Supplementary Methods, Results, and Task Schematic

Methods

Task Success Range

Skill assessments provided empirical samples of task-level error rates across nine discrete movement times. This data was used to model the continuous relationship between error rates and movement times, allowing the determination of the highest level of performance that a participant could achieve. We predicted that the severity of a participant's motor impairment would affect the range of movement times over which they were able to successfully perform the task. We hypothesized that training in the task could increase this range, which would be characterized by a reduction of the minimum movement time at which a participant could successfully complete the task.

A previously defined, empirically derived 'speed accuracy function' (SAF) model [1,2] was fit to the data:

$$\text{model predicted error rate} = 1/[1+a(\ln(\text{trial duration})^{b})]$$

The two-parameter SAF model defines the relationship between speed and accuracy. Parameters A and B are empirically defined parameters approximating to an inflection point and slope, respectively. These were determined for each group by fitting the model to the collected data. Separate SAF models were fit to the data from the pre and post-training skill assessments for each participant. Model predicted error rates were interpolated across movement times ranging from 0 to 14 seconds at 100ms intervals. Using SAF model fits for the pre and post-training skill assessments for each participant, we identified the highest level of performance that the model predicted the participant could achieve before and after training. This corresponded to the minimum trial duration at which the participant would have been able to complete a skill assessment with at least one success (i.e. equating to an error rate of 95%, or one success in twenty attempts).

Trial targets attempted

The task level analysis considered only trials where participants hit all five targets to be successful. Errors could thus arise due to the participant missing a target (i.e. deficits in accuracy, examined in another analysis), or failing to attempt to move the cursor to all five of the targets in the allotted time (i.e. failing to produce forces at the required rate). Here we examined the number of displacements of the cursor from the home position, assessing whether the participant made an attempt to each of the five targets on each trial. The number of target attempts was recorded for each trial, and results were submitted to a mixed model ANOVA with factors of *trial duration*, *session*, and *group*.

Trial Endpoint Variability

Previous studies suggest motor learning can be characterized as a reduction in variability of motor control[3–7]. Cursor endpoint standard deviation for the attempt to hit each target was calculated from the absolute (unsigned) distance of the cursor relative to the target, then summed for each trial. These data were submitted to a mixed-design ANOVA with factors of *trial duration*, *session*, and *group*.

Differences between targets

Targets closer to the home position required the production of smaller, more precise forces. A further analysis examined the effect of target on endpoint errors. As in the main manuscript, magnitudes of errors when attempting to hit each of the targets were measured as the shortest distance from the cursor endpoint to the outer boundary of the corresponding target (consistent with errors participants observed during the task). Any attempts falling within the target boundaries thus had 0cm error. Error was analyzed using a mixed-model ANOVA with factors of duration, session, target, and group.

Trial Durations in Skill Assessments

In skill assessments participants completed trials in time with an auditory metronome, allowing us to manipulate trial duration as an independent variable. The primary motivation for requiring participants to complete trials in a fixed time was to control for between-group differences in movement speed that would confound comparisons. We probed for the presence of any differences in trial duration using a mixed-model ANOVA on trial duration, examining the factors of *duration, session,* and *group*.

Results

The SAF model predicted a larger range of success following training

The SAF model was fit to the data acquired from each skill assessment for each individual participant (average $r^2 = 0.92 \pm 0.07$; see Fig I A-C). The model was used to determine the range of task level success for each subject by predicting the highest level of performance they could achieve. This was quantified as the movement time corresponding to a 95% error rate (or, the fastest trial duration at which, if tested, the participant would have made at least 1 success in the 20 trials recorded). An ANOVA revealed a significant difference between the pre training range of task success across groups $F_{2,27}=10.38$, $p<0.001$. Both the healthy control and mild-to-moderate impairment groups could successfully complete the task at significantly faster speeds than the moderate-to-severe impairment group ($p<0.001$ and $p<0.01$, respectively). All groups were able to significantly improve their range of success between the pre and post-training skill assessments (all $p<0.05$, see Fig I D-F). An ANOVA comparing post training range of performance revealed a significant difference between groups, $F_{2,27}=16.93$, $p<0.001$. Again, the healthy control and mild-to-moderate impairment groups could complete the task at significantly shorter trial durations than participants in the moderate-to-severe impairment group (both $p<0.001$).

