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Supplementary Materials for

A lower-extremity exoskeleton improves knee extension in children with crouch gait from cerebral palsy

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The PDF file includes:

Other Supplementary Material for this manuscript includes the following:
(available at www.sciencetranslationalmedicine.org/cgi/content/full/9/404/eaam9145/DC1)

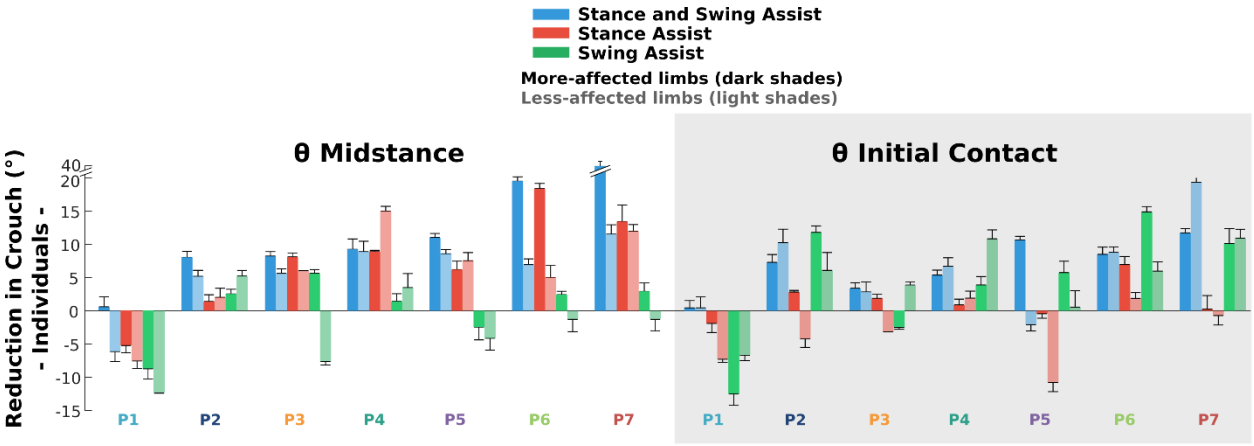

Fig. S1. Effect of exoskeleton assistance mode on crouch by individual. Individual mean changes in crouch for the three assistance modes as measured by knee extension angle compared to baseline in midstance phase (θ midstance) and at foot contact (θ initial contact). Participants (P1 to P7) were arranged from left-to-right by least-to-most improvement in crouch during stance and swing assist condition for their more-affected limb. Darker and lighter bars depict the more- and less-affected limbs, respectively. Error bars denote ½ standard deviation.

