

## Correction



**Cite this article:** Beck ON, Gosyne J, Franz JR, Sawicki GS. 2021 Correction to: 'Cyclically producing the same average muscle-tendon force with a smaller duty increases metabolic rate'. *Proc. R. Soc. B* **288**: 20210012. <https://doi.org/10.1098/rspb.2021.0012>

# Correction to: 'Cyclically producing the same average muscle-tendon force with a smaller duty increases metabolic rate'

Owen N. Beck, Jonathan Gosyne, Jason R. Franz and Gregory S. Sawicki

ONB, 0000-0002-1802-6036

*Proc. R. Soc. B* **287**, 20200431 (published online 19 August 2020) (doi:10.1098/rspb.2020.0431)

We wish to correct two subtle errors to the published article. Correcting these errors does not change the conclusion of our article.

First, we used an incorrect value for each participant's maximal soleus shortening velocity. As stated in our article, we selectively studied the human soleus because it is primarily composed of slow economical fibres. This is notable because during submaximal voluntary muscle contractions, such as those recorded in the present study's metabolic trials, the body generally activates slower more economical muscle fibres before activating faster less economical muscle fibres. When our participants repeatedly contracted their soleus for 5 min, they probably activated slower more economical muscle fibres (commonly referred to as Type 1 fibres). Accordingly, we should have used a maximal shortening velocity indicative of slow human soleus muscle fibres: 4.4 lengths per second (Bohm *et al.* 2019 *Proc. R. Soc. B*). Rather, in the article, we erroneously used a mixed combination of slow and fast soleus fibres to estimate the soleus maximum shortening velocity: 6.77 lengths per second (Bohm *et al.* 2019 *Proc. R. Soc. B*).

In the published article, we referred to this rationale many times, including in the last paragraph of the introduction as well as in the fourth paragraph of the discussion:

1. 'By studying the soleus, which has a relatively homogeneous fibre-type composition [32], the greater metabolic energy expenditure that is associated with activating less economical muscle fibres over shorter durations of active force production should be trivial. This enabled us to investigate how duty factor affects metabolic energy expenditure, independent from the metabolic influence of active force production duration (e.g. fibre-type recruitment) ...'
2. 'Producing the same cycle-average force over shorter durations typically increases metabolic energy expenditure owing to the activation of faster, less economical muscle fibres [12,17,18]. However, given soleus' relatively homogeneous muscle fibre composition [32], it probably yields similar rates of metabolic energy per unit active muscle volume ( $\dot{\rho}_p$  in equation (1.5)). Therefore, we reasoned that the metabolic influence of the duration of active force production was probably minimal in our study.'

The following is the relevant original text and the corresponding corrected text, with updated wording **bolded**.

— Page 3, Methods, lines 1–7.

- (I) Original text: 'Eleven of the 14 volunteers who enrolled in our study completed the protocol (resulting sample size: 11 participants; average  $\pm$  s.d.; age:  $24.5 \pm 3.5$  years; height:  $1.78 \pm 0.06$  m; mass:  $74.8 \pm 10.7$  kg; Achilles tendon moment arm:  $5.0 \pm 0.8$  cm; optimal soleus fascicle length:  $3.86 \pm 0.7$  cm; maximum soleus fascicle shortening velocity:  $26.1 \pm 4.6$  cm  $s^{-1}$ ; and resting metabolic power  $80 \pm 11$  W).'
- (II) Corrected text: 'Eleven of the 14 volunteers who enrolled in our study completed the protocol (resulting sample size: 11 participants; average  $\pm$  s.d.;

age:  $24.5 \pm 3.5$  years; height:  $1.78 \pm 0.06$  m; mass:  $74.8 \pm 10.7$  kg; Achilles tendon moment arm:  $5.0 \pm 0.8$  cm; optimal soleus fascicle length:  $3.86 \pm 0.7$  cm; **estimated maximum soleus fascicle shortening velocity:  $170 \pm 30 \text{ mm s}^{-1}$  (assuming maximum soleus fascicle shortening velocity equals  $4.4 L_0 \text{ s}^{-1}$  [42]); and resting metabolic power  $80 \pm 11$  W).**

— Page 4, Methods, Soleus kinetics, paragraph 2 lines 7–11.

(I) Original text: ‘Additionally, we reasoned that maximal soleus shortening velocity equals  $6.77 L_0 \text{ s}^{-1}$  [42], that initial participant resting pennation angle was consistent across trials and that passive soleus fascicle force was negligible.’

