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CORRECTION

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Correction to: The biomechanics and applications of strongman exercises: a systematic review

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The original article [1] contained an error whereby the symbol ‘ \otimes ’ originally included in and below Tables 2, 3, 4 and 5 did not display properly. This has been rectified in the following versions of these tables.

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Table 2 Walking/carrying results comparisons - farmers walk

	Winwood et al. [7]			Keogh et al. [34]			
	Farmers walk	Unloaded walk	Effect size	Higher performer	Lower performer	Effect size	Group ave.
Spatiotemporal							
Ground contact time (s)	0.46 ± 0.06* (MVP)	0.67 ± 0.06 (MVP)	-3.50	0.29 ± 0.02† (MVP*)	0.34 ± 0.03 (SVP*)	-1.96	0.30 ± 0.03‡ (MVP)
	0.53 ± 0.09* (AP)	0.77 ± 0.07 (AP)	-3.00	0.39 ± 0.04† (AP)	0.32 ± 0.03 (AP)	1.98	0.36 ± 0.04 (AP)
Stride rate (Hz)	1.42 ± 0.17* (MVP)	0.88 ± 0.06 (MVP)	4.20	2.01 ± 0.13† (MVP*)	1.83 ± 0.04 (SVP*)	1.88	1.97 ± 0.13‡ (MVP)
	1.21 ± 0.12* (AP)	0.82 ± 0.04 (AP)	4.40	1.88 ± 0.10† (AP)	1.64 ± 0.12 (AP)	2.17	1.79 ± 0.14 (AP)
Stride length (m)	1.04 ± 0.12* (MVP)	1.43 ± 0.11 (MVP)	-3.40	1.83 ± 0.04† (MVP*)	1.40 ± 0.17 (SVP*)	3.48	1.67 ± 0.10‡ (MVP)
	0.85 ± 0.19* (AP)	1.33 ± 0.11 (AP)	-3.10	1.38 ± 0.16 (AP)	1.33 ± 0.09 (AP)	0.39	1.32 ± 0.12 (AP)
Average velocity (m/s)	1.48 ± 0.19 (MVP)	1.26 ± 0.15 (MVP)	1.28	3.66 ± 0.17† (MVP)	2.83 ± 0.36 (MVP)	2.95	3.29 ± 0.38‡ (MVP)
	1.05 ± 0.21 (AP)	1.11 ± 0.09 (AP)	-0.37	2.61 ± 0.38 (AP)	2.19 ± 0.27 (AP)	1.27	2.41 ± 0.32 (AP)
Kinematic							
Ankle angle at FS (°)	95.0 ± 3.00* (MVP)	105 ± 2.00 (MVP)	-3.80	101 ± 6.00† (SVP*)	113 ± 5.00 (MVP*)	-2.17	110 ± 9.00 (MVP)
	96.00 ± 6.00* (AP)	105 ± 2.00 (AP)	-2.30	99.0 ± 8.00 (AP)	106 ± 6.00 (AP)	-0.99	100 ± 8.00 (AP)
Ankle angle at TO (°)	100 ± 5.00* (MVP)	115 ± 9.00 (MVP)	-2.10	118 ± 5.00 (MVP*)	117 ± 7.00 (SVP*)	0.16	114 ± 6.00 (MVP)
	105 ± 6.00 (AP)	118 ± 5.00 (AP)	-2.30	108 ± 4.00† (AP)	114 ± 3.00 (AP)	-1.70	111 ± 5.00 (AP)
Ankle ROM (°)	4.00 ± 4.00 (MVP)	10.0 ± 10.0 (MVP)	-0.70	-1.00 ± 4.00† (SVP)	1.00 ± 5.00 (MVP)	-2.43	-4.00 ± 7.00‡ (MVP)
Knee angle at FS (°)	154 ± 7.00* (MVP)	178 ± 6.00 (MVP)	-3.70	156 ± 6.00 (MVP*)	166 ± 16.0 (SVP*)	-0.83	155 ± 6.00‡ (MVP)
	150 ± 9.00* (AP)	174 ± 10.0 (AP)	-2.50	147 ± 7.00 (AP)	151 ± 5.00 (AP)	-0.66	150 ± 6.00 (AP)
Thigh angle at FS (°)	34.0 ± 6.00* (MVP)	23.0 ± 7.00 (MVP)	1.80	38.0 ± 3.00† (MVP*)	31.0 ± 4.00 (SVP*)	1.98	34.0 ± 3.00 (MVP)
	-19.0 ± 5.00 (MVP)	-22.0 ± 10.0 (MVP)	0.40	-44.0 ± 4.00† (MVP*)	-35.0 ± 6.00 (SVP*)	-1.77	-38.0 ± 4.00‡ (MVP)
Trunk angle at FS (°)	78.0 ± 3.00* (MVP)	90.0 ± 2.00 (MVP)	-4.10	-	-	-	-
	69.0 ± 5.00* (AP)	85.0 ± 2.00 (AP)	-4.30	-	-	-	-
Trunk angle at TO (°)	76.0 ± 4.00* (MVP)	87.0 ± 2.00 (MVP)	-3.20	-	-	-	-
	70.0 ± 5.00* (AP)	84.0 ± 4.00 (AP)	-3.40	-	-	-	-
Kinetic							
Mean anterior GRF (N)	127 ± 31.0* (MVP)	83.0 ± 25.0 (MVP)	1.60	-	-	-	-
Peak anterior GRF (N)	447 ± 98.0* (MVP)	259 ± 53.0 (MVP)	2.40	-	-	-	-
Mean medial GRF (N)	120 ± 41.0* (MVP)	70.0 ± 36.0 (MVP)	1.30	-	-	-	-
Peak medial GRF (N)	241 ± 73.0* (MVP)	120 ± 62.0 (MVP)	1.80	-	-	-	-
Mean posterior GRF (N)	159 ± 45.0* (MVP)	94.0 ± 34.0 (MVP)	1.60	-	-	-	-

