

Preliminary validity of the Draw a Shape Test for upper extremity assessment in multiple sclerosis

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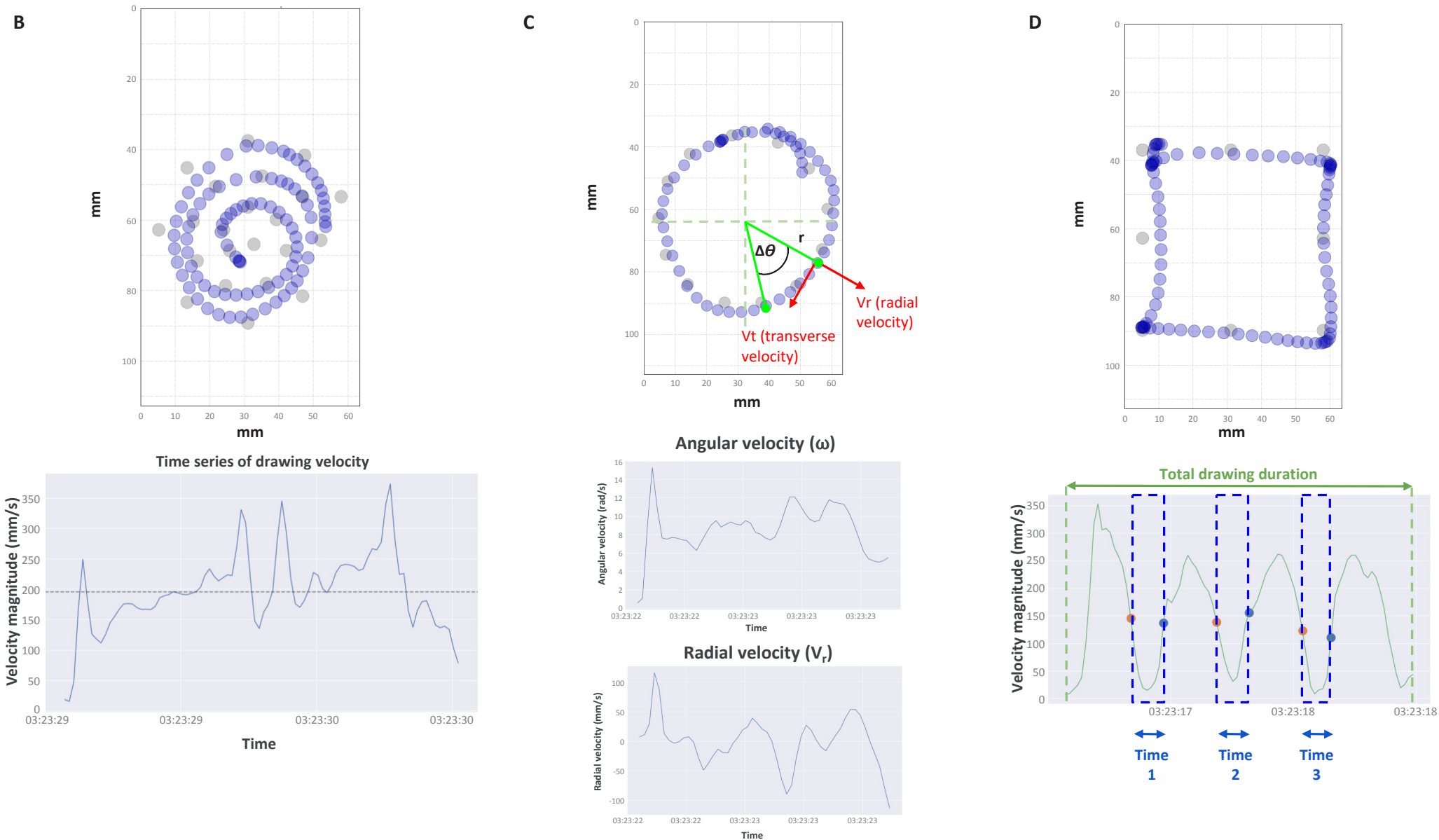
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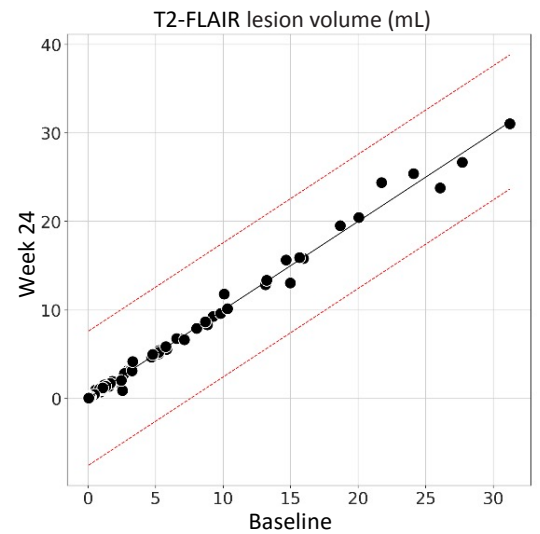
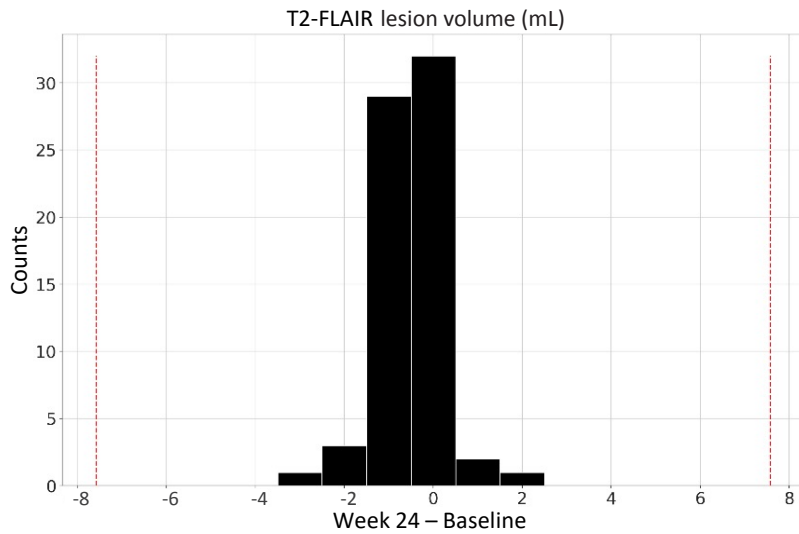
