

Analysis of correlation between frequency of transitions to improvement in performance

June 28, 2019

1 Introduction

We will be analysing the movement times of finger thumb opposition movements in motor sequence learning. Our claim is that frequently practised movements will show a more significant improvement in performance as compared to less frequently practised movements. The movement time in this case is defined as the difference in time between the release of one key and the pressing of the next key. Here an improvement in performance in the transition would mean a reduction in it's movement time.

2 The Experiment

This analysis has been done on pre-collected data. The experiment employed 11 subjects of which the data of 8 subjects has been utilised. Participants were to spell 5 letter meaningful words shown on a computer screen. The participant wears a glove which consists of 9 alphabets, 1 backspace, 1 capslock and 1 space on the phalanges of 4 fingers while the thumb is used for pressing the key letter. A participant will spell as many words as they can in blocks of 2 minutes with 30 seconds interval between blocks. They performed 12 blocks per day over a course of 15 consecutive days.

The letters present on the glove are 'A', 'E', 'H', 'I', 'N', 'O', 'R', 'S', 'T'. The dictionary consists of 281 words. Each participant had to spell each dictionary word correctly at least 10 times over the course of the experiment. Mispelled words were not considered in the analysis.

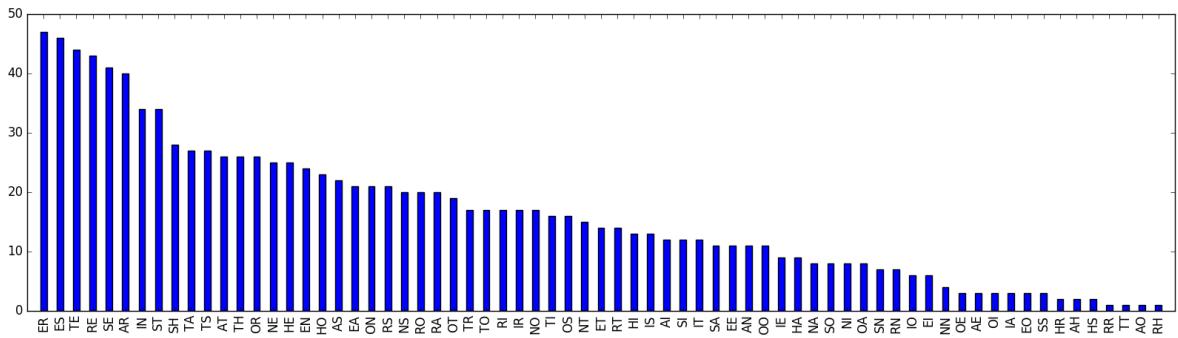
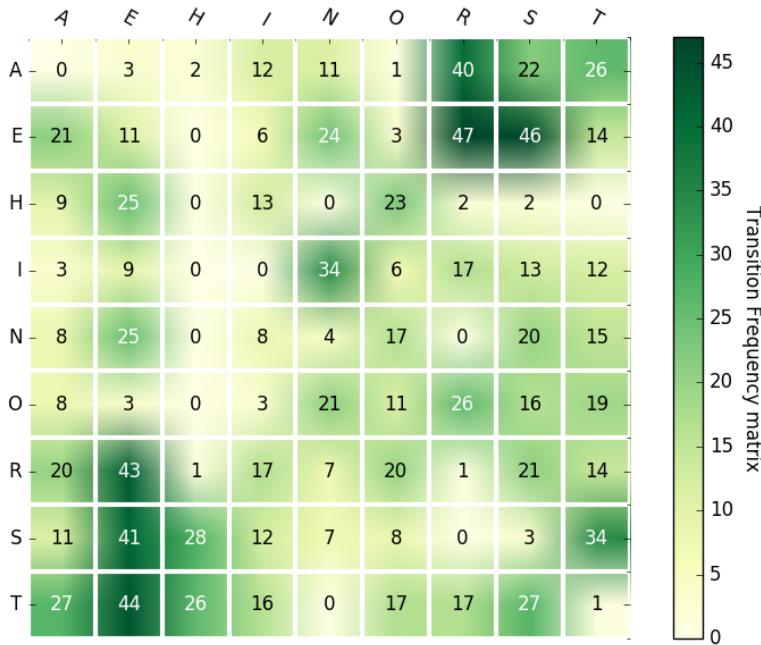
The participant had to press space after spelling each word. We considered the movement times between letters alone and not that of a letter to the space key or vice versa. This means that for each correctly spelled word there are 4 movement times.