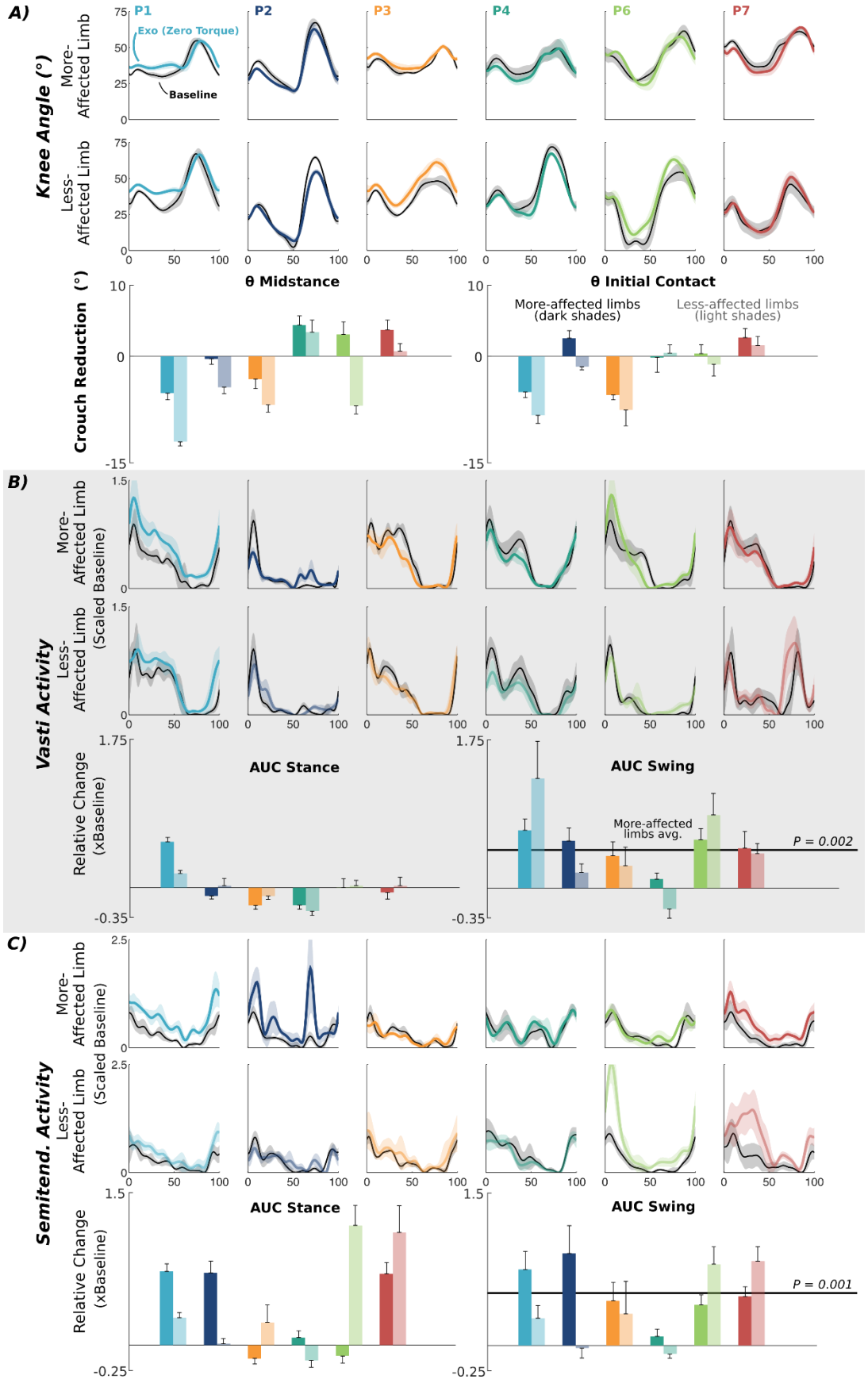
A)
Knee Angle (°)
More-Affected Limb
Less-Affected Limb
P1
P2
P3
P4
P6
P7
Exo (Zero Torque)
Baseline
θ Midstance
θ Initial Contact
Crouch Reduction (°)
More-affected limbs (dark shades)
Less-affected limbs (light shades)
B)
Vasti Activity
More-Affected Limb (Scaled Baseline)
Less-Affected Limb (Scaled Baseline)
Relative Change (xBaseline)
AUC Stance
AUC Swing
More-affected limbs avg.
P = 0.002
C)
Semitend. Activity
More-Affected Limb (Scaled Baseline)
Less-Affected Limb (Scaled Baseline)
Relative Change (xBaseline)
AUC Stance
AUC Swing
P = 0.001

Fig. S2. Biomechanical effects of walking with the null exoskeleton. (**A**) Knee angle for more- and less-affected limbs during walking at baseline (thin black lines) and with the exoskeleton in the zero torque mode (colored lines) at final assessment. Data from the null exoskeleton were not available for P5 (see Methods). Bar charts below are the mean crouch reduction during the zero torque condition at midstance and initial contact for each individual. Vastus lateralis (**B**) and semitendinosus (**C**) EMG activity for more- and less-affected limbs during baseline (thin black lines) and with the null exoskeleton mode (colored lines); EMG activity was scaled to baseline. Bars below are the mean change in muscle activity during null exoskeleton walking relative to baseline during stance (left) and swing (right). Dark and light bars depict more- and less-affected limbs, respectively, and error bars denote ½ standard deviation. Lines across the bar charts indicate group-level significant mean changes from baseline for more-affected (dark shade) and less-affected (light shade) limbs (paired t-tests, $P < 0.05$). For all gait cycle plots, shaded regions depict ± 1 standard deviation, and dark and light shaded lines depict more- and less-affected limbs, respectively.

