LEARNING EFFECTS STUDY: REPORT

SARAH GREGOR

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OVERVIEW OF PROJECT:

Some of the ongoing studies that use the KINARM (Kinesiological Instrument for Normal and Altered Reaching Movements) End-Point robot have patients come back and complete the same tasks at multiple time points. Repeated measurements are done in order to quantify any improvements in daily functioning, by looking at changes in patient's scores on each task completed. However, it is important to rule out the possibility of learning, for example how to maneuver the robot or complete the tasks, as a cause of the improvements seen. Recognizing the repeated task variability that naturally occurs is another important aspect to understand, in order to make conservative judgments about when a score should be considered abnormal. This study was undertaken in order to quantify the learning effects seen when repeatedly using the KINARM End-Point as well as to understand what repeated task variability can be expected for the different parameters of each task completed. We propose that most learning is likely to occur between time point 1 (week 1) and time point 2 (week 2), and any change in score that occurs after time point 2 is likely due to retest variability.

METHODS:

PARTICIPANTS

A total of 10 healthy subjects (20–23 years of age, 6 females, 4 males) from Queen's University participated in a 1-hour KINARM session a week, for 6 weeks. Healthy participants in this age range were selected, as they likely will exhibit the most dramatic learning effects possible as compared to the rest of the population. Participants came in at the same time each week +/- 1 day. The subjects were all right-handed, had normal or corrected vision, and reported no neurological or musculoskeletal disorders. Each subject provided a written informed consent and was compensated for their time.

ROBOTIC ASSESSMENT

All assessments were done using the KINARM End-Point robot (BKIN Technologies Ltd, Kingston). Participants sat in a chair that was adjusted to the appropriate height for him or her to see the screen in front of them. The chair was then locked into place and vision to their arms was occluded. Subjects completed tasks seen on a virtual reality platform by maneuvering handles that move in the same horizontal plane of the screen.

All participants completed the same 11 tasks per session in the same order. These included: visual guided reaching, visual reverse fast timing: non-displacement, arm position – matching, kinesthesia, trail making (version A and B), spatial span, perturbation, ball on bar,

object hit, and object hit and avoid. For both versions of the trail making task, participants were randomly assigned to complete a single pattern per session until all 3 patterns were completed. For the weeks 4-6 they repeated the patterns in the same order as they had done previously (eg. 1-3-2-1-3-2). For the object hit and avoid task, participants were randomly assigned to complete one of the six versions of the task per session. This resulted in all participants completing each version of the task in a different order, with everyone completing each version only once.

STATISTICAL ANALYSIS:

All analyses were done using MATLAB (Mathworks, Inc, *Natick,* Massachusetts, USA). Analyses were not done for the visual reverse fast timing: non-displacement, kinesthesia, perturbation or ball on bar tasks as the software needed for analysis has yet to be developed.

Tasks included in the analysis had their week-to-week results for each test parameter compared using a paired t-test at a statistical significance of 0.01. The null hypothesis was that there is no significant difference in participant scores per parameter between weeks. We propose that if the null hypothesis is rejected, this may indicate that learning has occurred. Due to our hypothesis that most learning occurs between weeks 1 and 2, the mean change and standard deviation (SD) of the change between these weeks were also measured to further quantify any improvements. Mean change was calculated by subtracting the first time point from the second time point. Lastly, the mean, SD, and standard error of the mean (SEM) for each participant was measured for each test parameter that was analyzed. Only results from weeks 2 to 6 were included in this analysis in order to rule out any possible deviation due to learning. We believe that the average SD found between all participants for a specific test parameter can be used to help determine re-test variability for that parameter.

