RELIABILITY AND VALIDITY OF NOVEL METHODS IN THE ASSESSMENT OF COLD-INDUCED SHIVERING.

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INTRODUCTION

CONTEXT: Shivering defined as the 'simultaneous asynchronous contraction of the muscle fibres in both flexor and extensor muscles' [1].

Both the onset and magnitude of shivering are influenced by corresponding reductions in skin or deep-body temperature, but also a range of non-thermal factors [2-3].

Despite various forms shivering quantification in research and practice, a direct comparison between metrics has yet to be performed, specifically in quantifying shivering onset.

AIM: The purpose of this methodological study was twofold:

1. To compare the test-retest reliability of four independent metrics for the assessment of shivering onset; whole-body oxygen uptake ($\dot{V}O_2$), electromyography (**EMG**), mechanomyography (**MMG**) and bedside shivering assessment scale (**BSAS**).
2. To compare the validity across metrics as appropriate methodological tools for shivering research.

METHODOLOGY

PARTICIPANTS: Ten healthy volunteers (age, 23 ± 3 yrs; stature, 1.75 ± 0.07 m; mass, 71.1 ± 11.5 kg).

DESIGN: Repeated measures design, visiting the laboratory on three occasions, undertaking identical sessions (*Fig 1*). Prior to cold exposure, participants remained seated in a thermoneutral environment (21°C) for 20 mins allowing skin temperature to stabilise.

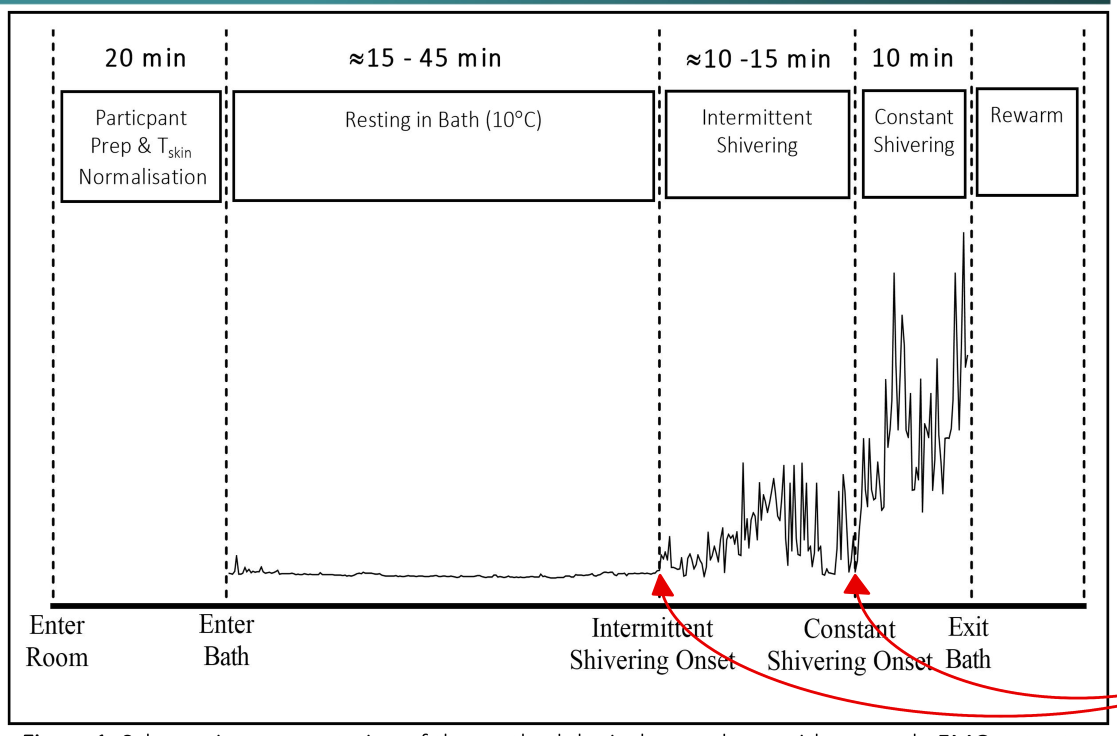

Figure 1: Schematic representation of the methodological procedures with a sample EMG output.