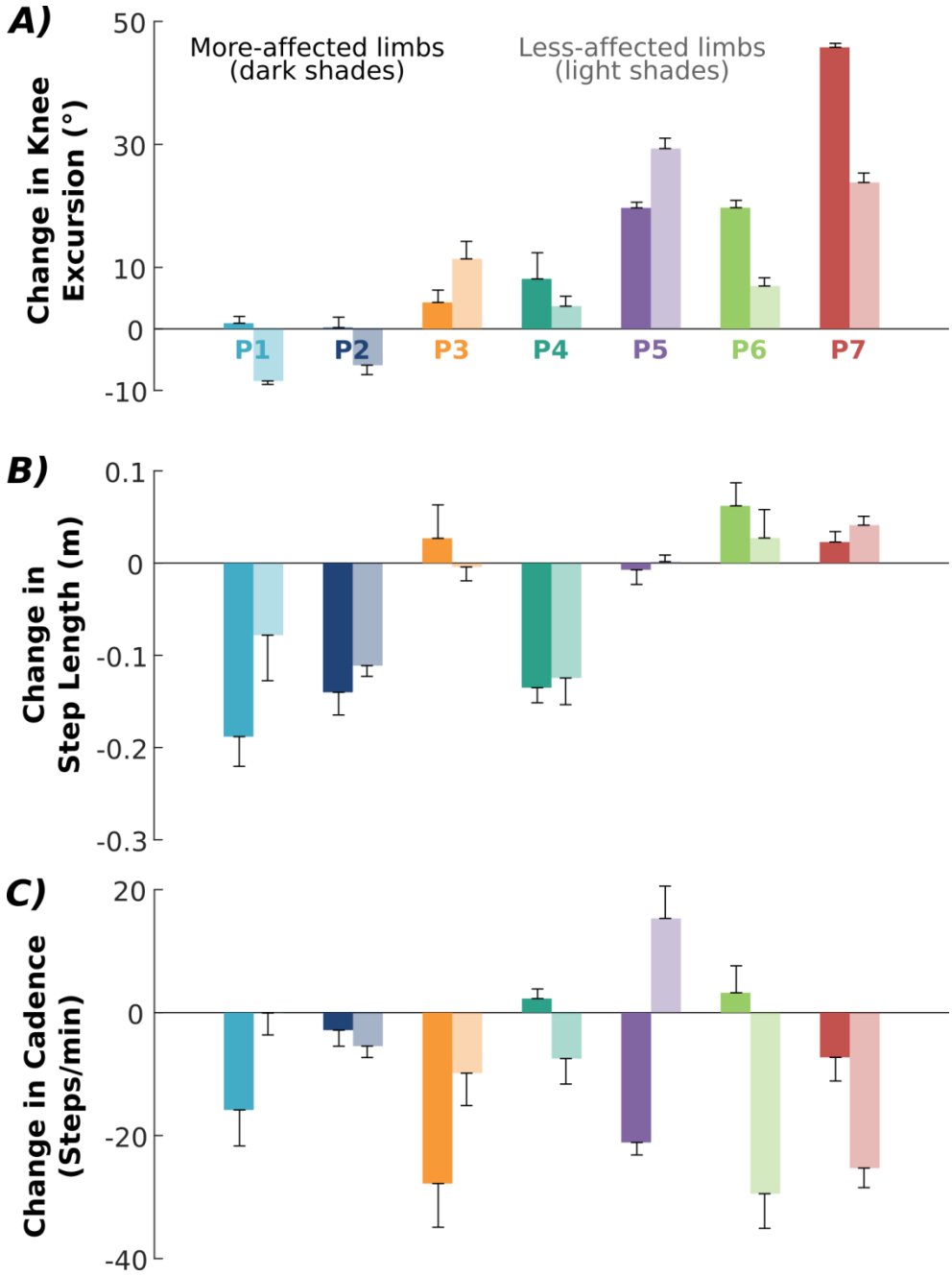

Fig. S3. Effect of exoskeleton assistance on gait parameters. Differences between baseline and walking with the exoskeleton in (**A**) knee excursion, (**B**) step length, and (**C**) cadence on the final assessment. Darker and lighter bars depict more- and less-affected limbs, respectively. For each bar plot, participants (P1 to P7) are presented from left-to-right by least-to-most improvement in crouch for their more-affected limb, and error bars denote ½ standard deviation. Mean total knee excursion (more-affected limb, $P = 0.07$; less-affected limb, $P = 0.14$), step length (more-affected limb, $P = 0.25$; less-affected limb, $P = 0.14$) and cadence (more-affected limb, $P=0.07$; less- affected limb, $P = 0.12$) were not significantly different at the group level (paired t-tests, $P < 0.05$).