RESULTS:

Across all nine tasks, 97 parameters were analyzed. Tables 1 – 9 display separate summary tables for each task examined, consisting of all the analyses done for each test parameter of that specific task. The tables include the analysis of the overall mean change in scores and SD between weeks 1 and 2 in order to help quantify any changes found when learning is expected to occur. We then included the results of paired t-tests comparing consecutive week results for each test parameter. We found seven parameters between weeks 1 and 2 and two parameters between weeks 3 and 4 that reject the null hypothesis of no significant change in score. Comparing weeks 4 and 5, four parameters rejected the null hypothesis; however, two of these parameters are likely dependent on each other (matching right hand parameters: variability X and variability X/Y). Each test parameter that rejected the

null hypothesis can be found in Table 10. Lastly, the summary tables include the SD of the mean score found between the non-learning weeks, weeks 2 to 6, for each test parameter. These values are included in order to understand what retest variability should be expected. We conclude from the data that only limited learning may occur when using the KINARM End-Point robot repeatedly, mostly occurring between first and second uses.

APPENDIX:

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Posture speed (m/s)	0.001	0.002	0	0	0	0	0	0.001
Reaction time (s)	0.010	0.019	0	0	0	0	0	0.018
No reaction time	0.000	0.000	NaN	NaN	NaN	0	0	0.045
Initial direction error (rad)	-0.007	0.006	1	0	0	0	0	0.005
Initial distance ratio	0.023	0.028	0	0	0	0	0	0.018
Initial speed ratio	0.008	0.018	0	0	0	0	0	0.018
Speed maxima count	-0.324	0.394	0	0	0	0	0	0.239
Min max speed difference (m/s)	-0.004	0.007	0	0	0	0	0	0.003
Movement time (s)	-0.120	0.095	1	0	0	0	0	0.072
Path length ratio	-0.033	0.049	0	0	0	0	0	0.021
Max speed (m/s)	0.026	0.057	0	0	0	0	0	0.037
No movement end count	0.000	0.000	NaN	NaN	NaN	0	0	0.045

Z - Posture speed (m/s)	0.362	0.912	0	0	0	0	0	0.679
Z - Reaction time (s)	0.357	0.640	0	0	0	0	0	0.602
Z - Initial direction error (rad)	-0.796	0.721	1	0	0	0	0	0.593
Z - Initial distance ratio	0.882	1.034	0	0	0	0	0	0.663
Z - Speed maxima count	-0.861	1.046	0	0	0	0	0	0.635
Z - Min max speed difference (m/s)	-0.629	1.049	0	0	0	0	0	0.527
Z - Movement time (s)	-0.891	0.694	1	0	0	0	0	0.492
Z - Path length ratio	-0.648	0.970	0	0	0	0	0	0.465
Z - Max speed (m/s)	0.394	0.944	0	0	0	0	0	0.569

Table 1: Visual Guided Reaching: Left Hand

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Posture speed (m/s)	0.000	0.001	0	0	0	0	0	0.001
Reaction time (s)	0.005	0.014	0	0	0	0	0	0.023
No reaction time	0.000	0.000	NaN	NaN	NaN	NaN	NaN	0.000
Initial direction error (rad)	-0.003	0.007	0	0	0	0	0	0.006
Initial distance ratio	0.007	0.022	0	0	0	0	0	0.017
Initial speed ratio	-0.001	0.029	0	0	0	0	0	0.017
Speed maxima count	-0.168	0.317	0	0	0	0	0	0.295
Min max speed difference (m/s)	0.000	0.004	0	0	0	0	0	0.003
Movement time (s)	-0.097	0.135	0	0	0	0	0	0.062
Path length ratio	-0.011	0.023	0	0	0	0	0	0.024
Max speed (m/s)	0.050	0.041	1	0	0	0	0	0.035
No movement end count	0.000	0.000	NaN	NaN	NaN	NaN	NaN	0.000
Z - Posture speed (m/s)	0.243	0.507	0	0	0	0	0	0.594
Z - Reaction time (s)	0.216	0.525	0	0	0	0	0	0.702

Z - Initial direction error (rad)	-0.412	0.781	0	0	0	0	0	0.690
Z - Initial distance ratio	0.265	0.832	0	0	0	0	0	0.634
Z - Speed maxima count	-0.447	0.841	0	0	0	0	0	0.783
Z - Min max speed difference (m/s)	0.022	0.551	0	0	0	0	0	0.641
Z - Movement time (s)	-0.654	1.017	0	0	0	0	0	0.415
Z - Path length ratio	-0.232	0.479	0	0	0	0	0	0.654
Z - Max speed (m/s)	0.773	0.635	1	0	0	0	0	0.531