After Training Participants Made More Cursor Movements In Fast Trials

A mixed model ANOVA examining the number of movements made per trial during the skill assessments (see Supplementary Fig II A) revealed a significant main effect of *trial duration*, $F(8,216)=27.699$, $p<0.001$, and a significant *trial duration x group* interaction, F(16,216)=6.011, p<0.001. There was also a significant main effect of *session*, F(1,27)=12.534, p=0.001, and a *trial duration x session* interaction, F(8,216) = 6.748, p<0.000. As expected, all participants made fewer cursor movements when performing the task at faster trial durations. This effect was more prominent in patients with higher impairment level, whereby the moderate-to-severe group made less movements than the mild-to-moderate or healthy control groups. After training, the number of attempts to hit the targets when performing trials at high speeds improved for all groups.

Training Reduced Cursor Endpoint Variability

A mixed-design ANOVA examining cursor endpoint variability (see Fig II B) revealed significant main effects of *trial duration*, $F_{8,216}$=64.536, p<0.001, and *session*, F(1,27)=35.016, p<0.000, and a *duration x group* interaction, $F_{16,216}$=27.708, p=0.008. Participants had greater endpoint variability when moving at shorter trial durations. This varied by group, such that control participants were less variable than mild participants, who in turn were less variable than severe participants (post hoc comparisons on mean performance across groups, p<0.05). Participants made less variable movements after training.

Error was greater for targets requiring smaller, more precise contractions

A mixed-design ANOVA examining cursor endpoint error for each target revealed that participants made significantly greater errors when attempting to move to targets closer to the home position (i.e those requiring smaller, more precise forces to hit; main effect of target, $F_{4,108}$=2509.78, *p*<0.001). This effect was greater when participants completed faster trials (target x duration interaction, $F_{32,864}$=50.51, p<0.001), particularly for those with greater impairment (target x duration x group interaction, $F_{64,864}$=5.752, p<0.001). Training led participants to make less error in their movements (main effect of session, $F_{1,27}$=8.05, p<0.01). In particular, training allowed participants with greater impairment to make fast movements with less error (*target* x *duration* x *session* x *group* interaction, $F_{64,864}$=2.11, p<0.001). Fig 4B illustrates these effects.

Trial durations were well matched in skill assessments

A mixed-model ANOVA examining trial durations in skill assessments revealed no significant differences in trial durations across groups (main effect of *group*, and interactions for *session x group*, *desired trial duration x group*, and *session x desired trial duration x group* effects all F<2.0, p>0.1. There was a trivial main effect of trial duration, confirming that participants performed faster trials in less time ($F_{8,16}$=661.38, p<0.001). Following training, there was a tendency for participants to complete slower trials at marginally faster speeds (i.e. trials with durations of 12.5s - 6.6s were each completed on average 348ms faster after training, significant *session x duration* interaction, $F_{8,16}$=3.30, p<0.01). We consider this to represent a marginal change in participant trial durations (i.e. a ~350ms change represents <5% of the attempted movement times). Critically, as these marginal increases in speed were accompanied by increases in accuracy for all groups (see main results), these results are consistent with the view that training improved the speed-accuracy trade-off for all groups.