We will be looking at the frequency of letter transitions and analysing the correlation between the frequency of a transition and change in it's movement time with practise.

3 Heat Maps

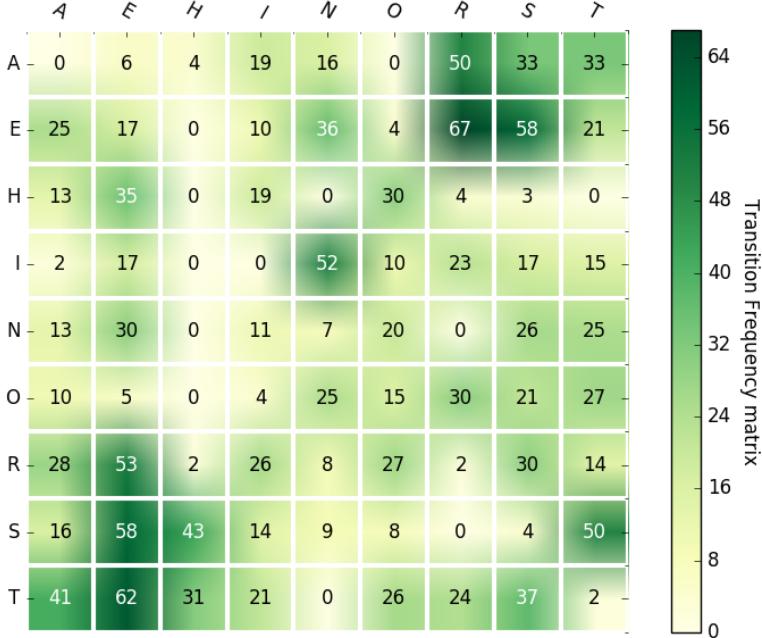
Looking at the most frequent transition and least frequent transition of each subject alone would not give a generalised output. For this purpose we will identify which are the most frequent and least frequent transitions common to all subjects and which are also common apriori i.e. the transitions occurring in the dictionary.

In order to identify these transitions, the apriori and posterior distributions were plotted. The apriori distribution is as follows. Below we have a heat map and a bar plot of the transition frequencies.

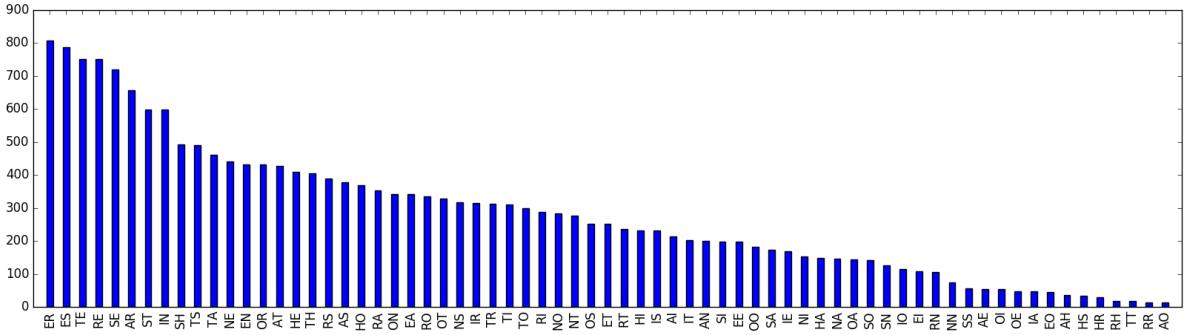


Similarly the frequency plots were obtained for each subject. We looked at the frequency per day as well as the total frequency across all days. Below are the plots for subject 1.