COOLING STIMULUS: Passive cooling via lower body cold-water immersion at 10 ± 0.4°C, with an industrial fan placed 1.5 m away to encourage convective cooling of the upper body (T_a, 21.2 ± 1.2°C; air velocity, 3.5 ± 0.18 m·s)*(Fig 2)* whilst avoiding immersion of equipment.

Participants remained in the bath until 10 mins after they were deemed to be maximally whole-body shivering.

Figure 2: Methodological set-up to induce deep-body cooling.

ASSESSMENT OF SHIVERING:

VO_2 – continuous breath-by-breath via metabolic cart.

EMG – wireless surface EMG (right pectoralis major, posterior deltoid, trapezius). Sampled at 1000 Hz and the signal rectified.

MMG – tri-axial accelerometer, 30 x 20 x 10 mm; 13 g (right pectoralis major). Movement axes was sampled at 1000 Hz and collated by square rooting the sum of squares.

BSAS – subjective stages; *1.* minor localised shivering-related muscular twitches, *2.* noticeable intermittent burst shivering of the extremities, *3.* generalised sustained whole-body shivering.

DATA ANALYSIS: All data sub-sampled into 10 s average time blocks and graphed as a function time to synchronise sampling rates.

Intermittent shivering onset was defined via visual identification of the inflection point, by a secondary inflection point for constant shivering.

Inflection points independently established by three researchers and the median was used. The corresponding time elapsed (relative to entry into the bath), and T_{rec} was noted.

RESULTS

RELIABILITY:

Table 1: Test-retest reliability of four independent metrics for the assessment of shivering onset during lower-body cold water immersion.

	TRIAL 1	TRIAL 2	TRIAL 3	MEAN DIFF	MEAN CV (%)	ICC
			ONSET TIME (S)			
$\dot{V}O_2$						
- *Intermittent*	2210 ± 622	2057 ± 560	2120 ± 741	360 ± 168	13.7 ± 5.5	0.90 [0.70 – 0.98]
- *Constant*	2500 ± 679	2516 ± 729	2520 ± 756	344 ± 208	10.8 ± 5.5	0.93 [0.80 – 0.98]
EMG						
- *Intermittent*	2018 ± 700	1957 ± 629	1983 ± 780	378 ± 298	14.4 ± 10.9	0.84 [0.50 – 0.96]
- *Constant*	2363 ± 688	2296 ± 718	2399 ± 830	426 ± 335	13.8 ± 11.0	0.82 [0.41 – 0.96]
MMG						
- *Intermittent*	2191 ± 776	1833 ± 649	1959 ± 798	322 ± 175	12.8 ± 7.9	0.94 [0.81 – 0.99]
- *Constant*	2516 ± 768	2432 ± 856	2363 ± 862	261 ± 232	9.2 ± 8.0	0.96 [0.89 – 0.99]
BSAS						
- *Minor*	1728 ± 785	1689 ± 749	1555 ± 617	335 ± 244	15.1 ± 7.1	0.85 [0.55 – 0.96]
- *Intermittent*	2352 ± 840	2421 ± 1054	2209 ± 845	359 ± 241	12.8 ± 8.4	0.95 [0.86 – 0.99]
- *Constant*	2884 ± 870	2888 ± 1070	2714 ± 948	351 ± 217	10.0 ± 6.7	0.96 [0.89 – 0.99]
			ONSET RECTAL TEMPERATURE (°C)			
$\dot{V}O_2$						
- *Intermittent*	36.94 ± 0.40	36.80 ± 0.51	37.06 ± 0.26	0.31 ± 0.19	0.6 ± 0.4	0.77 [0.27 – 0.95]
- *Constant*	36.83 ± 0.41	36.74 ± 0.56	36.90 ± 0.26	0.27 ± 0.17	0.6 ± 0.4	0.86 [0.56 – 0.97]
EMG						
- *Intermittent*	36.99 ± 0.38	36.87 ± 0.58	37.06 ± 0.22	0.28 ± 0.23	0.6 ± 0.4	0.82 [0.42 – 0.96]
- *Constant*	36.85 ± 0.41	36.74 ± 0.59	36.92 ± 0.22	0.34 ± 0.21	0.7 ± 0.4	0.78 [0.24 – 0.95]
MMG						
- *Intermittent*	36.96 ± 0.41	36.88 ± 0.57	37.06 ± 0.23	0.28 ± 0.18	0.6 ± 0.3	0.86 [0.53 – 0.97]
- *Constant*	36.89 ± 0.43	36.65 ± 0.70	37.01 ± 0.22	0.29 ± 0.25	0.6 ± 0.5	0.84 [0.47 – 0.97]
BSAS						
- *Minor*	37.07 ± 0.38	37.03 ± 0.43	37.15 ± 0.21	0.26 ± 0.12	0.6 ± 0.3	0.83 [0.47 – 0.96]
- *Intermittent*	36.87 ± 0.41	36.79 ± 0.51	36.97 ± 0.24	0.28 ± 0.12	0.6 ± 0.3	0.86 [0.59 – 0.97]
- *Constant*	36.64 ± 0.40	36.63 ± 0.56	36.79 ± 0.21	0.27 ± 0.17	0.6 ± 0.4	0.85 [0.53 – 0.96]