Table 2: Visual Guided Reaching: Right Hand

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Variability X (m)	-0.003	0.007	0	0	0	0	0	0.005
Variability Y (m)	-0.001	0.004	0	0	0	0	0	0.002
Variability XY (m)	-0.003	0.007	0	0	0	0	0	0.004
Contraction/expansion ratio X	-0.035	0.089	0	0	0	0	0	0.066
Contraction/expansion ratio Y	0.012	0.061	0	0	0	0	0	0.048
Contraction/expansion ratio XY	-0.016	0.106	0	0	0	0	0	0.092
Shift X (m)	0.008	0.041	0	0	0	0	0	0.021
Shift Y (m)	-0.008	0.007	1	0	0	0	0	0.009
Shift XY (m)	-0.003	0.030	0	0	0	0	0	0.013
Abs error X (m)	-0.002	0.023	0	0	0	0	0	0.010
Abs error Y (m)	0.000	0.005	0	0	0	0	0	0.004
Abs error XY (m)	-0.002	0.020	0	0	0	0	0	0.008

Z - Variability X (m)	-0.397	1.008	0	0	0	0	0	0.651
Z - Variability Y (m)	-0.188	1.211	0	0	0	0	0	0.544
Z - Variability XY (m)	-0.340	1.032	0	0	0	0	0	0.593
Z - Contraction/expansion ratio X	-0.250	0.640	0	0	0	0	0	0.474
Z - Contraction/expansion ratio Y	0.134	0.681	0	0	0	0	0	0.541
Z - Contraction/expansion ratio XY	-0.085	0.580	0	0	0	0	0	0.503
Z - Shift X (m)	0.199	1.060	0	0	0	0	0	0.544
Z - Shift Y (m)	-0.453	0.401	1	0	0	0	0	0.538
Z - Shift XY (m)	-0.166	1.669	0	0	0	0	0	0.693
Z - Abs error X (m)	-0.054	1.565	0	0	0	0	0	0.653
Z - Abs error Y (m)	-0.025	0.764	0	0	0	0	0	0.606
Z - Abs error XY (m)	-0.027	1.423	0	0	0	0	0	0.578

Table 3: Arm Position Matching: Left Hand

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Variability X (m)	-0.006	0.007	0	0	0	1	0	0.004
Variability Y (m)	-0.002	0.003	0	0	0	0	0	0.002
Variability XY (m)	-0.006	0.007	0	0	0	1	0	0.004
Contraction/expansion ratio X	-0.016	0.134	0	0	0	0	0	0.051
Contraction/expansion ratio Y	0.011	0.084	0	0	0	0	0	0.034
Contraction/expansion ratio XY	-0.009	0.198	0	0	0	0	0	0.068
Shift X (m)	-0.009	0.038	0	0	0	0	0	0.020
Shift Y (m)	0.001	0.016	0	0	0	0	0	0.009
Shift XY (m)	0.002	0.023	0	0	0	0	0	0.012
Abs error X (m)	-0.002	0.016	0	0	0	0	0	0.009
Abs error Y (m)	0.000	0.010	0	0	0	0	0	0.005
Abs error XY (m)	-0.002	0.017	0	0	0	0	0	0.009
Z - Variability X (m)	-0.849	0.950	0	0	0	1	0	0.716

Z - Variability Y (m)	-0.588	1.022	0	0	0	0	0	0.683
Z - Variability XY (m)	-0.972	0.951	0	0	0	1	0	0.730
Z - Contraction/expansion ratio X	-0.112	0.964	0	0	0	0	0	0.363
Z - Contraction/expansion ratio Y	0.153	1.090	0	0	0	0	0	0.449
Z - Contraction/expansion ratio XY	-0.048	1.081	0	0	0	0	0	0.371
Z - Shift X (m)	-0.243	0.977	0	0	0	0	0	0.516
Z - Shift Y (m)	0.082	0.972	0	0	0	0	0	0.569
Z - Shift XY (m)	0.155	1.287	0	0	0	0	0	0.653
Z - Abs error X (m)	-0.093	1.179	0	0	0	0	0	0.637
Z - Abs error Y (m)	0.005	1.285	0	0	0	0	0	0.665
Z - Abs error XY (m)	-0.086	1.270	0	0	0	0	0	0.642