Table 2 Walking/carrying results comparisons - farmers walk (Continued)

	Winwood et al. [7]		Keogh et al. [34]			
	Farmers walk	Unloaded walk	Higher performer	Lower performer	Effect size	Group ave.
Peak posterior GRF (N)	389 ± 143* (MVP)	211 ± 77.0 (MVP)	-	-	1.50	-
Mean vertical GRF (N)	2540 ± 376* (MVP)	1030 ± 247 (MVP)	-	-	4.70	-
Peak vertical GRF (N)	3630 ± 608* (MVP)	1510 ± 387 (MVP)	-	-	4.10	-
Peak lateral GRF (N)	210 ± 73.0* (MVP)	119 ± 45.0 (MVP)	-	-	1.50	-

All data are reported as means ± standard deviation, unless specified otherwise. Effect sizes reported for between exercise [7] and between performance standard [34]. A positive effect size indicates the left-hand column (farmers walk or higher performer) had a greater value than the respective right-hand column (unloaded walk or lower performer). * significant difference to unloaded walking, † significant difference to low performing athletes, ☆ significant difference to acceleration phase, * comparison between phase based on distance, GRF ground reaction force, ave average, MVP maximum velocity phase, SVP submaximal velocity phase

Table 3 Significant differences in muscle activation and kinetic outcomes between the walking/carrying exercises

