Supplementary Information for

Human locomotion over obstacles reveals real-time prediction of energy expenditure for optimised decision-making

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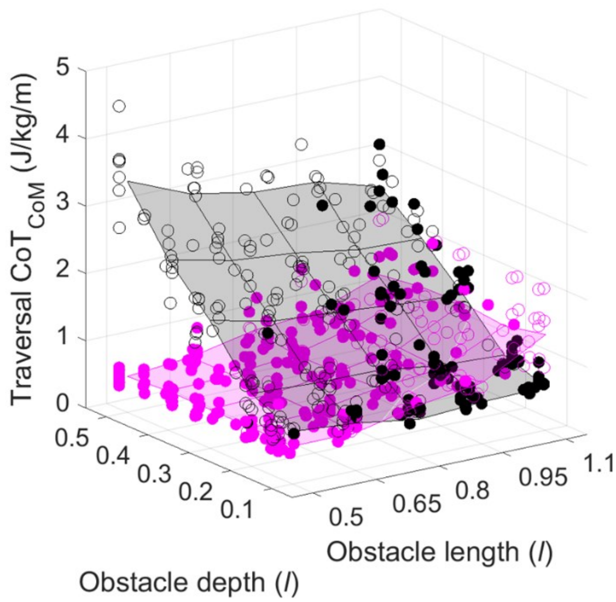

Fig. S1. Centre of mass mechanical cost of transport (CoT_{CoM}) for the complete obstacle traversal task, displayed for OVER strategy traversals (pink) and IN strategy traversals (dark grey). Obstacle length and depth reported as proportion of participant leg length (*l*). Circles show values for freely-selected IN strategy trials (●), freely-selected OVER strategy trials (●), non-preferred IN strategy trials (○) and non-preferred OVER strategy trials (○).

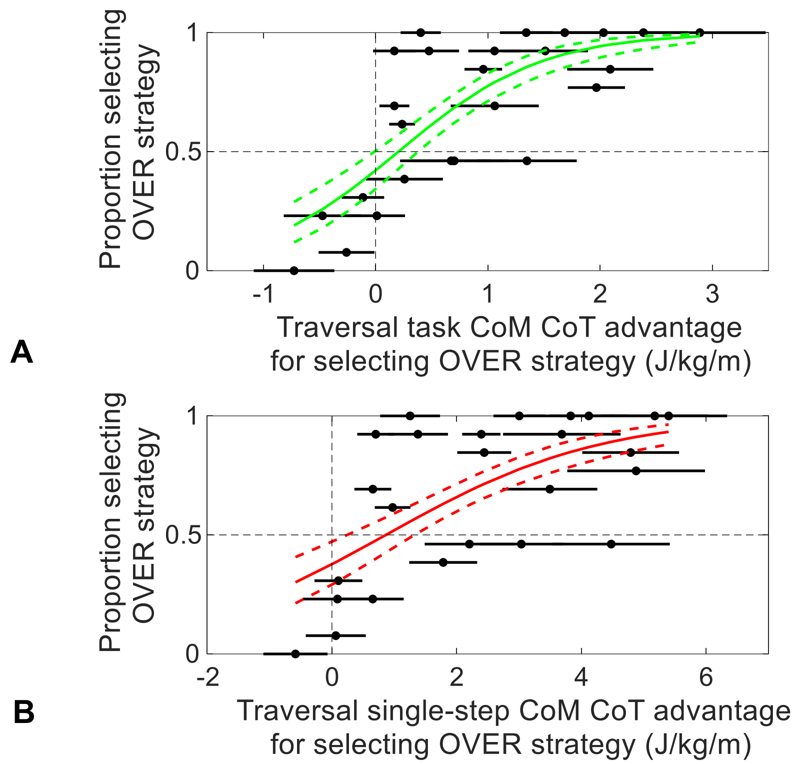

Fig. S2. Relationship between obstacle traversal strategy relative cost and selection probability, based on objective functions (A) minimisation of task-level CoT_{CoM}, (B) minimisation of step-level CoT_{CoM}. Solid lines represent fitted logistic curves and dotted lines the corresponding 95% confidence interval. Each point (with associated horizontal bars) represents the mean ± SD difference in the outcome variable between the two traversal strategies for a single obstacle length-depth combination. The vertical dashed line at x = 0 indicates equal cost for IN and OVER strategy traversals: points to the left of this line represent lower cost for IN and points to the right of this line represent lower cost for OVER. The point of subjective equality (equal likelihood of selecting the IN and the OVER strategy) is marked by a horizontal line at y=0.5.