NOTE: ***Intermittent,*** onset of intermittent shivering. ***Constant,*** onset of constant shivering. ***Trial 1,2 & 3***, data are mean ± SD; *n* = 10. ***Mean Diff***, mean ± SD of the within subjects difference across trials, with a root sum of squares applied to ensure positive values. ***Mean CV***, mean ± SD of the within subjects co-efficient of variation across trials. ***ICC***, Intra-class correlation co-efficient across trials with 95% confidence intervals, based on a mean-rating (*k* = 3), absolute-agreement, 2-way mixed-effects model.

VALIDITY:

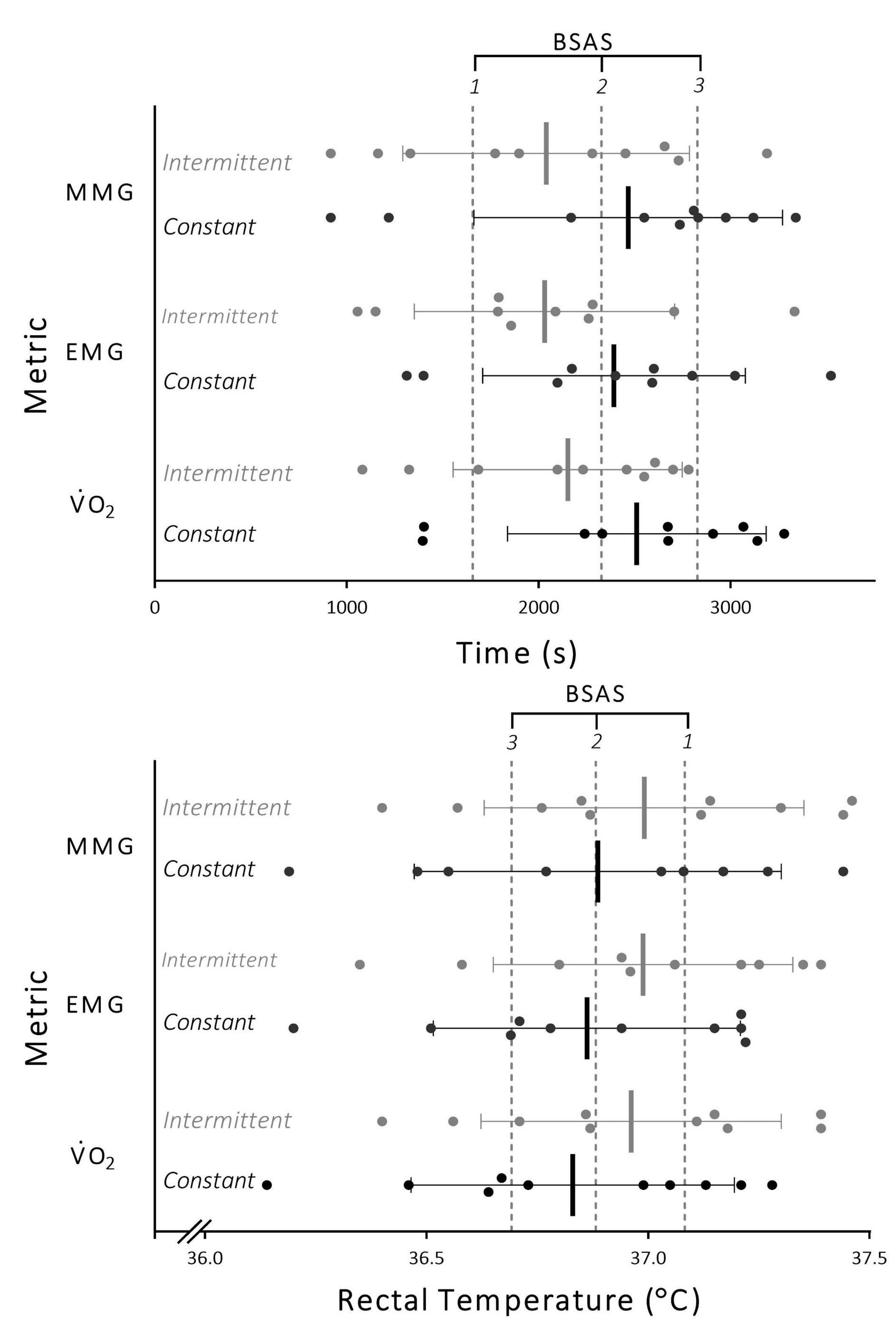

Figure 3: Onset of intermittent and constant shivering assessed via various metrics during lower body cold water immersion.
NOTE: Data are mean ± SD with individual data points. Intermittent, onset of intermittent shivering. Constant, onset of constant shivering. n = 10.