	Farmers walk [35]	LH suitcase carry [35]	RH suitcase carry [35]	Yoke walk [35]
Muscle activity (%MVC)				
Left upper erector spinae	77.6 ± 29.3 ‡	47.1 ± 6.20	32.4 ± 4.60 *✧	69.3 ± 17.5 ‡
Right upper erector spinae	91.4 ± 54.7 †	24.9 ± 17.6 *‡✧	52.1 ± 17.3 †	65.6 ± 14.4†
Left lower erector spinae	106 ± 51.1 †	31.6 ± 10.1 *‡✧	77.4 ± 21.3 †	79.2 ± 10.2 †
Right lower erector spinae	144 ± 36.7 ‡	96.9 ± 20.4 ‡	44.1 ± 9.10 *†✧	107 ± 31.5 ‡
Left latissimus dorsi	169 ± 55.4 *‡	97.4 ± 55.7	68.9 ± 23.2 ✧	51.9 ± 26.4 ✧
Right latissimus dorsi	152 ± 26.7 *†	65.3 ± 6.20 ✧	91.4 ± 39.1	45.5 ± 31.7 ✧
Left external oblique	39.3 ± 30.6 †	12.6 ± 5.30 *‡✧	61.5 ± 21.9 †	47.5 ± 31.7 †
Right external oblique	50.4 ± 17.4 ‡	65.1 ± 24.4 ‡	29.0 ± 17.8 *†✧	58.8 ± 17.4 ‡
Right rectus abdominis	13.3 ± 3.80	14.6 ± 4.50	5.60 ± 1.80 *	22.3 ± 18.1 ‡
Right gluteus maximus	114 ± 70.3 ‡	78.2 ± 39.5	50.5 ± 31.2 *✧	113 ± 52.1 ‡
Right gluteus medius	108 ± 66.9 ‡	64.1 ± 38.7	57.3 ± 23.6 *✧	108 ± 69.7 ‡
Right bicep femoris	54.0 ± 13.7 †	31.2 ± 7.50 *‡ ✧	48.3 ± 8.6 †	61.7 ± 6.30 †
Right rectus femoris	77.4 ± 35.6	41.1 ± 9.20 *	56.5 ± 11.5 *	107 ± 23.5 †‡
Kinetic				
Muscular anterior/posterior shear (N)	2800 †	1680 ✧	1160	1890
Muscular compressive load (N)	7900 †	5800 *✧	6700	7800 †
Muscular axial twist stiffness (Nm/rad)	27,200 †‡	19,100 ✧	24,600 ✧	25,900
Muscular flexion/extension stiffness (Nm/rad)	35,600	24,000 *	27,500	38,600 †

All data are reported as means ± standard deviation, unless specified otherwise. * significant difference to yoke walk, † significant difference to left hand suitcase carry, ‡ significant difference to right hand suitcase carry, ✧ significant difference to farmers walk, LH left hand, MVC maximum voluntary contraction RH right hand