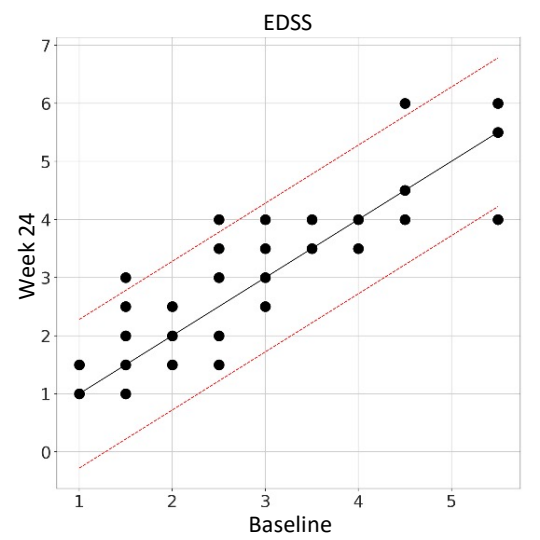
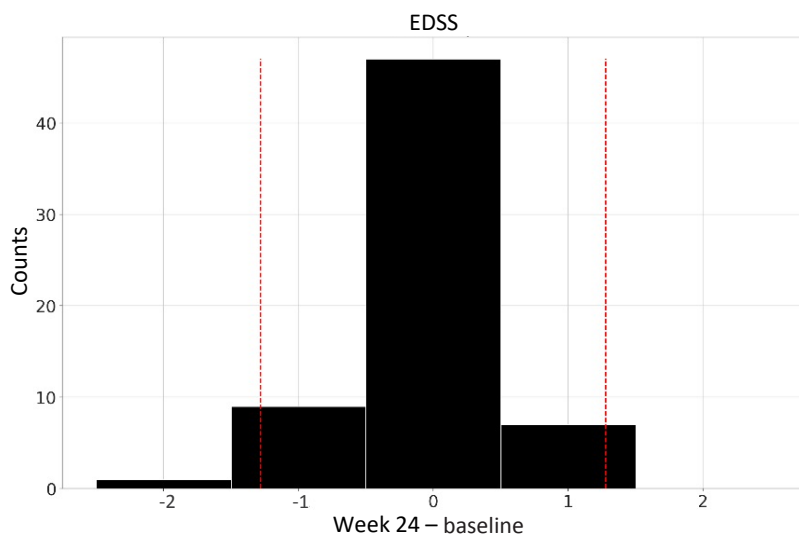
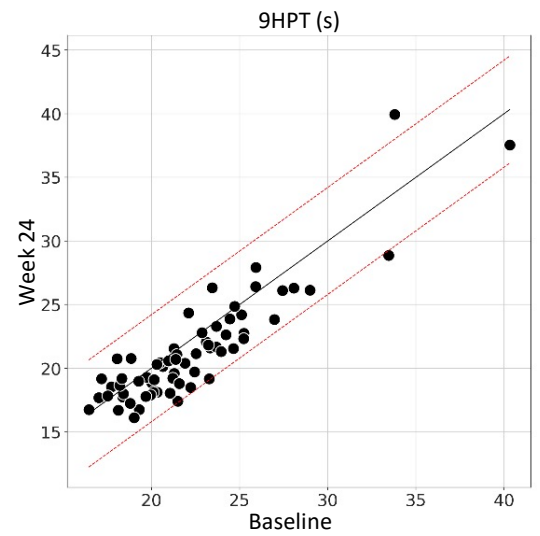
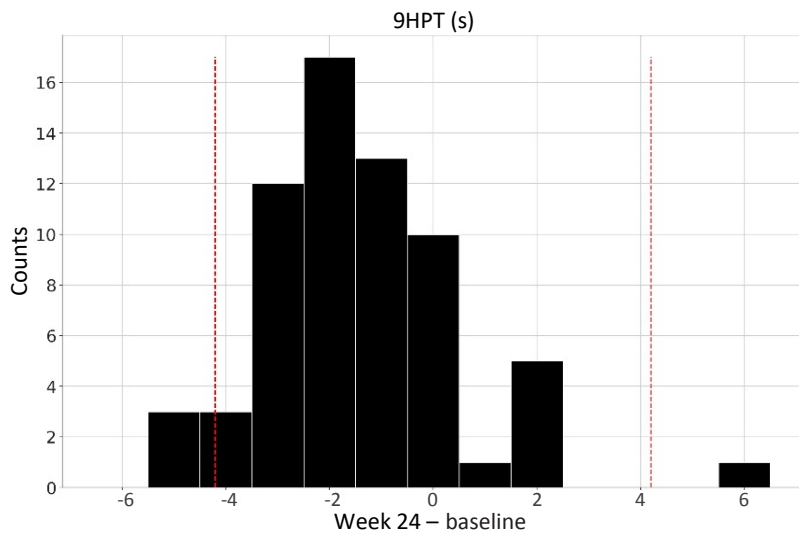
**At the time of writing author was an employee of F. Hoffmann-La Roche Ltd; current affiliation is Biogen, Cambridge, MA, US