Table 4: Arm Position Matching: Right Hand

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Total hits	10.100	10.418	0	0	0	0	0	4.611
Hits with left	9.600	6.995	1	0	0	0	0	6.774
Hits with right	0.500	10.395	0	0	0	0	0	6.041
Hand bias of hits	-0.035	0.051	0	0	0	0	0	0.042
Miss bias	0.023	0.129	0	0	0	0	0	0.091
Hand transition	0.017	0.042	0	0	0	0	0	0.023
Hand selection overlap	0.013	0.033	0	0	0	0	0	0.027
Median error	2.000	9.510	0	0	0	0	0	10.029
Distractor hits left	0.000	0.000	NaN	NaN	NaN	NaN	NaN	0.000
Distractor hits right	0.000	0.000	NaN	NaN	NaN	NaN	NaN	0.000
Distractor hits total	0.000	0.000	NaN	NaN	NaN	NaN	NaN	0.000
Hand speed left (m/s)	-0.021	0.039	0	0	0	0	0	0.034
Hand speed right (m/s)	-0.030	0.059	0	0	0	0	0	0.035

Hand speed bias	-0.011	0.047	0	0	0	0	0	0.033
Movement area left hand (m^2)	0.001	0.031	0	0	0	0	0	0.017
Movement area right hand (m^2)	-0.006	0.029	0	0	0	0	0	0.016
Movement area bias	-0.018	0.106	0	0	0	0	0	0.064
Z - Total hits	0.756	0.646	1	0	0	0	0	0.399
Z - Hand bias of hits	-0.467	0.685	0	0	0	0	0	0.559
Z - Miss bias	0.397	1.990	0	0	0	0	0	1.394
Z - Hand transition	0.569	1.431	0	0	0	0	0	0.787
Z - Hand selection overlap	0.313	0.817	0	0	0	0	0	0.657
Z - Median error	0.362	1.723	0	0	0	0	0	1.818
Z - Hand speed left (m/s)	-0.222	0.488	0	0	0	0	0	0.453
Z - Hand speed right (m/s)	-0.334	0.717	0	0	0	0	0	0.436
Z - Hand speed bias	-0.163	0.759	0	0	0	0	0	0.524
Z - Movement area left hand (m^2)	0.028	0.844	0	0	0	0	0	0.477
Z - Movement area right hand (m^2)	-0.177	0.885	0	0	0	0	0	0.495

Z - Movement area bias	-0.266	1.563	0	0	0	0	0	0.939

Table 5: Object Hit

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Total hits	7.400	7.230	0	0	1	0	0	6.560
Hits with left	1.100	7.795	0	0	0	0	0	5.778
Hits with right	6.300	7.573	0	0	0	0	0	5.033
Hand bias of hits	0.027	0.075	0	0	0	0	0	0.047
Miss bias	0.044	0.120	0	0	0	0	0	0.069
Hand transition	-0.013	0.033	0	0	0	0	0	0.022
Hand selection overlap	-0.013	0.042	0	0	0	0	0	0.023
Median error	-0.133	8.421	0	0	0	0	0	6.726
Distractor hits left	0.200	3.360	0	0	0	0	0	2.477
Distractor hits right	0.300	5.519	0	0	0	0	0	2.697
Distractor hits total	0.500	7.517	0	0	0	0	0	4.344
Hand speed left (m/s)	-0.032	0.023	1	0	0	0	0	0.024
Hand speed right (m/s)	-0.021	0.030	0	0	0	0	0	0.032
Hand speed bias	0.030	0.067	0	0	0	0	0	0.043