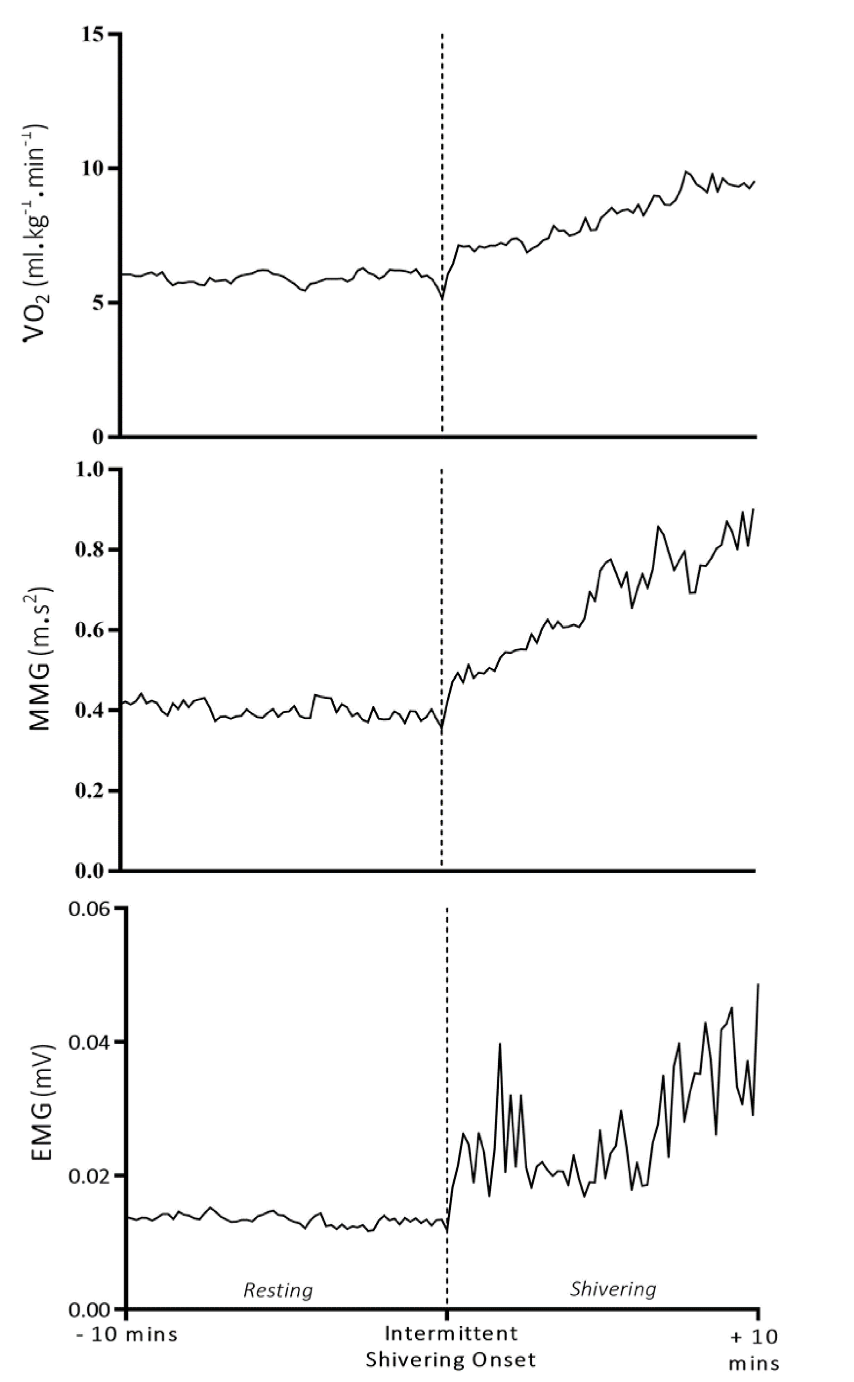

Figure 4: Representation of signal to noise ratio across three independent metrics in the assessment of shivering onset.
NOTE: Data are means of three repeated trials across subjects; n = 10. Intermittent shivering onset defined via visual inspection of inflection points.

DISCUSSION

RELIABILITY: In view of the ICC values observed, all metrics provide a good-excellent degree of test-retest reliability in the assessment shivering onset *(Table 1)*. Interestingly, time elapsed relative to cold exposure provided a more consistent predictor of shivering onset than core temperature; thus evidence is presented for the addition of a temporal element in the regulation of thermal homeostasis.

VALIDITY: Chronologically, MMG and EMG were similar in the identification of shivering onset, while a lag was seen in $\dot{V}O_2$ derived identification *(Fig 3)*. As such MMG and EMG present a suitable choice for research requiring real time objective identification of shivering onset. BSAS 1 preceded any activity registered via other metrics, yet comparing objective metrics with BSAS equivalent stages (i.e. BSAS stage 2 vs. objective intermittent shivering, and BSAS 3 vs. objective constant shivering), a lag was seen in identification via BSAS. Note, considerable variability exists in the magnitude of the delay.