A		
Feature	Computational definition	Variables
Spatial features		
Trace accuracy	$DT \cap RT$	DT : touch points of the drawn trace RT : reference shape trace
Temporal features		
Mean linear velocity, mm/s	$mean(\dot{y}(t_n))$	$\dot{y}(t_n) = \left. \frac{dy(t)}{dt} \right _{t=t_n}$: derivative of the displacement (mm/s) $y(t)$: the displacement time series as a function of time
CV linear velocity	$\frac{SD(\dot{y}(t_n))}{mean(\dot{y}(t_n))}$	$\dot{y}(t_n) = \left. \frac{dy(t)}{dt} \right _{t=t_n}$: derivative of the displacement (mm/s) $y(t)$: the displacement time series as a function of time
Mean angular velocity, rad/s	$mean(\dot{\theta}(t_n))$	$\dot{\theta}(t_n) = \left. \frac{d\theta(t)}{dt} \right _{t=t_n}$: derivative of the angular displacement (rad/s) $\theta(t)$: the angular displacement time series as a function of time
CV angular velocity	$\frac{SD(\dot{\theta}(t_n))}{mean(\dot{\theta}(t_n))}$	$\dot{\theta}(t_n) = \left. \frac{d\theta(t)}{dt} \right _{t=t_n}$: derivative of the angular displacement (rad/s) $\theta(t)$: the angular displacement time series as a function of time
Mean radial velocity, mm/s	$mean(\dot{r}(t_n))$	$\dot{r}(t_n) = \left. \frac{dr(t)}{dt} \right _{t=t_n}$: derivative of the radial displacement (mm/s) $r(t)$: the radial displacement time series as a function of time
CV radial velocity	$\frac{SD(\dot{r}(t_n))}{mean(\dot{r}(t_n))}$	$\dot{r}(t_n) = \left. \frac{dr(t)}{dt} \right _{t=t_n}$: derivative of the radial displacement (mm/s) $r(t)$: the radial displacement time series as a function of time
Dwell time ratio	$\frac{\sum_{i=1}^n t_i}{D_T}$	$\sum_{i=1}^n t_i$: total time spent at the corners ($n = 3$) of the SQUARE shape, computed as the full width at half minimum of the troughs in the velocity time series (s) D_T : total drawing time (s)
Spatiotemporal features		
Trace celerity, 1/s	$\frac{Trace\ accuracy}{D_T}$	D_T : total drawing time (s)



Supplementary figure 1. The Draw a Shape Test features.