(II) Corrected text: ‘Additionally, we reasoned that maximal soleus shortening velocity equals  **$4.4 L_0 \text{ s}^{-1}$**  [42], that initial participant resting pennation angle was consistent across trials and that passive soleus fascicle force was negligible.’

Secondly, we incorrectly reported soleus fascicle velocities in  $\text{cm s}^{-1}$ , the data are actually in  $\text{mm s}^{-1}$ . In other words, we overestimated fascicle shortening velocity by a factor of 10. The following is the relevant original text and the corresponding corrected text, with updated wording **bolded**.

— Page 1, Abstract, lines 13–18.

(I) Original text: ‘Mechanistically, smaller duty factors increased maximum muscle-tendon force ( $p < 0.001$ ), further stretching in-series tendons and shifting soleus fascicles to shorter lengths and faster velocities, thereby increasing soleus total active muscle volume ( $p < 0.001$ ). Participant soleus total active muscle volume well-explained net metabolic power ( $r = 0.845$ ;  $p < 0.001$ ).’

(II) Corrected text: ‘Mechanistically, smaller duty factors increased maximum muscle-tendon force ( $p < 0.001$ ), further stretching in-series tendons and shifting soleus fascicles to shorter lengths and faster velocities, thereby increasing soleus total active muscle volume **in the higher moment level, but not the lower moment level ( $p = 0.003$  and  $p = 0.336$ , respectively)**. Participant soleus total active muscle volume well-explained net metabolic power ( $r = 0.844$ ;  $p < 0.001$ ).’

— Page 5, Results, paragraph 2, lines 1–4.

(I) Original text: ‘Despite not affecting isometric active muscle volume (equation (1.1)), duty factor influenced total active muscle volume ( $p < 0.001$ ) (equation (1.4)) by modulating soleus fascicle force-length and force-velocity potential.’

(II) Corrected text: ‘Despite not affecting isometric active muscle volume (equation (1.1)), duty factor influenced total active muscle volume **in the higher moment level, but not the lower moment level ( $p = 0.003$  and  $p = 0.336$ , respectively)** (equation (1.4)) by modulating soleus fascicle force-length and force-velocity potential.’

— Page 5, Results, paragraph 2, lines 11–15.

(I) Original text: ‘Nonetheless, combining the trends of decreasing duty factors, shorter fascicle lengths and faster velocities; decreasing duty factor increased total soleus active muscle volume within both moment levels ( $p < 0.001$ ) (figure 4).’

(II) Corrected text: ‘Nonetheless, combining the trends of decreasing duty factors, shorter fascicle lengths and faster velocities; decreasing duty factor increased total soleus active muscle volume **in the higher moment level ( $p = 0.003$ )** (figure 4).’

— Page 5, Results, paragraph 2, line 15 through page 6, lines 1–5.

(I) Original text: ‘Further, because decreasing duty factor reduced soleus force-length and force-velocity potential but did not affect pennation angle, it increased the difference between total and isometric active muscle volume within each moment level ( $p < 0.001$ ) (electronic supplementary material, figure S2).’

(II) Corrected text: ‘Further, because decreasing duty factor reduced soleus force-length and force-velocity potential but did not affect pennation angle, it increased the difference between total and isometric active muscle volume **(lower and higher moment level  $p = 0.054$  and  $p = 0.048$ , respectively)** (electronic supplementary material, figure S2).’

— Page 6, Results, right column, lines 1–4.

(I) Original text: ‘Across both moment levels, participant total active muscle volume explained 72% of the change in net metabolic power ( $r = 0.845$ ;  $p < 0.001$ ) (figure 6).’

(II) Corrected text: ‘Across both moment levels, participant total active muscle volume explained **71%** of the change in net metabolic power ( $r = 0.844$ ;  $p < 0.001$ ) (figure 6).’

— Page 7, Results, left column, lines 1–4.

(I) Original text: ‘Additionally, decreasing duty factor and increasing total soleus active muscle volume both yielded greater soleus ( $p \leq 0.010$ ) and lateral gastrocnemius ( $p \leq 0.033$ ) activation (figure 7).’