Subject 1: Total frequency across all days, Heat plot



Subject 1: Total frequency across all days, Bar plot



It was observed that for each day there were no common transitions throughout meaning that the top 3 or top 4 kept changing day by day. But when we looked at the total frequency across all days it was observed that the top 4 and bottom 4 transitions were common for each subject and matched with those in the apriori distribution, although the order was not the same. While, top 3 or top 5 transitions were not the same. These common transitions are:

Top 4: E-R, E-S, T-E, R-E

Bottom 4: R-R, T-T, A-O, R-H

These are the transitions that we will be considering for further analysis. The average movement time for the top 4 and bottom 4 is taken for all further analysis so that we can observe the general tendency of how movement time changes with practise for more frequent transitions as compared to the least frequent transitions.

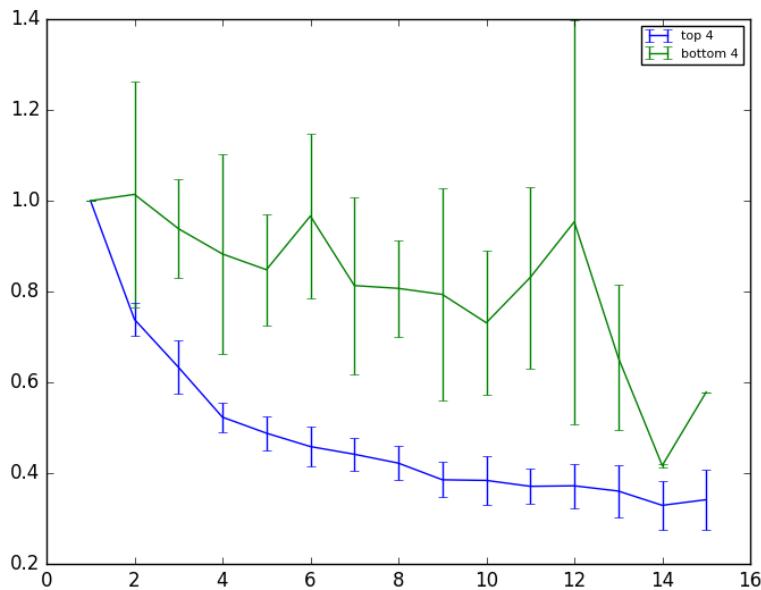
4 Error Plots

The error plots were constructed in order to observe the movement times after averaging across the considered transitions. These were constructed in 2 fashions.

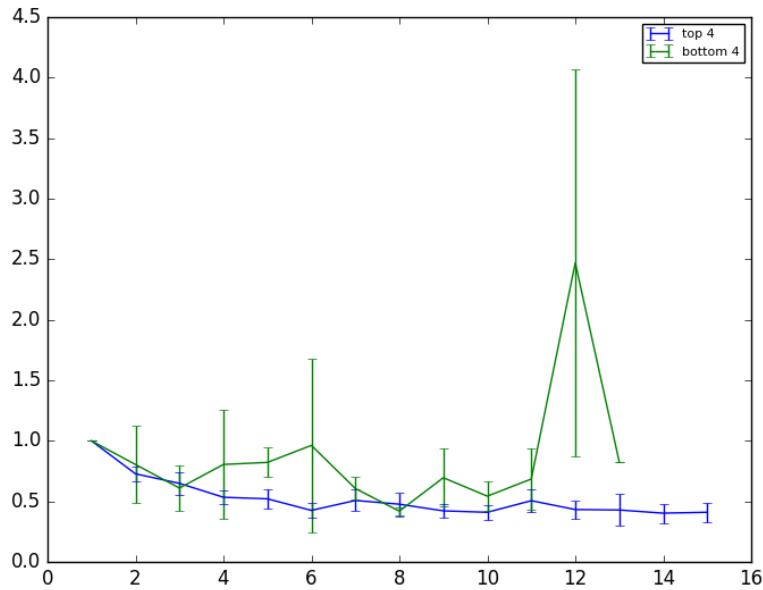
- 1) The first method was averaging the movement times by day/ block per subject for each transitions, then averaging across subjects and then averaging the top 4 and bottom 4 transitions.
- 2) The second method was considering all the movement times of the transitions for each subject across days/blocks and averaging at the end.