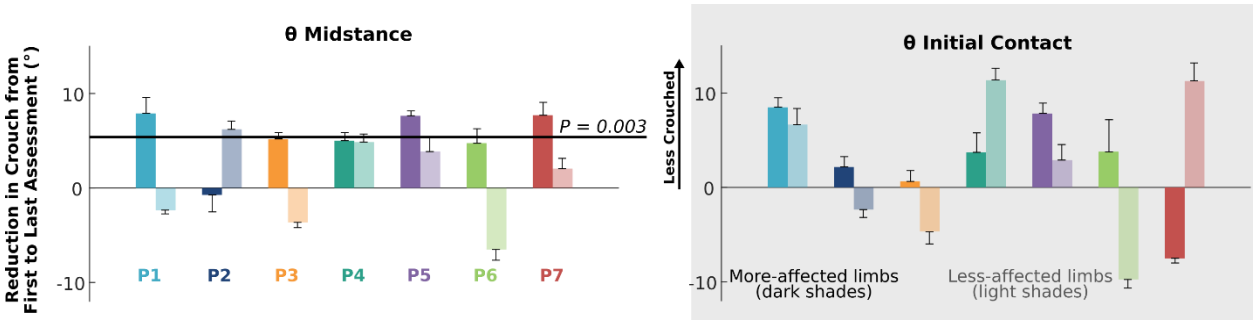

Fig. S4. Individual differences in crouch between first and last assessments. Individual mean reductions in crouch between the first and last assessments during exoskeleton walking as assessed by change in knee extension angle in stance phase (θ midstance) and at foot contact (θ initial contact) for participants P1 to P7. Darker and lighter bars depict the more- and less-affected limbs, respectively. At the group-level (n = 7) θ midstance was significantly more extended at the last assessment compared to the first as indicated by the black horizontal line at the average value (paired t-test, $P = 0.003$). Error bars denote ½ standard deviation.