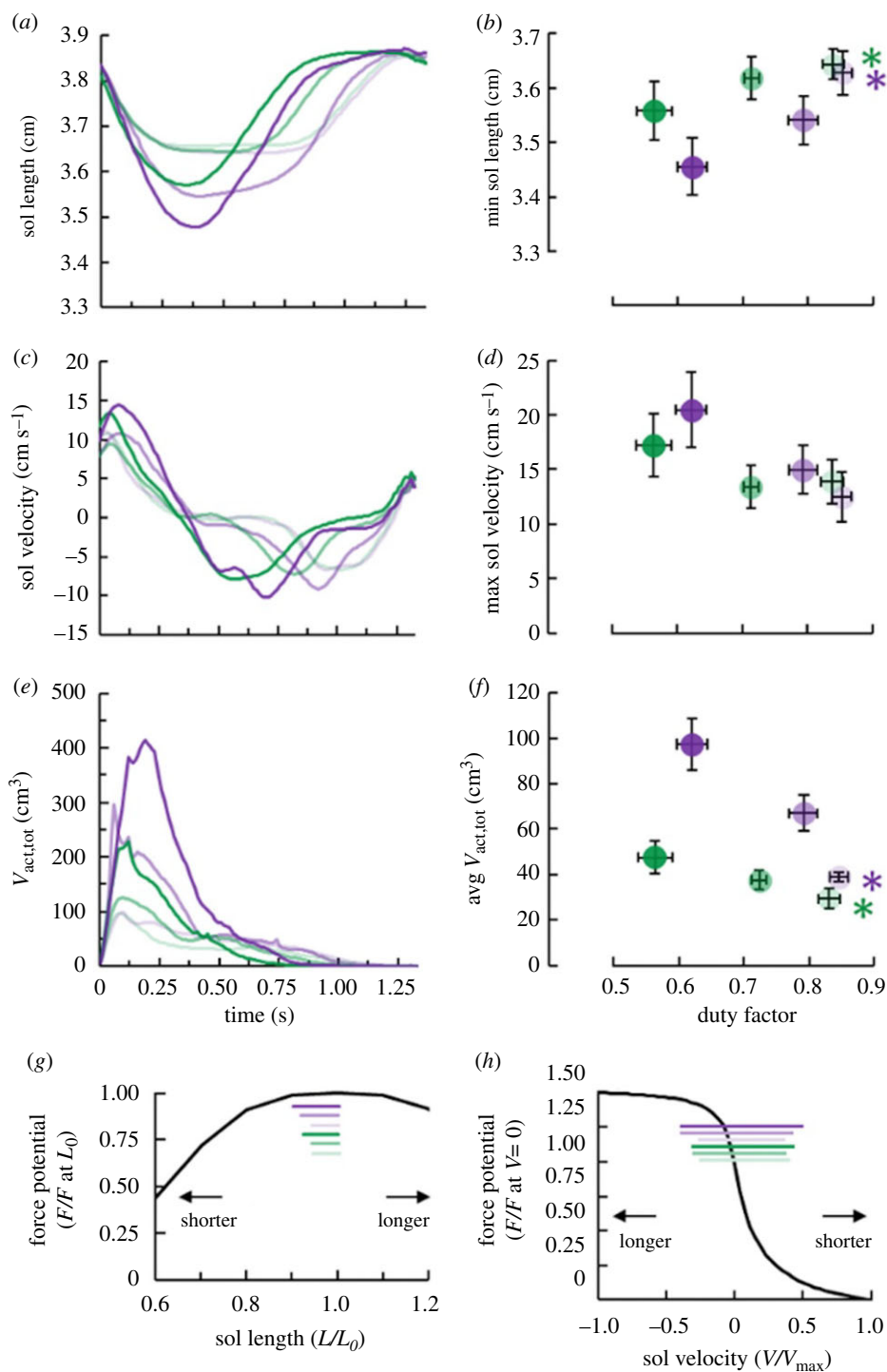
(II) Corrected text: ‘Additionally, duty factor, **but not** total soleus active muscle volume ( **$p \geq 0.3149$** ), yielded greater soleus ( $p \leq 0.010$ ) and lateral gastrocnemius ( $p \leq 0.033$ ) activation (figure 7). **Theoretically, total soleus active muscle volume and measured activation should be directly related [11].**

— Page 7, Discussion, paragraph 4, lines 23–26 and page 8, lines 1–4.

