., 2014). Mathematical models of reaching movements suggest that jerk indicates the smoothness of a trajectory and are supported by experimental studies. The hypothesis that jerk is minimized has been investigated in a variety of tasks including pointing, reaching and throwing. In climbing, jerkiness of the hip (in translation and rotation) has been evaluated over a whole climb and shows that fluency improves over repeated trials.

In addition to simple derivatives, the path of the hip has also been analysed using various signal processing methods. Any variable that varies over time has a corresponding frequency spectrum that can be calculated through Fourier analysis. In our case we are interested in the displacement of the climber, or some derivative of the displacement. It's common to analyse the power of the frequency spectrum as a function of frequency – the power spectral density (see Figure 4).

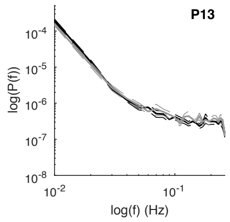

Figure 4: Power of each frequency during two climbs for a single climber

The problem with calculating the power spectral density (PSD) over the whole trial is that any differences that occur in certain sections of the climb are overlooked. For example, if the climber oscillates at a different frequency at the crux than during the rest of the climb, this won't be visible in the PSD. One solution is to calculate the frequency component in windows. In a repeatable signal such as walking this can be done easily with consistent window sizes throughout the trial. However, during a climb the rate of movement can be inconsistent, e.g. 50% of the climb duration may correspond to 50% of the distance on one trial but 60% on the next. Consequently if we want to understand how the movement is related to sections of the climb, the windows need to be defined from spatial measures rather than temporal measures. Figure 5 shows the PSD for two trials in each of the sections defined as in Figure 2.

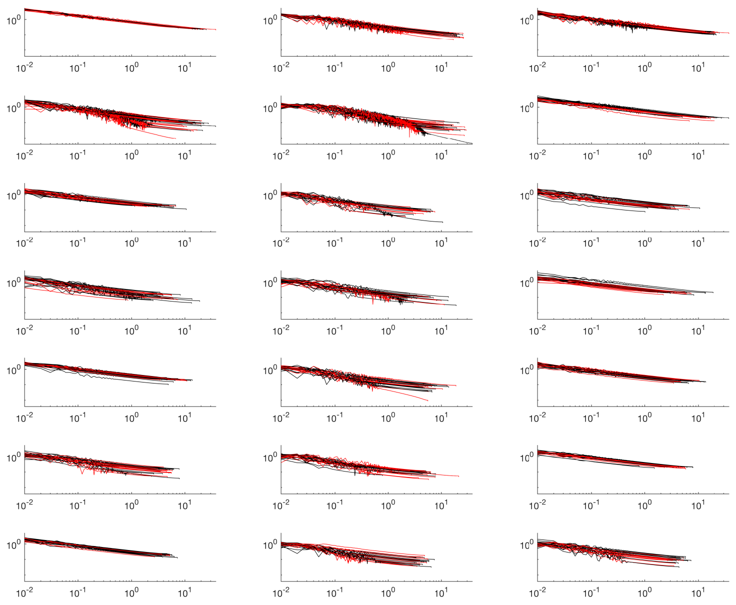

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Figure 5: Power of each frequency in each of the sections (rows) in each plane of movement (columns)

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