1) Method 1:

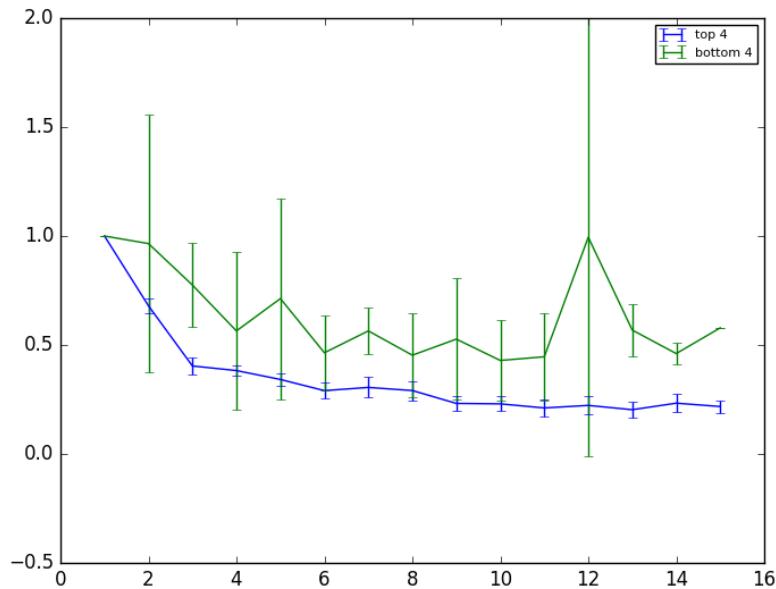
- i) Average across all subjects taken across each day.