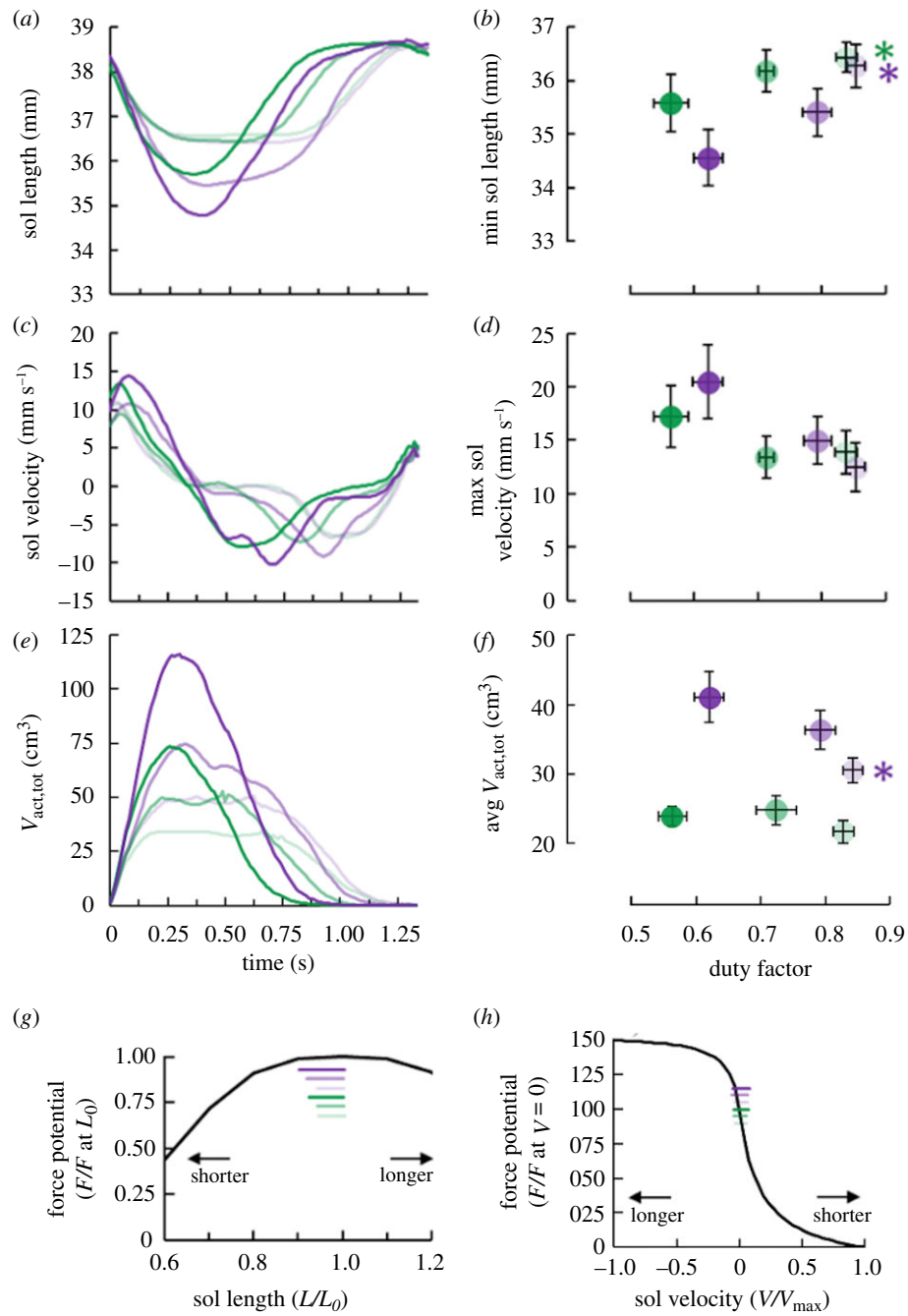
(I) Original text: ‘To ensure that the activation of different muscle fibre types (from the soleus and gastrocnemius muscles) did not affect our conclusions, we performed post hoc analyses which revealed that scaling total active muscle volume by the rate of active force production (1/ground contact duration in [17,18]) did not improve the correlation between participant total active muscle volume and net metabolic power ( $r = 0.840$  versus  $0.845$ ).’

(II) Corrected text: ‘To ensure that the activation of different muscle fibre types (from the soleus and gastrocnemius muscles) did not affect our conclusions, we performed *post hoc* analyses which revealed that scaling total active muscle volume by the rate of active force production (1/ground contact duration in [17,18]) did not improve the correlation between participant total active muscle volume and net metabolic power ( $r = 0.861$  versus  **$0.844$** ).’