Table 4 Pulling significant results comparisons - heavy sled pull

	Winwood et al. [38]		Keogh et al. [32]		Effect size	Group ave.
	Heavy sled pull	Back squat	Higher performer	Lower performer		
Spatiotemporal						
Ground contact time (s)	0.35 ± 0.04 (MVP)	-	0.33 ± 0.04† (MVP)	0.76 ± 0.37 (MVP)	-1.63	0.48 ± 0.23 (MVP)
	0.38 ± 0.03 (AP)	-	0.42 ± 0.19 (AP)	0.57 ± 0.23 (AP)	-0.71	0.53 ± 0.32 (AP)
Stride rate (s)	1.42 ± 0.14 (MVP)	-	1.63 ± 0.12† (MVP)	1.10 ± 0.42 (MVP)	1.72	1.37 ± 0.39 (MVP)
	1.41 ± 0.14 (AP)	-	1.50 ± 0.55 (AP)	1.29 ± 0.37 (AP)	0.45	1.45 ± 0.50 (AP)
Swing time (s)	0.33 ± 0.04 (MVP)	-	0.29 ± 0.03 (MVP)	0.27 ± 0.05 (MVP)	0.49	0.28 ± 0.04✱ (MVP)
	0.31 ± 0.06 (AP)	-	0.28 ± 0.07† (AP)	0.23 ± 0.05 (AP)	0.82	0.25 ± 0.06 (AP)
Stride length (m)	1.29 ± 0.17✱ (MVP)	-	1.29 ± 0.26† (MVP)	0.80 ± 0.16 (MVP)	2.27	1.03 ± 0.26✱ (MVP)
	1.00 ± 0.15 (AP)	-	0.85 ± 0.25† (AP)	0.65 ± 0.04 (AP)	1.12	0.74 ± 0.28 (AP)
Kinematic						
Average velocity (m/s)	1.83 ± 0.22✱ (MVP)	-	2.08 ± 0.08† (MVP)	0.99 ± 0.50 (MVP)	3.04	1.61 ± 0.55✱ (MVP)
	1.39 ± 0.13 (AP)	-	1.22 ± 0.20† (AP)	0.79 ± 0.32 (AP)	1.61	1.04 ± 0.30 (AP)
Knee angle at FS (°)	114 ± 6.00✱ (MVP)	-	132 ± 9.00† (MVP)	112 ± 22.0 (MVP)	1.19	124 ± 18.0✱ (MVP)
	103 ± 9.00 (AP)	-	125 ± 12.0† (AP)	110 ± 10.0 (AP)	1.36	116 ± 13.0 (AP)
Knee angle at TO (°)	138 ± 14.0 (MVP)	-	153 ± 7.00 (MVP)	148 ± 10.0 (MVP)	0.59	149 ± 9.00✱ (MVP)
	133 ± 14.0 (AP)	-	148 ± 14.0† (AP)	138 ± 17.0 (AP)	0.65	141 ± 15.0 (AP)
Thigh angle at FS (°)	-	-	23.0 ± 5.00† (MVP)	19.0 ± 5.0 (MVP)	0.80	21.0 ± 5.00✱ (MVP)
	-	-	14.0 ± 10.0 (AP)	16.0 ± 8.00 (AP)	-0.22	15.0 ± 10.0 (AP)
Trunk angle at FS (°)	61.0 ± 13.0 (MVP)	-	41.0 ± 7.00† (MVP)	8.00 ± 29.0 (MVP)	1.56	26.0 ± 24.0✱ (MVP)
	77.0 ± 30.0 (AP)	-	29.0 ± 17.0† (AP)	2.00 ± 16.0 (AP)	1.64	14.0 ± 21.0 (AP)
Trunk angle at TO (°)	61.0 ± 11.0 (MVP)	-	41.0 ± 9.00† (MVP)	14.0 ± 25.0 (MVP)	1.59	28.0 ± 21.0✱ (MVP)
	69.0 ± 20.0 (AP)	-	31.0 ± 15.0† (AP)	10.0 ± 14.0 (AP)	1.45	19.0 ± 19.0 (AP)
Kinetic						
Mean anterior GRF (N)	555 ± 107* (SC to MKE)	43.0 ± 22.0 (SC to MKE)	-	-	-	-
Peak anterior GRF (N)	810 ± 174* (SC to MKE)	126 ± 73.0 (SC to MKE)	-	-	-	-
Mean vertical GRF (N)	1330 ± 364* (SC to MKE)	2580 ± 648 (SC to MKE)	-	-	-	-
Peak vertical GRF (N)	1740 ± 463* (SC to MKE)	3500 ± 1270 (SC to MKE)	-	-	-	-
Mean resultant ant/post force (N)	271 ± 89.0✱ (MVP)	-	-	-	-	-
	526 ± 162 (AP)	-	-	-	-	-
Mean resultant med/lat force (N)	-5.00 ± 22.0✱ (MVP)	-	-	-	-	-
	24.0 ± 8.00 (AP)	-	-	-	-	-

All data are reported as means ± standard deviation, unless specified otherwise. Spatiotemporal and kinematic effect sizes reported for between phase [38] and between performance standard [32]. Kinetic effect sizes reported for between exercise (heavy sled pull vs back squat). A positive effect size indicates the left-hand column (higher performer or heavy sled pull) or top row (maximum velocity phase) had a greater value than the respective right-hand column (lower performer or back squat) or bottom row (acceleration phase). * significant difference to back squat, † significant difference to low performing athletes, ✱ significant difference to acceleration phase, ant/post anterior/posterior, AP acceleration phase, ave average, FS foot strike, GRF ground reaction force, med/lat medial/lateral, MVP maximum velocity phase, SC to MKE start of concentric phase to maximum knee extension, TO toe off