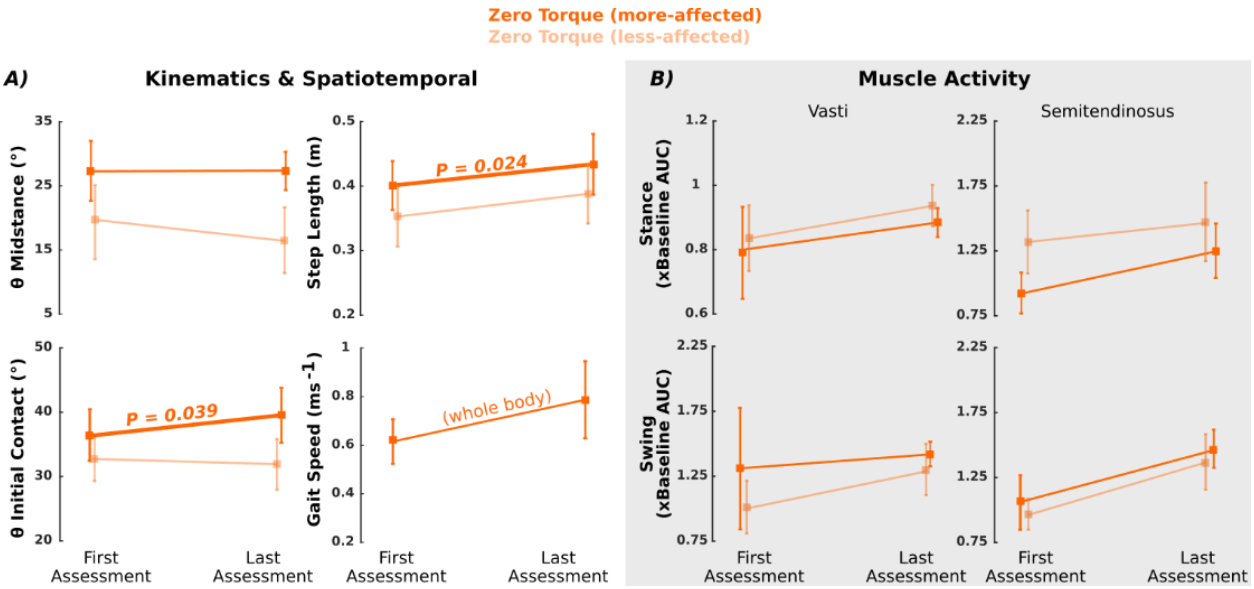

Fig. S5. Group-level change in biomechanical measures between first and last assessments during walking with the null exoskeleton. (**A**) Kinematic and spatiotemporal measures for the more-affected (dark shades) and less-affected (light shades) limbs, and change in whole body gait speed at the first and last assessment during walking with the exoskeleton set to zero torque assistance. (**B**) The change in muscle activity during exoskeleton walking relative to baseline was measured by area under the curve (AUC) for vastus lateralis and semitendinosus during stance (top row) and swing (bottom row) phases during the first and last assessments. EMG data during the exoskeleton trials were normalized by the EMG data from baseline walking within visits. For walking with the exoskeleton set to zero torque, there were no significant differences between assessments for vasti muscle activity during stance (more-affected limb, $P = 0.51$; less-affected limb, $P = 0.37$) and swing (more-affected limb, $P = 0.79$; less-affected limb, $P = 0.29$) or for the semitendinosus muscle activity during stance (more-affected limb, $P = 0.33$; less-affected limb, $P = 0.42$) and swing (more-affected limb, $P = 0.21$; less-affected limb, $P = 0.07$). All values plotted are group mean (n = 5); error bars denote ± ½ standard deviation. P1 and P5 were omitted from this group analysis because null exoskeleton data were not available for the first and last assessments, respectively. Bold lines and p-values indicate significant differences between visits (paired t-tests, $P < 0.05$).

Table S1. Knee torque measurement by exoskeleton condition and muscle strength. Values are mean (standard deviation) partitioned by gait phase. NA indicates data that were not available. Muscle strength is the mean across limbs as assessed in the seated position with the limb positioned at the midpoint of each participant's knee range of motion.

	Stance and Swing Torque (Nm/kg)		**Stance Only Torque (Nm/kg)**		**Swing Only Torque (Nm/kg)**		**Zero Torque (Nm/kg)**		**Knee Extensor Strength (Nm/kg)**	**Knee Flexor Strength (Nm/kg)**
	Stance	Swing	Stance	Swing	Stance	Swing	Stance	Swing		
P1	0.15 (0.03)	0.08 (0.04)	0.16 (0.01)	0.03 (0.04)	0.02 (0.02)	0.02 (0.02)	0.00 (0.00)	0.00 (0.00)	0.38 (0.01)	0.27 (0.04)
P2	0.12 (0.03)	0.06 (0.04)	0.08 (0.02)	0.00 (0.00)	0.01 (0.03)	0.06 (0.03)	0.00 (0.00)	0.00 (0.00)	0.94 (0.22)	0.55 (0.00)
P3	0.13 (0.05)	0.08 (0.04)	0.13 (0.05)	0.00 (0.01)	0.02 (0.05)	0.08 (0.02)	0.00 (0.00)	0.00 (0.00)	0.29 (0.01)	0.05 (0.01)
P4	0.32 (0.09)	0.03 (0.06)	0.24 (0.13)	0.00 (0.02)	0.03 (0.07)	0.11 (0.04)	0.00 (0.01)	0.00 (0.01)	1.08 (0.25)	0.39 (0.00)
P5	0.17 (0.02)	0.06 (0.05)	0.17 (0.03)	0.00 (0.02)	0.02 (0.06)	0.11 (0.05)	NA	NA	0.68 (0.19)	0.31 (0.01)
P6	0.16 (0.06)	0.07 (0.07)	0.16 (0.06)	0.02 (0.05)	0.02 (0.06)	0.06 (0.05)	0.00 (0.01)	0.00 (0.01)	1.11 (0.21)	0.29 (0.03)
P7	0.13 (0.03)	0.04 (0.04)	0.10 (0.03)	0.00 (0.02)	0.02 (0.04)	0.04 (0.02)	0.00 (0.01)	-0.01 (0.00)	0.69 (0.11)	0.32 (0.06)