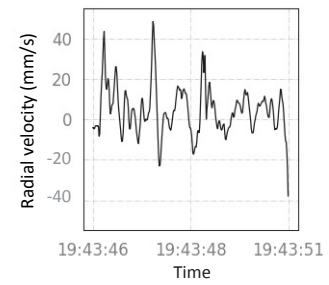
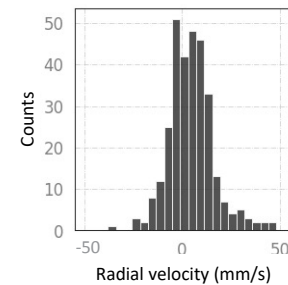
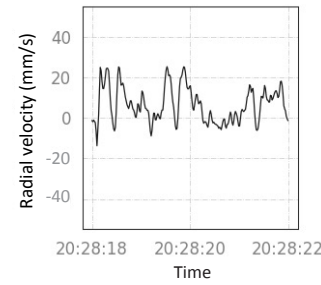
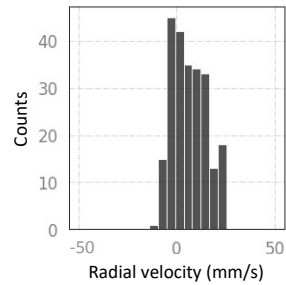
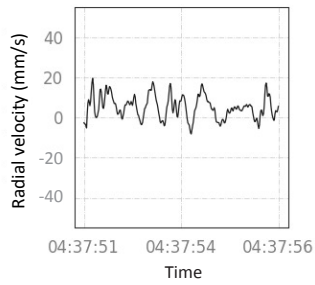
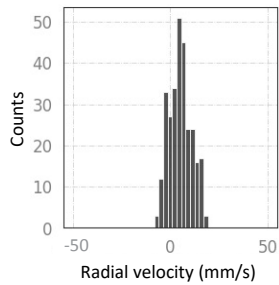
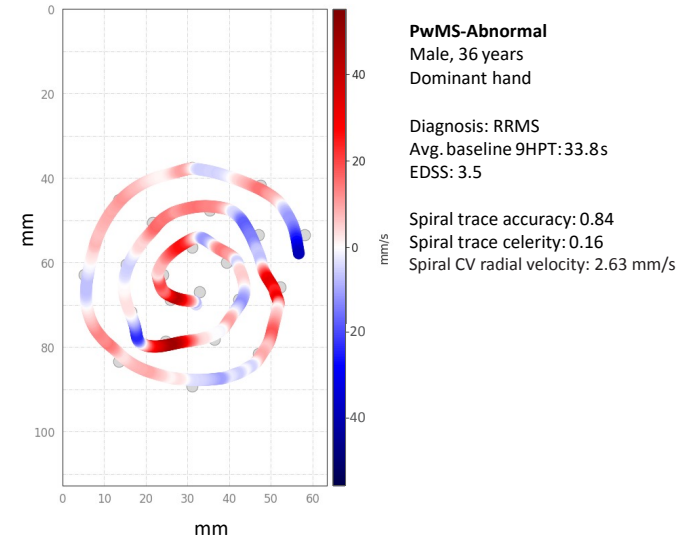
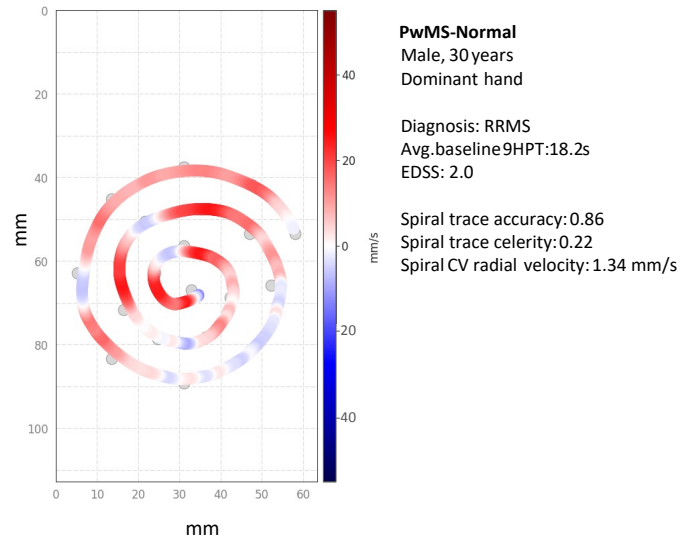
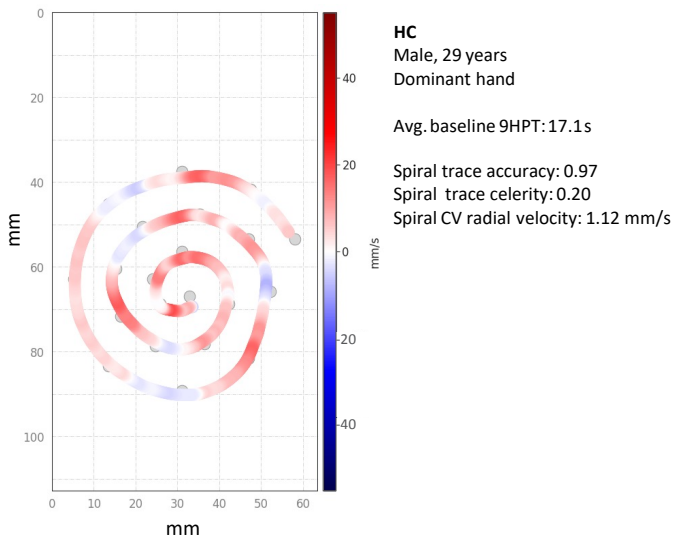
(A) Mathematical definitions for each of the feature groups. (B) Illustration of linear velocity with drawn trace (top) and time series (bottom). Linear velocity was computed as either the mean or the coefficient of variation (CV) over time for all shapes individually. (C) Illustration of angular and radial velocities with drawn trace (top) and time series (bottom). Angular and radial velocity features were computed as either the mean or the CV over time for the circle and spiral separately. (D) Illustration of dwell time ratio with drawn trace (top) and time series (bottom). Dwell time ratio is defined as the ratio of the time spent in the three corners of the square, computed as the full width at half minimum of the troughs in the velocity time series, divided by the total drawing duration measured in seconds. This feature was computed for the square only.



Supplementary figure 2. Clinical and MRI measures from baseline to week 24 (end of study).

Histograms (left) depicting the changes of 9HPT (top row), EDSS (middle row), and T2-FLAIR lesion volume (bottom row) from baseline to week 24. Scatter plots (right) showing relationship of each measure at baseline and week 24. The red-dashed lines indicate the standard deviation of the 9HPT, EDSS, and T2-FLAIR lesion volume measurements at baseline.

9HPT, Nine-Hole Peg Test; EDSS, Expanded Disability Status Scale; FLAIR, fluid-attenuated inversion recovery.



Supplementary figure 3. Increased variability in spiral radial velocity with higher levels of MS-related impairment.

The top row shows the drawn traces of the spiral shape for a HC (left), a PwMS-Normal (middle), and a PwMS-Abnormal (right), with the color bar indicating the radial velocity. The bottom row shows the corresponding histograms and time series of the spiral radial velocity.

9HPT, Nine-Hole Peg Test; CV, coefficient of variation; EDSS, Expanded Disability Status Scale; HC, healthy control; MS, multiple sclerosis; PwMS, people with multiple sclerosis; RRMS, relapsing-remitting multiple sclerosis.