Movement area left hand (m^2)	-0.021	0.021	0	0	0	0	0	0.018
Movement area right hand (m^2)	-0.019	0.034	0	0	0	1	0	0.019
Movement area bias	0.014	0.096	0	0	0	0	0	0.061
Z - Total hits	0.627	0.651	0	0	1	0	0	0.553
Z - Hand bias of hits	0.363	0.935	0	0	0	0	0	0.572
Z - Miss bias	0.709	1.923	0	0	0	0	0	1.100
Z - Hand transition	-0.400	1.013	0	0	0	0	0	0.671
Z - Hand selection overlap	-0.411	1.312	0	0	0	0	0	0.704
Z - Median error	-0.009	1.385	0	0	0	0	0	1.092
Z - Distractor hits total	0.364	0.964	0	0	0	0	0	0.714
Z - Hand speed left (m/s)	-0.614	0.447	1	0	0	0	0	0.469
Z - Hand speed right (m/s)	-0.381	0.553	0	0	0	0	0	0.583
Z - Hand speed bias	0.384	0.850	0	0	0	0	0	0.538
Z - Movement area left hand (m^2)	-0.650	0.717	0	0	0	0	0	0.589
Z - Movement area right hand (m^2)	-0.598	1.146	0	0	0	1	0	0.627

Z - Movement area bias	0.159	1.056	0	0	0	0	0	0.671

Table 6: Object Hit and Avoid

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Total score	3.100	8.157	0	0	0	0	0	8.561
Mean score	0.194	0.510	0	0	0	0	0	0.535
Test time (s)	-2.386	18.007	0	0	0	0	0	14.774
Time per target (s)	-0.087	0.073	1	0	0	0	0	0.053
Longest correct path	0.100	0.876	0	0	0	0	0	0.508
Shortest failed path	0.500	1.354	0	0	1	1	0	1.033
Timeout count	-0.100	0.316	0	NaN	NaN	NaN	NaN	0.000

Table 7: Spatial Span

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Test time (s)	-2.358	3.734	0	0	0	0	0	2.293
Dwell time (s)	-1.137	1.657	0	0	0	0	0	1.257
Time ratio	-0.079	0.310	0	0	0	0	0	0.213
Error count	-0.300	0.675	0	0	0	0	0	0.598

Table 8: Trail Making: Version A

	Δ week 1 to 2		T-Test between Weeks (Learning)					SD of mean score weeks 2-5 (Retest variability)
	Mean	SD	1/2	2/3	3/4	4/5	5/6	
Test time (s)	0.449	9.783	0	0	0	0	0	5.322
Dwell time (s)	0.187	5.635	0	0	0	0	0	3.375
Time ratio	-0.155	0.665	0	0	0	0	0	0.381
Error count	0.600	1.897	0	0	0	0	0	1.435

Table 9: Trail Making: Version B

Week	Task	Parameter	Mean Change	SD
Week 1 – Week 2	Reaching (L Hand)	Initial Direction Error (rad)	- 0.007	0.006
	Reaching (L Hand)	Movement Time (s)	- 0.120	0.095
	Reaching (R Hand)	Max Speed (m/s)	+ 0.050	0.041
	Matching (L Hand)	Shift Y (m)	- 0.008	0.007
	Object Hit	Hits with left	+ 9.600	6.995
	Object Hit and Avoid	Hand Speed Left (m/s)	- 0.032	0.023
	Spatial Span	Time per Target (s)	- 0.087	0.073
Week 3 – Week 4	Object Hit and Avoid	Total Hits	+ 7.900	4.630
	Spatial Span	Shortest Failed Path	+ 1.000	0.667
Week 4 – Week 5	Matching (R Hand)	Variability X (m)	+ 0.007	0.005
	Matching (R Hand)	Variability X/Y (m)	+ 0.007	0.005
	Object Hit and Avoid	Movement area right hand (m^2)	+ 0.019	0.017
	Spatial Span	Shortest Failed Path	- 1.300	1.252

Table 10: Parameters that have rejected the null hypothesis, p = 0.01.