Supplementary Methods

Estimating metabolic cost of transport from published empirical data

The metabolic cost of transport for each of the two strategies (OVER and IN) was estimated based on the data presented in and Bertram (2005) and Nagle et al. (1965), respectively. Specifically:

Cost estimation for OVER strategy obstacle traversals

Estimations for the OVER strategy were based on the results published in Bertram (2005). This paper reports the measured metabolic cost of continuous walking at a range of experimentally imposed speed-frequency combinations in a cohort of healthy adult participants. To use these data to estimate the metabolic cost of stepping over a hole obstacle, we made the following assumptions regarding the behaviour of our participants during the experimental trials:

1. Participants would achieve a normal walking speed on the raised trackway during the approach to the obstacle.
2. Participants would cross the obstacle by maintaining or increasing their step length while maintaining walking speed. The minimum step length required to step over an obstacle of given length comprises the sum of the length of the obstacle and the length of the foot, minus a permitted foot 'overhang' distance to allow for the fact that the entire foot does not need to be supported by the trackway during the adaptive step (e.g. Elliott et al. 2015).

Assumptions were verified using the kinematic data collected. Dimensionless approach speed was 0.45±0.05, equivalent to a mean approach speed of 1.33 m/s and comparable to normal overground walking (Jordan et al., 2007). The mean measured offset (landing foot length supported by the trackway during the crossing step) was 0.13 m.

The step length associated with each step frequency-speed combination with metabolic cost data reported in Bertram (2005) was calculated, and translated to an *equivalent obstacle length* (i.e. the maximum obstacle length that could be successfully crossed using that step length):

$$equivalent\ obstacle\ length = step\ length - 0.13 \tag{1}$$

Mean metabolic cost data ($J.kg^{-1}.m^{-1}$) from the closest provided walking speed (1.5 m/s) was used to estimate metabolic cost of transport for the full range of step lengths tested experimentally (1.13 m, 0.88 m , 0.71 m, 0.62 m, 0.56 m, 0.51 m; calculated from reported speed and step frequency in Bertram 2005 Table 2) and were translated to equivalent obstacle lengths using Equation 1 above. These values were used to estimate the metabolic cost of transport for each equivalent obstacle length. For equivalent obstacle lengths lower than normal walking step length, it was assumed that participants would not *reduce* their step length to step over a narrow obstacle so the cost of transport for normal walking at this speed was used as the estimate for the crossing.

Cost estimation for IN strategy obstacle traversals

Estimations for the IN strategy were calculated from the results and empirical equations published in Nagle et al. (1965). This paper reports the oxygen consumption of healthy adult participants repeatedly stepping up to and (separately) down from an adjustable-height raised platform, across a range of platform heights and imposed step frequencies. The cost of each IN obstacle crossing was modelled as

$$\frac{energy\ expenditure\ for\ stepping\ down + energy\ expenditure\ for\ stepping\ up}{crossing\ length} \tag{2}$$

Predicted oxygen consumption was calculated using the equation on p.747 of Nagle et al. (1965). The step frequency used in the calculation was that freely selected for a walking speed of 1.5 m/s (a comfortable walking speed) in Bertram (2005), to correspond to the speed used in the OVER strategy estimation described in the preceding section. Predicted oxygen consumption values were lastly converted to $J.kg.m^{-1}$ by assuming 20.1 J released per mL O_2.

The calculated metabolic cost of transport estimations for both IN and OVER strategy obstacle traversals are shown in Figure 2A in the main manuscript text. It should be noted that these are estimations only, intended to demonstrate the likely existence of an intersection in the metabolic cost planes for the two strategies within the range of obstacle geometries that can be traversed by humans using both strategies rather than aiming to fully account for the metabolic cost of each strategy in detail.

Gait event detection

The start and end of stance phase were identified automatically, using identical thresholds for all participants. The start of stance phase was defined as the first frame in which the horizontal velocity of the Toe marker decreased below 0.004 m/s and either the downwards vertical velocity of the Toe marker decreased below 0.005 m/s or the downwards vertical velocity of the Ankle marker decreased below 0.002 m/s. The end of stance phase was defined as the last frame before the horizontal velocity of the Toe marker next increased above 0.004 m/s. These thresholds enabled the starts and ends of stance phases of both normal walking gait and obstacle traversal steps to be identified to within 3 frames (±0.025 s) of the visually-identified start and end frames (the first and last frames in which the foot was in contact with the ground). All detected gait events were validated by visual inspection.

References

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