Supplementary table 1. Spearman's rank correlations with standard clinical scales and MRI measures in PwMS by handedness.

Feature	Handedness	Spearman's rank correlation coefficient ¹						
		9HPT, s	MSIS-29 hand items	EDSS	EDSS cerebellar functional system	EDSS pyramidal functional system	Total brain volume, mL	T2-lesion volume, mL
9HPT time, s	D	1.00	0.50	0.57	0.65	0.44	-0.45	0.18
	ND	1.00	0.37	0.43	0.54	0.36	-0.41	0.32
Spatial features								
<i>Trace accuracy</i>								
Line bottom to top	D	-0.33	-0.36	-0.36	-0.16	-0.36	0.29	-0.19
	ND	-0.38	-0.30	-0.36	-0.26	-0.32	0.39	-0.34
Line top to bottom	D	-0.30	-0.32	-0.38	-0.23	-0.38	0.29	-0.14
	ND	-0.26	-0.34	-0.41	-0.23	-0.37	0.41	-0.24
Square	D	-0.32	-0.37	-0.36	-0.23	-0.34	0.32	-0.20
	ND	-0.44	-0.42	-0.43	-0.38	-0.38	0.46	-0.25
Circle	D	-0.36	-0.38	-0.37	-0.20	-0.35	0.24	-0.15
	ND	-0.41	-0.36	-0.40	-0.26	-0.37	0.37	-0.27
Figure-of-8	D	-0.44	-0.43	-0.38	-0.25	-0.34	0.23	-0.16
	ND	-0.42	-0.35	-0.33	-0.22	-0.30	0.37	-0.26
Spiral	D	-0.38	-0.45	-0.39	-0.22	-0.32	0.27	-0.24
	ND	-0.49	-0.38	-0.39	-0.27	-0.31	0.42	-0.29
Mean overall trace accuracy	D	-0.38	-0.43	-0.41	-0.22	-0.39	0.27	-0.21
	ND	-0.42	-0.40	-0.44	-0.28	-0.40	0.43	-0.30
Temporal features								
<i>Mean linear velocity, mm/s</i>								
Line bottom to top	D	-0.11	0.21	0.12	-0.18	0.16	0.10	-0.17
	ND	-0.19	0.18	0.19	-0.03	0.17	0.01	-0.04
Line top to bottom	D	-0.20	0.11	0.00	-0.25	0.03	0.17	-0.21
	ND	-0.24	0.17	0.12	-0.07	0.15	0.05	-0.01
Square	D	-0.15	0.16	0.08	-0.19	0.09	0.10	-0.12
	ND	-0.24	0.12	0.13	-0.04	0.12	0.00	-0.08
Circle	D	-0.12	0.17	0.12	-0.18	0.15	0.11	-0.11
	ND	-0.17	0.20	0.15	-0.08	0.14	0.02	-0.01
Figure-of-8	D	-0.14	0.15	0.06	-0.22	0.09	0.17	-0.13
	ND	-0.17	0.18	0.13	-0.10	0.14	0.04	0.00
Spiral	D	-0.13	0.17	0.07	-0.23	0.08	0.17	-0.13
	ND	-0.20	0.20	0.17	-0.08	0.15	0.01	0.01

CV linear velocity

Line bottom to top	D	0.09	0.13	0.10	-0.06	0.14	-0.09	-0.01
	ND	-0.09	-0.16	0.02	-0.04	0.05	-0.24	0.26
Line top to bottom	D	0.18	0.12	0.15	0.10	0.18	-0.11	0.00
	ND	0.13	-0.02	0.10	0.06	0.06	-0.28	0.21
Square	D	0.22	0.15	0.15	0.13	0.13	-0.16	0.21
	ND	0.21	0.06	0.15	0.14	0.16	-0.33	0.28
Circle	D	0.38	0.19	0.31	0.39	0.35	-0.40	0.25
	ND	0.47	0.06	0.13	0.28	0.20	-0.44	0.32
Figure-of-8	D	0.52	0.35	0.45	0.47	0.49	-0.35	0.35
	ND	0.55	0.15	0.28	0.32	0.31	-0.36	0.31
Spiral	D	0.48	0.42	0.39	0.41	0.27	-0.29	0.35
	ND	0.46	0.18	0.18	0.31	0.13	-0.37	0.39

Mean angular velocity, rad/s

Circle	D	-0.14	0.17	0.12	-0.19	0.14	0.12	-0.11
	ND	-0.17	0.20	0.16	-0.06	0.15	0.02	-0.01
Spiral	D	-0.15	0.14	0.05	-0.25	0.05	0.18	-0.13
	ND	-0.23	0.17	0.14	-0.10	0.13	0.06	-0.04

CV angular velocity

Circle	D	0.38	0.15	0.27	0.41	0.29	-0.40	0.24
	ND	0.48	0.05	0.11	0.27	0.17	-0.44	0.34
Spiral	D	0.27	0.12	0.15	0.19	0.10	-0.15	0.21
	ND	0.47	0.13	0.31	0.34	0.23	-0.24	0.22