Assessment of signal to noise ratio favoured EMG (SNR,1.43 ± 2.11) as an analytical tool, followed by MMG (SNR,0.67 ± 0.84) and finally $V\,O_2$ (SNR,0.37 ± 0.66) *(Fig 4)*.

INTEGRATION OF METRICS: Each metric in isolation presents a series of key limitations, thus development of an integrated measure of shivering onset, based on the current data is proposed:

$$\text{Shivering}^{(\text{GlobalSNR}^{Live})} = \left(\left(\frac{EMG_{\bar{x}((t-750)-(t-150))} - EMG_{\bar{x}(t-150)}}{2\sigma_{EMG((t-750)-(t-150))}} \right) + \left(\frac{MMG_{\bar{x}((t-750)-(t-150))} - MMG_{\bar{x}(t-150)}}{2\sigma_{MMG((t-750)-(t-150))}} \right) + \left(\frac{\dot{V}O_{2\bar{x}((t-630)-(t-30))} - \dot{V}O_{2\bar{x}(t-150)}}{2\sigma_{\dot{V}O_2((t-630)-(t-30))}} \right) \middle/ 3 \right)$$

Where:

- $\boldsymbol{GlobalSNR^{Live}}$ is a real time metric based on the mean SNR of VO_2, EMG and MMG.
- $\bar{x}$ is a rolling average of given time block
- t is current time in seconds
- 2σ is two standard deviations

Intermittent shivering onset: $\boldsymbol{GSNR^{Live}}$ *> 0.51.*

REFERENCES / CONFLICTS OF INTEREST

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The authors declare no conflicts of interests and the study did not receive funding from external sources to Loughborough.