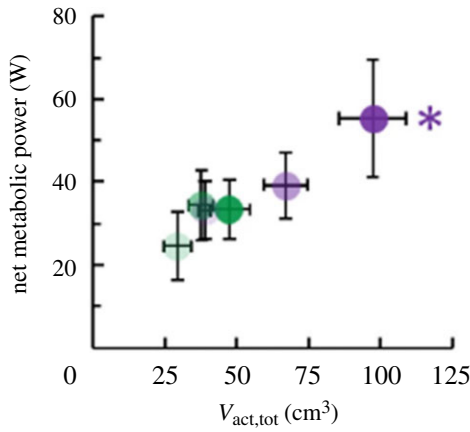
The following are relevant original figures and the corresponding corrected figure.



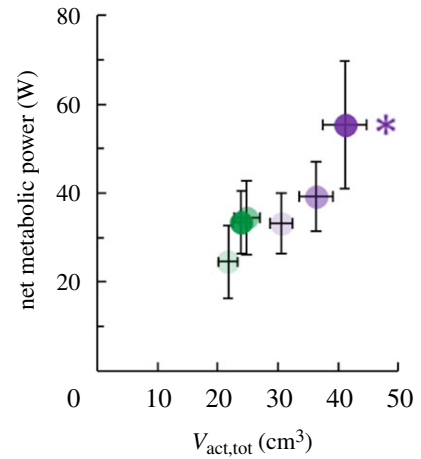
**Original Figure 4.** Left column: average time-series graphs of (a) soleus (sol) fascicle length, (c) soleus fascicle shortening velocity and (e) total soleus active muscle volume ( $V_{act,tot}$ ). Right column: average ( $\pm$  s.e.) (b) minimum soleus fascicle length, (d) maximum soleus fascicle velocity and (f) cycle-average total soleus active muscle volume versus duty factor. Bottom row: Hill-type (g) force-length force potential expressed as a fraction of force ( $F$ ) at optimal fascicle length ( $L_0$ ), and (h) force-velocity potential expressed as a fraction of force at zero velocity ( $V$ ). Maximum shortening velocity is expressed as  $V_{max}$ . Lighter to darker colour indicates longer to shorter duration of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's duty factor affects the indicated dependent variable ( $p < 0.05$ ).



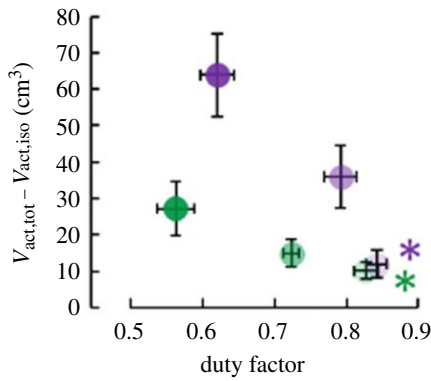
**Corrected Figure 4.** Left column: average time-series graphs of (a) soleus (sol) fascicle length, (c) soleus fascicle shortening velocity and (e) total soleus active muscle volume ( $V_{act,tot}$ ). Right column: average ( $\pm$  s.e.) (b) minimum soleus fascicle length, (d) maximum soleus fascicle velocity and (f) cycle-average total soleus active muscle volume versus duty factor. Bottom row: Hill-type (g) force-length force potential expressed as a fraction of force ( $F$ ) at optimal fascicle length ( $L_0$ ) and (h) force-velocity potential expressed as a fraction of force at zero velocity ( $V$ ). Maximum shortening velocity is expressed as  $V_{max}$ . Lighter to darker colour indicates longer to shorter duration of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's duty factor affects the indicated dependent variable ( $p < 0.05$ ).



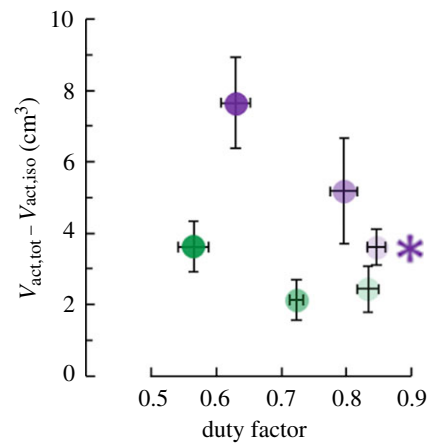
**Original Figure 6.** Average ( $\pm$  s.e.) net metabolic power versus total soleus active muscle volume ( $V_{\text{act,tot}}$ ). Lighter to darker colour indicates longer to shorter duration of active moment production per ankle moment level. Green and purple asterisks (\*) indicate that total soleus active muscle volume affects the indicated dependent variable ( $p < 0.05$ ).