Mean radial velocity, mm/s

Circle	D	0.14	0.11	0.15	-0.01	0.16	-0.17	-0.07
	ND	-0.04	-0.11	-0.13	-0.03	-0.15	-0.05	0.09
Spiral	D	-0.16	0.15	0.06	-0.22	0.06	0.19	-0.13
	ND	-0.26	0.16	0.12	-0.11	0.10	0.07	-0.03

CV radial velocity

Circle	D	0.20	0.02	0.11	0.19	0.07	-0.13	-0.05
	ND	0.12	-0.14	-0.08	0.02	-0.14	-0.11	0.08
Spiral	D	0.66	0.54	0.53	0.49	0.45	-0.39	0.28
	ND	0.61	0.35	0.45	0.41	0.39	-0.39	0.33

Dwell time ratio

Square	D	0.17	0.30	0.17	0.03	0.15	-0.15	0.24
	ND	0.17	0.25	0.22	0.13	0.22	-0.23	0.25

Spatiotemporal features

Trace celerity, 1/s

Line bottom to top	D	-0.26	0.10	-0.05	-0.28	0.00	0.25	-0.31
	ND	-0.39	0.12	0.02	-0.19	0.05	0.15	-0.15
Line top to bottom	D	-0.37	-0.02	-0.21	-0.39	-0.15	0.34	-0.32
	ND	-0.42	-0.02	-0.06	-0.16	-0.04	0.21	-0.12
Square	D	-0.30	0.05	-0.09	-0.34	-0.04	0.26	-0.25
	ND	-0.47	-0.03	-0.05	-0.17	-0.03	0.21	-0.17
Circle	D	-0.31	0.05	-0.03	-0.28	0.01	0.26	-0.20
	ND	-0.43	0.03	-0.05	-0.21	-0.03	0.19	-0.18
Figure-of-8	D	-0.37	-0.01	-0.13	-0.36	-0.07	0.31	-0.26
	ND	-0.48	0.00	-0.02	-0.16	0.01	0.25	-0.14
Spiral	D	-0.31	-0.01	-0.13	-0.38	-0.09	0.32	-0.23
	ND	-0.49	0.03	-0.05	-0.24	-0.03	0.26	-0.23
Mean overall	D	-0.33	0.04	-0.12	-0.35	-0.07	0.30	-0.29
trace celerity	ND	-0.45	0.06	-0.03	-0.20	0.01	0.22	-0.15

Higher values indicated better performance on features assessing trace accuracy, mean velocity, and trace celerity. Lower values indicated better performance on features assessing CV velocity and dwell time ratio.

9HPT, Nine-Hole Peg Test; CV, coefficient of variation; D, dominant hand; EDSS, Expanded Disability Status Scale; ND, nondominant hand; PwMS, people with multiple sclerosis.

¹Spearman's rank correlation coefficients highlighted in bold face are statistically significant at $p < 0.05$.

Supplementary table 2. Descriptive statistics by subject group and handedness.