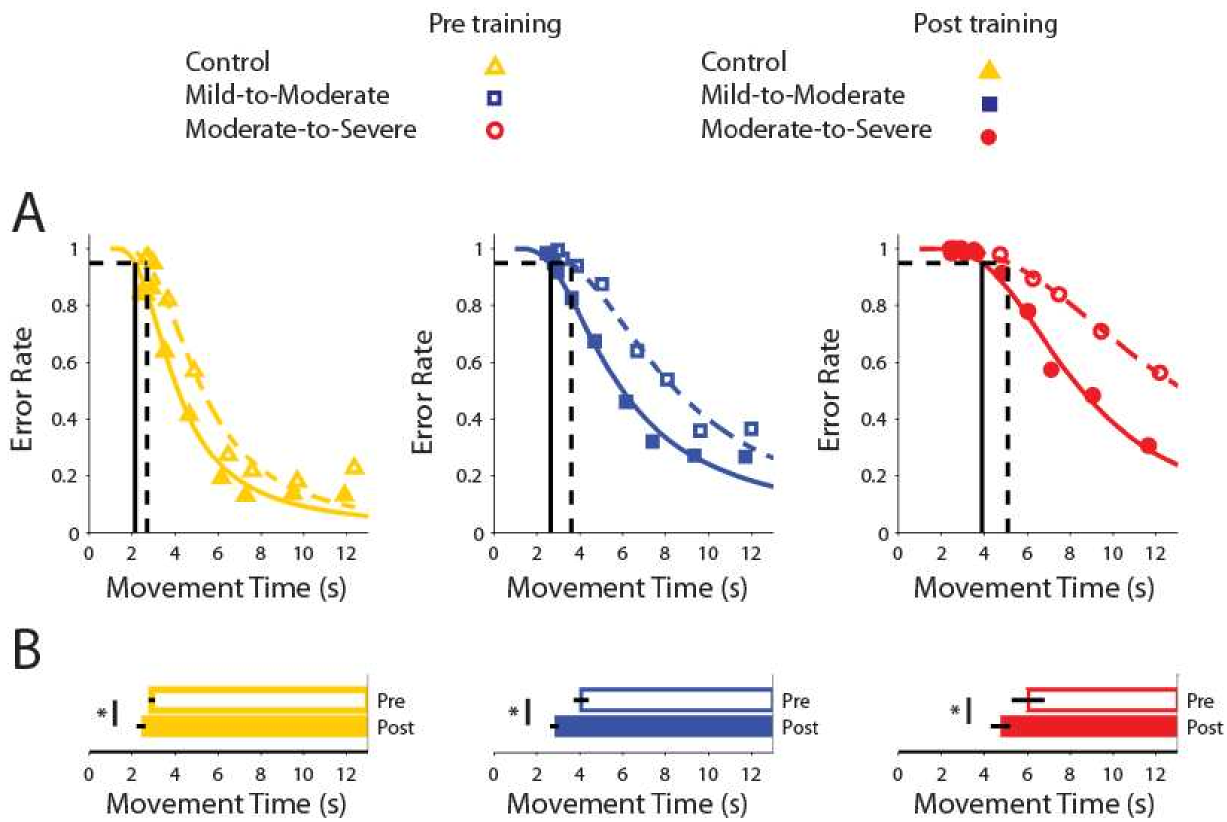

Fig I: SAF model fits and the range of task level success. *Data for the control, mild-to-moderate impairment, and moderate-to-severe impairment groups are shown in yellow, blue, and red, respectively. Open shapes show performance before training, close shapes show performance after training. A) SAF model fit to group data for illustrative purposes (note that all analyses were conducted on model fits to individual data). Color-coded dashed and solid colored lines show model fits to data from pre and post training skill assessments, respectively. Black dashed and solid black lines illustrate the measure used to determine the range of task level success for the pre and post training assessments, respectively. B) Illustration of the significant pre-post changes in the range of task success for each group.*