Table 5 Static lift significant result comparisons

	Winwood et al. [39]		Renals et al. [37]		McGill et al. [35]		Keogh et al. [33], McGill et al. [35]	
	165 mm diam log	Barbell clean & press	250 mm diam log	316 mm diam log	Log lift	Atlas stone	Tire flip	
Temporal								
Duration (s)	7.96 ± 3.77 (TD)	6.20 ± 1.96 (TD)	0.22 ± 0.02(PR) 0.67 ± 0.06 (TD)	0.22 ± 0.02(PR) 0.64 ± 0.07 (TD)	-	-	0.38 ± 0.17 (SP)(HP) ‡ 1.49 ± 0.92 (SP)(LP)	
Kinematic								
Dip depth (cm)	17.4 ± 4.40 (PP)	18.0 ± 6.60 (PP)	14.0 ± 3.00* (PP)	13.0 ± 2.00* (PP)	-	-	-	
Vertical lift velocity (m/s)	0.60 ± 0.10* (FP)	0.75 ± 0.15 (FP)	-	-	-	-	-	
	1.06 ± 0.41* (SP)	1.69 ± 0.15 (SP)	-	-	-	-	-	
Hip angle (°)	0.88 ± 0.07 (PP)	0.97 ± 0.08 (PP)	0.64 ± 0.07* (PP)	0.62 ± 0.06* (PP)	-	-	-	
	52.0 ± 6.00* (LO)	60.0 ± 6.00 (LO)	-	-	-	-	-	
	182 ± 5.00* (TR)	158 ± 15.0 (TR)	-	-	-	-	-	
HIP ROM (°)	126 ± 9.00* (EL)	116 ± 10.0 (EL)	-	-	-	-	-	
Knee angle (°)	99.0 ± 25.0* (SSP)	140 ± 11.0 (SSP)	-	-	-	-	-	
	139 ± 11.0* (TR)	125 ± 13.0 (TR)	-	-	-	-	-	
Trunk angle (°)	106 ± 2.00* (TR)	91.0 ± 6.00 (TR)	-	-	-	-	-	
	93.0 ± 5.00* (BD)	87.0 ± 2.00 (BD)	-	-	-	-	-	
Trunk ROM (°)	83.0 ± 8.00* (EL)	67.0 ± 12.0 (EL)	-	-	-	-	-	
Kinetic								
Braking mean force (N)	-	-	680 ± 262 (PP)	625 ± 252* (PP)	-	-	-	
Braking impulse (N.s)	-	-	116 ± 28.7* (PP)	106 ± 27.8* (PP)	-	-	-	
Braking mean power (W)	-	-	-943 ± 281* (PP)	-854 ± 276* (PP)	-	-	-	
Mean posterior force (N)	-67.0 ± 14.0* (EL)	-91.0 ± 27.0 (EL)	-	-	-	-	-	
Propulsive mean force (N)	-	-	3230 ± 357* (PP)	3130 ± 363* (PP)	-	-	-	
Propulsive impulse (N.s)	307 ± 56.8 (PP)	346 ± 66.8 (PP)	255 ± 38.8* (PP)	241 ± 28.7* (PP)	-	-	-	
Propulsive mean power (W)	1920 ± 591* (PP)	2960 ± 802 (PP)	2040 ± 377* (PP)	1900 ± 295* (PP)	-	-	-	
Musc ant/post shear (N)	-	-	-	-	2800\$	-	2600\$	
Musc comp load (N)	-	-	-	-	7500\$	-	8800\$	
Musc ax twist stiff (Nm/rad)	-	-	-	-	25-300\$	-	31,400\$	
Musc flex/ext. stiff (Nm/rad)	-	-	-	-	32,400\$	-	38,600\$	
Muscle activation (%MVC)								
Right rectus abdominis	-	-	-	-	27.3 ± 27.8#	77.6 ± 41.6	87.8 ± 63.9†	
Right external oblique	-	-	-	-	61.5 ± 49.1#	97.6 ± 67.7	107 ± 45.4†	

All data are reported as means ± standard deviation, unless specified otherwise. * significant difference to barbell, † significant difference to log lift, ‡ significant difference to tire flip, § value only provided in graph form and as such are approximate values with no standard deviation, Anti/post anterior/posterior, ax axial, BD bottom of dip, comp compressive, diam diameter, EL entire lift, flex/ext flexion/extension, FP first pull, HP higher performing athlete, LO lift off, LP lower performing athlete, MVC maximum voluntary contraction, PP push press phase, PR propulsive duration, SP second pull, SSP start of second pull, stiff stiffness, TD total lift duration, TR top retrieve phase