Feature	Handedness	Mean \pm SD				p^1			
		HC (<i>n</i> = 18 for D; <i>n</i> = 18 for ND)	PwMS (<i>n</i> = 69 for D; <i>n</i> = 59 for ND)	PwMS- Normal (<i>n</i> = 47 for D; <i>n</i> = 49 for ND)	PwMS- Abnormal (<i>n</i> = 22 for D; <i>n</i> = 20 for ND)	HC vs. PwMS	HC vs. PwMS- Low	HC vs. PwMS- Abnormal	PwMS-Low vs. PwMS- Abnormal
Spatial features									
<i>Trace accuracy</i>									
Line bottom	D	0.90 \pm 0.08	0.87 \pm 0.11	0.88 \pm 0.12	0.83 \pm 0.11	0.368	0.837	0.050	0.080
to top	ND	0.94 \pm 0.09	0.92 \pm 0.11	0.95 \pm 0.10	0.87 \pm 0.11	0.543	0.888	0.047	0.006
Line top to	D	0.85 \pm 0.06	0.81 \pm 0.12	0.82 \pm 0.11	0.77 \pm 0.12	0.351	0.781	0.057	0.067
bottom	ND	0.91 \pm 0.07	0.89 \pm 0.10	0.91 \pm 0.10	0.83 \pm 0.09	0.516	0.734	0.012	0.003
Square	D	0.91 \pm 0.05	0.89 \pm 0.09	0.90 \pm 0.08	0.87 \pm 0.10	0.637	1.000	0.221	0.315
	ND	0.92 \pm 0.07	0.89 \pm 0.10	0.92 \pm 0.09	0.84 \pm 0.09	0.346	0.799	0.002	<0.001
Circle	D	0.94 \pm 0.05	0.91 \pm 0.09	0.92 \pm 0.09	0.88 \pm 0.11	0.463	0.815	0.142	0.149
	ND	0.90 \pm 0.08	0.87 \pm 0.11	0.90 \pm 0.10	0.80 \pm 0.10	0.432	0.682	0.002	<0.001
Figure-of-8	D	0.94 \pm 0.05	0.90 \pm 0.10	0.92 \pm 0.09	0.87 \pm 0.10	0.216	0.681	0.014	0.034
	ND	0.93 \pm 0.09	0.90 \pm 0.12	0.94 \pm 0.10	0.82 \pm 0.11	0.476	0.641	0.003	<0.001
Spiral	D	0.89 \pm 0.05	0.85 \pm 0.10	0.87 \pm 0.08	0.82 \pm 0.12	0.232	0.598	0.034	0.062
	ND	0.89 \pm 0.07	0.86 \pm 0.09	0.89 \pm 0.08	0.79 \pm 0.10	0.356	0.832	0.003	<0.001
Mean overall	D	0.88 \pm 0.04	0.85 \pm 0.09	0.87 \pm 0.09	0.83 \pm 0.10	0.314	0.681	0.065	0.099
trace accuracy	ND	0.91 \pm 0.07	0.88 \pm 0.09	0.91 \pm 0.08	0.82 \pm 0.09	0.373	0.788	0.002	<0.001
Temporal features									
<i>Mean linear velocity, mm/s</i>									
Line bottom	D	62.7 \pm 19.3	55.0 \pm 33.9	55.4 \pm 21.4	54.0 \pm 52.2	0.075	0.247	0.013	0.050
to top	ND	39.9 \pm 15.1	35.0 \pm 31.6	38.3 \pm 35.9	27.0 \pm 14.9	0.029	0.090	0.010	0.132
Line top to	D	61.7 \pm 19.7	55.2 \pm 32.0	56.9 \pm 20.4	51.4 \pm 48.9	0.078	0.333	0.006	0.009
bottom	ND	34.7 \pm 12.7	33.6 \pm 28.3	36.6 \pm 31.1	26.2 \pm 18.5	0.368	0.788	0.050	0.062
Square	D	58.1 \pm 9.9	50.0 \pm 19.4	52.2 \pm 14.4	45.3 \pm 26.9	0.024	0.139	0.002	0.012
	ND	39.9 \pm 7.8	34.6 \pm 19.1	37.3 \pm 20.3	27.9 \pm 13.9	0.035	0.174	0.002	0.038
Circle	D	51.7 \pm 11.7	46.1 \pm 24.3	47.5 \pm 15.5	43.2 \pm 37.1	0.065	0.305	0.004	0.017
	ND	33.0 \pm 8.2	30.5 \pm 24.3	33.2 \pm 26.7	24.0 \pm 15.6	0.084	0.264	0.012	0.083
Figure-of-8	D	44.9 \pm 9.1	38.1 \pm 21.2	39.2 \pm 13.7	35.7 \pm 32.1	0.008	0.045	0.001	0.028
	ND	27.5 \pm 6.7	24.0 \pm 21.0	26.6 \pm 23.3	17.6 \pm 12.1	0.031	0.098	0.009	0.057
Spiral	D	50.8 \pm 9.7	45.0 \pm 23.3	45.8 \pm 15.0	43.1 \pm 35.5	0.019	0.095	0.003	0.028
	ND	33.1 \pm 7.3	30.2 \pm 22.0	33.0 \pm 23.9	23.4 \pm 14.5	0.041	0.166	0.005	0.044

CV linear velocity

Line bottom to top	D	0.51 ± 0.07	0.53 ± 0.09	0.52 ± 0.09	0.53 ± 0.09	0.683	0.681	0.765	0.898
	ND	0.43 ± 0.06	0.47 ± 0.08	0.47 ± 0.08	0.46 ± 0.10	0.075	0.042	0.447	0.500
Line top to bottom	D	0.51 ± 0.08	0.53 ± 0.10	0.51 ± 0.10	0.56 ± 0.11	0.714	0.860	0.201	0.139
	ND	0.45 ± 0.06	0.49 ± 0.09	0.48 ± 0.09	0.50 ± 0.08	0.197	0.365	0.085	0.302
Square	D	0.55 ± 0.06	0.57 ± 0.10	0.55 ± 0.08	0.60 ± 0.13	0.600	0.895	0.265	0.189
	ND	0.49 ± 0.06	0.52 ± 0.08	0.51 ± 0.07	0.55 ± 0.09	0.271	0.641	0.035	0.033
Circle	D	0.31 ± 0.02	0.33 ± 0.04	0.32 ± 0.03	0.36 ± 0.05	0.018	0.177	< 0.001	0.002
	ND	0.36 ± 0.03	0.40 ± 0.05	0.38 ± 0.04	0.44 ± 0.06	0.004	0.045	< 0.001	< 0.001
Figure-of-8	D	0.34 ± 0.02	0.36 ± 0.04	0.35 ± 0.03	0.38 ± 0.06	0.080	0.519	< 0.001	0.001
	ND	0.37 ± 0.03	0.40 ± 0.05	0.39 ± 0.04	0.45 ± 0.06	0.041	0.420	< 0.001	< 0.001
Spiral	D	0.31 ± 0.03	0.35 ± 0.05	0.33 ± 0.03	0.38 ± 0.07	< 0.001	0.015	< 0.001	< 0.001
	ND	0.38 ± 0.05	0.43 ± 0.06	0.41 ± 0.04	0.47 ± 0.07	0.004	0.048	< 0.001	< 0.001

Mean angular velocity, rad/s

Circle	D	1.93 ± 0.45	1.73 ± 0.94	1.78 ± 0.59	1.63 ± 1.45	0.070	0.326	0.004	0.016
	ND	1.24 ± 0.30	1.15 ± 0.92	1.25 ± 1.02	0.90 ± 0.59	0.080	0.258	0.011	0.086
Spiral	D	3.06 ± 0.61	2.71 ± 1.42	2.77 ± 0.92	2.59 ± 2.16	0.020	0.107	0.002	0.022
	ND	1.97 ± 0.39	1.83 ± 1.35	2.02 ± 1.48	1.37 ± 0.83	0.039	0.198	0.002	0.019