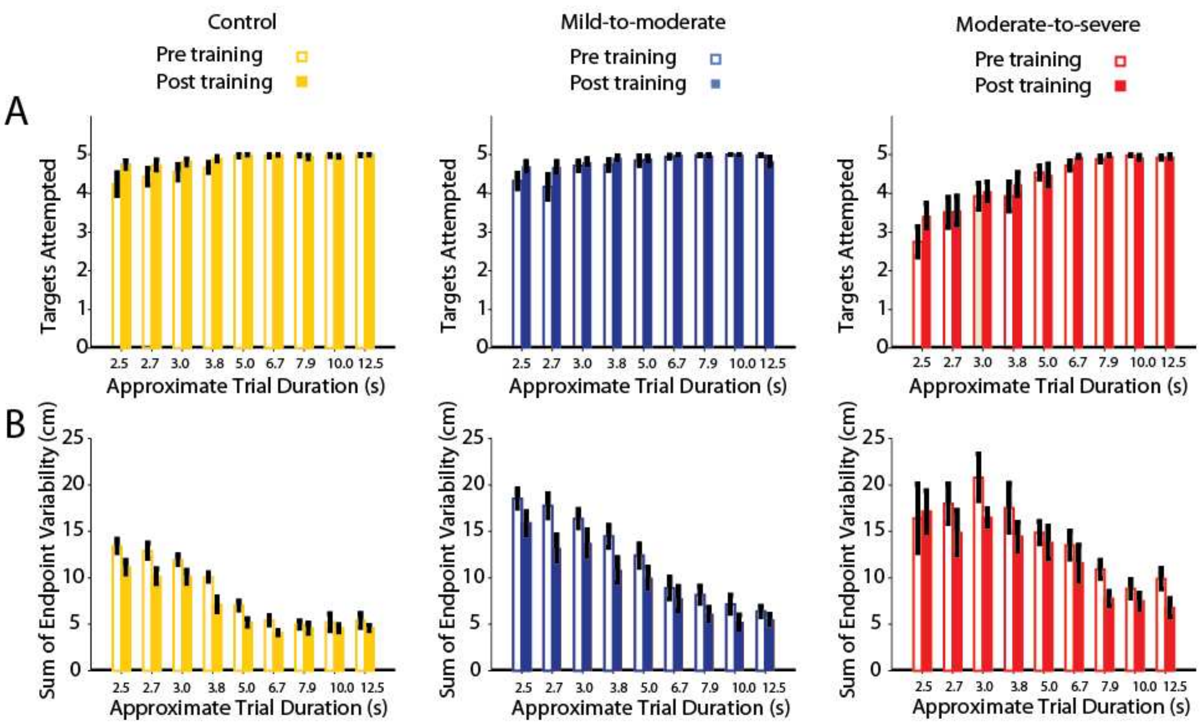

Fig II: Trial Targets Attempted and Trial Endpoint Variability analyses*. Data for the control, mild-to-moderate impairment, and moderate-to-severe impairment groups are shown in yellow, blue, and red, respectively. Open bars show pre-training performance, filled bars show post-training performance. A) Within group comparisons of the number of targets attempted pre and post-training. B) Endpoint variability when attempting to hit the targets pre and post training.*

Schematic of Visual Display

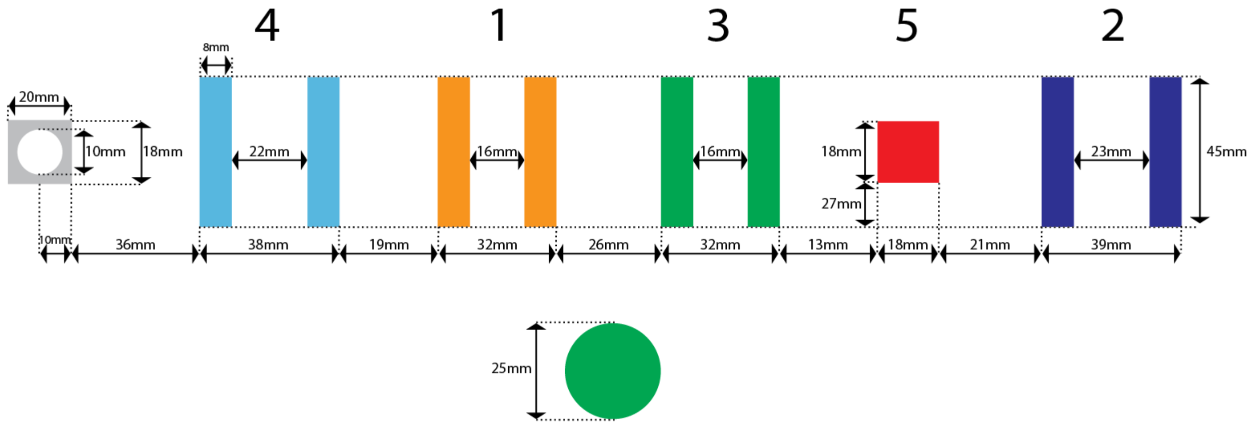

Fig III: Schematic of visual display with dimensions*. Note that as described in the main manuscript participants 'hit' a target if the cursor stopped within its boundaries (e.g. participants hit target 4 if the center of the cursor stopped within the 38mm region between the two outer edges of the target)."*

References:

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