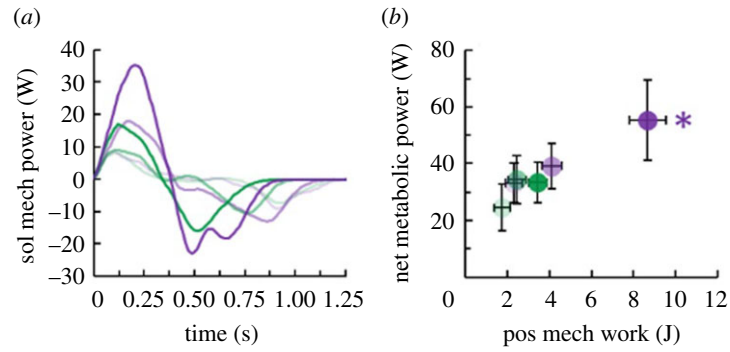
**Corrected Figure 6.** Average ( $\pm$  s.e.) net metabolic power versus total soleus active muscle volume ( $V_{\text{act,tot}}$ ). Lighter to darker colour indicates longer to shorter duration of active moment production per ankle moment level. Green and purple asterisks (\*) indicate that total soleus active muscle volume affects the indicated dependent variable ( $p < 0.05$ ).



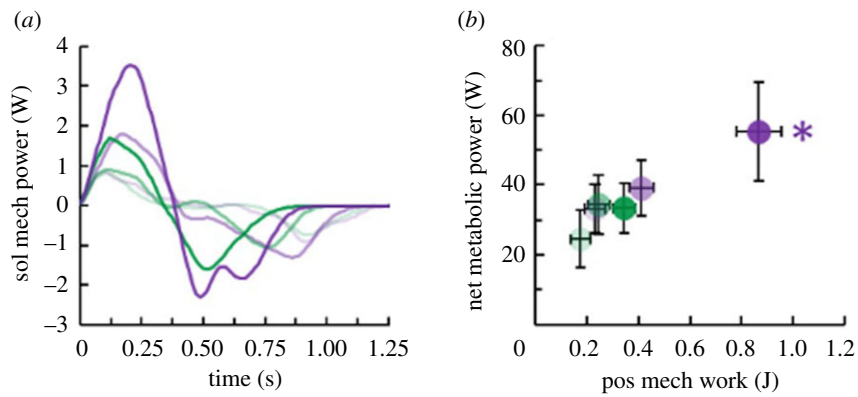
**Original Supplementary Material Figure 2.** Average ( $\pm$  SE) total soleus active muscle volume ( $V_{\text{act,tot}}$ ) minus isometric soleus active muscle volume ( $V_{\text{act,iso}}$ ) versus duty factor. Green and purple symbols indicate the lower and higher average ankle moment levels, respectively. Lighter to darker colours indicate longer to shorter durations of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's duty factor affects the indicated dependent variable ( $p < 0.05$ ).



**Corrected Supplementary Material Figure 2.** Average ( $\pm$  SE) total soleus active muscle volume ( $V_{\text{act,tot}}$ ) minus isometric soleus active muscle volume ( $V_{\text{act,iso}}$ ) versus duty factor. Green and purple symbols indicate the lower and higher average ankle moment levels, respectively. Lighter to darker colours indicate longer to shorter durations of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's duty factor affects the indicated dependent variable ( $p < 0.05$ ).



**Original Supplementary Material Figure 3.** (a) Soleus (Sol) mechanical power versus time and (b) net metabolic power versus positive mechanical work. Lighter to darker colour indicates longer to shorter duration of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's positive mechanical work affects indicated dependent variable ( $p < 0.05$ ).



**Corrected Supplementary Material Figure 3.** (a) Soleus (Sol) mechanical power versus time and (b) net metabolic power versus positive mechanical work. Lighter to darker colour indicates longer to shorter duration of active force production per ankle moment level. Green and purple asterisks (\*) indicate that the corresponding average moment level's positive mechanical work affects indicated dependent variable ( $p < 0.05$ ).