CV angular velocity

Circle	D	0.30 ± 0.02	0.33 ± 0.05	0.31 ± 0.03	0.35 ± 0.06	0.015	0.124	< 0.001	0.002
	ND	0.36 ± 0.03	0.40 ± 0.06	0.38 ± 0.04	0.45 ± 0.07	0.003	0.039	< 0.001	< 0.001
Spiral	D	0.54 ± 0.04	0.53 ± 0.06	0.53 ± 0.05	0.54 ± 0.07	0.958	0.837	0.605	0.309
	ND	0.55 ± 0.05	0.55 ± 0.07	0.54 ± 0.06	0.59 ± 0.08	0.967	0.351	0.070	0.003

Mean radial velocity, mm/s

Circle	D	0.02 ± 0.27	0.02 ± 0.31	-0.01 ± 0.24	0.09 ± 0.43	0.489	0.509	0.568	0.857
	ND	0.10 ± 0.32	0.18 ± 0.38	0.21 ± 0.40	0.12 ± 0.34	0.777	0.724	0.953	0.751
Spiral	D	4.34 ± 0.84	3.79 ± 1.86	3.89 ± 1.21	3.57 ± 2.82	0.017	0.086	0.003	0.020
	ND	2.93 ± 0.55	2.65 ± 1.79	2.93 ± 1.93	1.98 ± 1.15	0.021	0.134	< 0.001	0.009

CV radial velocity

Circle	D	0.79 ± 10.91	1.39 ± 8.85	0.82 ± 8.74	2.59 ± 9.16	0.550	0.379	0.935	0.328
	ND	13.86 ± 11.02	13.65 ± 12.29	12.99 ± 12.67	15.28 ± 11.46	0.536	0.724	0.320	0.355
Spiral	D	1.71 ± 0.16	1.87 ± 0.39	1.74 ± 0.24	2.16 ± 0.05	0.241	0.815	< 0.001	< 0.001
	ND	2.23 ± 0.29	2.43 ± 0.58	2.22 ± 0.37	2.94 ± 0.67	0.402	0.488	< 0.001	< 0.001

Dwell time ratio

Square	D	0.39 ± 0.04	0.37 ± 0.07	0.37 ± 0.06	0.38 ± 0.07	0.483	0.403	0.786	0.662
	ND	0.39 ± 0.05	0.39 ± 0.06	0.38 ± 0.05	0.42 ± 0.07	0.942	0.534	0.279	0.059

Spatiotemporal features

Trace celerity, s⁻¹

Line bottom	D	0.82 ± 0.23	0.67 ± 0.33	0.70 ± 0.23	0.61 ± 0.48	0.013	0.074	0.002	0.009
to top	ND	0.59 ± 0.16	0.52 ± 0.30	0.58 ± 0.33	0.38 ± 0.16	0.049	0.302	< 0.001	0.002
Line top to	D	0.70 ± 0.20	0.58 ± 0.31	0.63 ± 0.21	0.48 ± 0.44	0.037	0.278	< 0.001	< 0.001
bottom	ND	0.46 ± 0.13	0.43 ± 0.27	0.49 ± 0.29	0.28 ± 0.14	0.167	0.944	< 0.001	< 0.001
Square	D	0.25 ± 0.04	0.20 ± 0.06	0.22 ± 0.05	0.18 ± 0.06	0.002	0.014	< 0.001	0.003
	ND	0.17 ± 0.03	0.15 ± 0.06	0.16 ± 0.05	0.11 ± 0.04	0.007	0.092	< 0.001	< 0.001
Circle	D	0.28 ± 0.05	0.24 ± 0.07	0.25 ± 0.05	0.21 ± 0.09	0.012	0.110	< 0.001	0.001
	ND	0.19 ± 0.03	0.16 ± 0.06	0.18 ± 0.06	0.12 ± 0.04	0.010	0.179	< 0.001	< 0.001
Figure-of-8	D	0.30 ± 0.05	0.24 ± 0.08	0.26 ± 0.06	0.21 ± 0.10	0.002	0.022	< 0.001	< 0.001
	ND	0.20 ± 0.03	0.17 ± 0.07	0.20 ± 0.07	0.12 ± 0.04	0.004	0.110	< 0.001	< 0.001
Spiral	D	0.16 ± 0.03	0.13 ± 0.04	0.14 ± 0.03	0.12 ± 0.06	0.003	0.030	< 0.001	0.002
	ND	0.11 ± 0.01	0.09 ± 0.04	0.10 ± 0.04	0.07 ± 0.03	0.006	0.110	< 0.001	< 0.001
Mean overall	D	0.42 ± 0.08	0.35 ± 0.14	0.37 ± 0.10	0.30 ± 0.19	0.009	0.071	< 0.001	0.002
trace celerity	ND	0.29 ± 0.05	0.26 ± 0.12	0.29 ± 0.13	0.18 ± 0.07	0.026	0.302	< 0.001	< 0.001

Higher values indicated better performance on features assessing trace accuracy, mean velocity, and trace celerity. Lower values indicated better performance on features assessing

CV velocity and dwell time ratio. *p* values in bold are < 0.05.

CV, coefficient of variation; D, dominant hand; HC, healthy control; ND, nondominant hand; PwMS, people with multiple sclerosis.

¹Mann–Whitney U test.