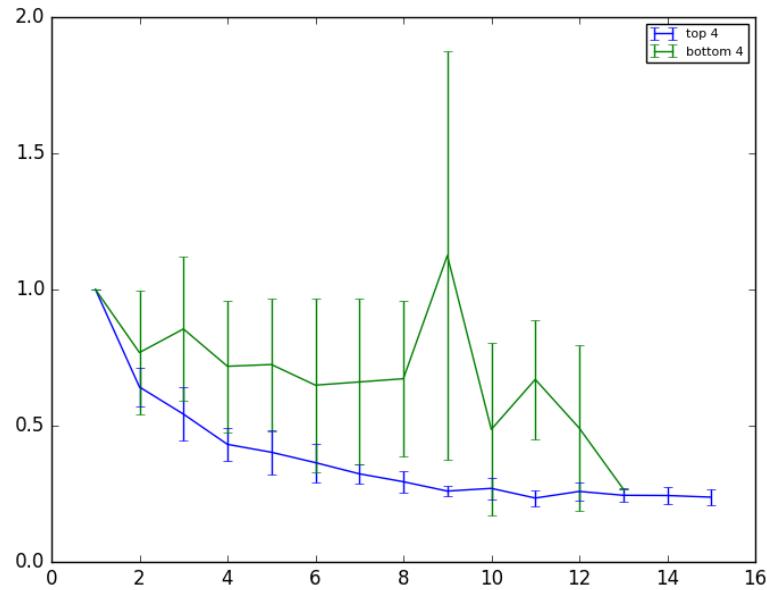
a) Subject 1



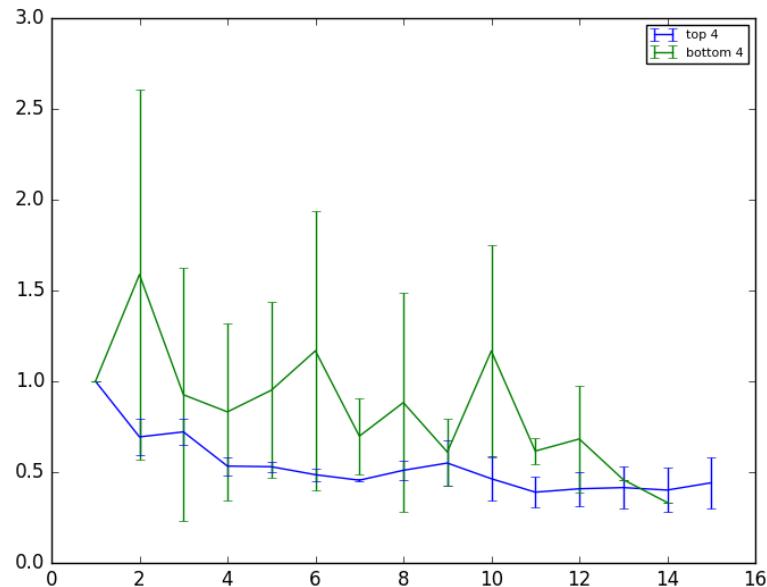
b) Subject 2



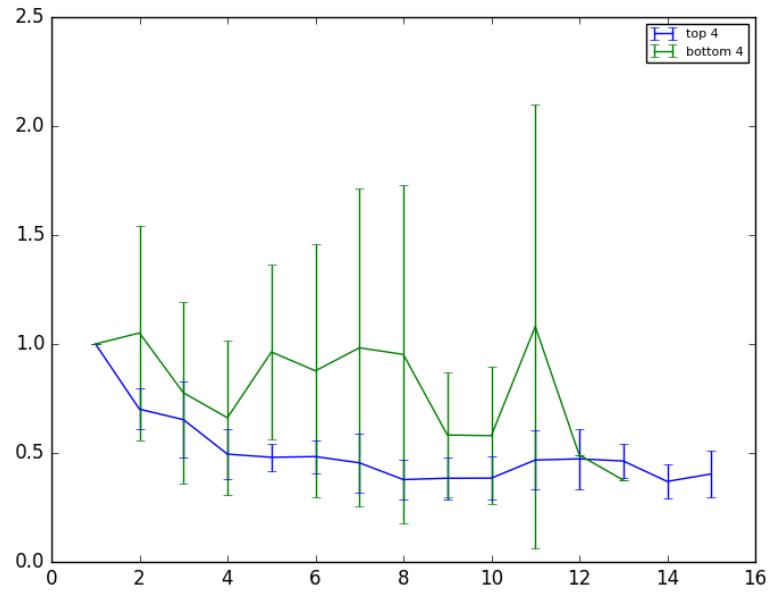
c)Subject 3



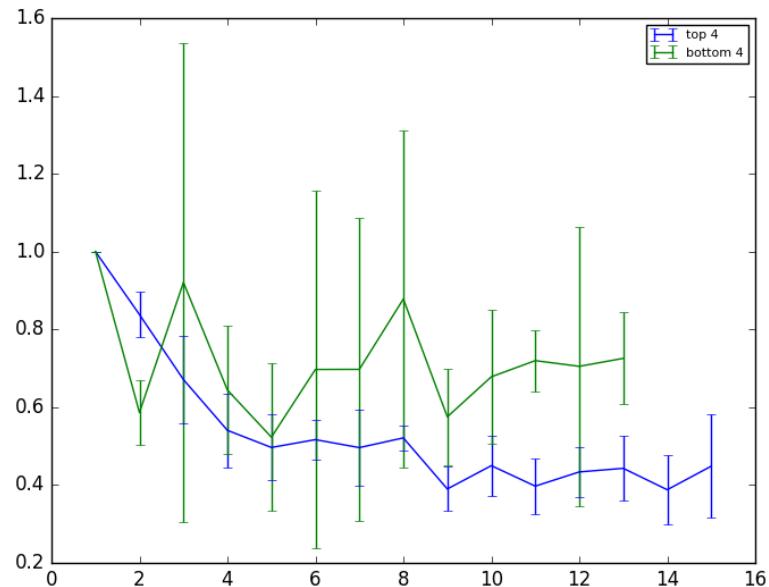
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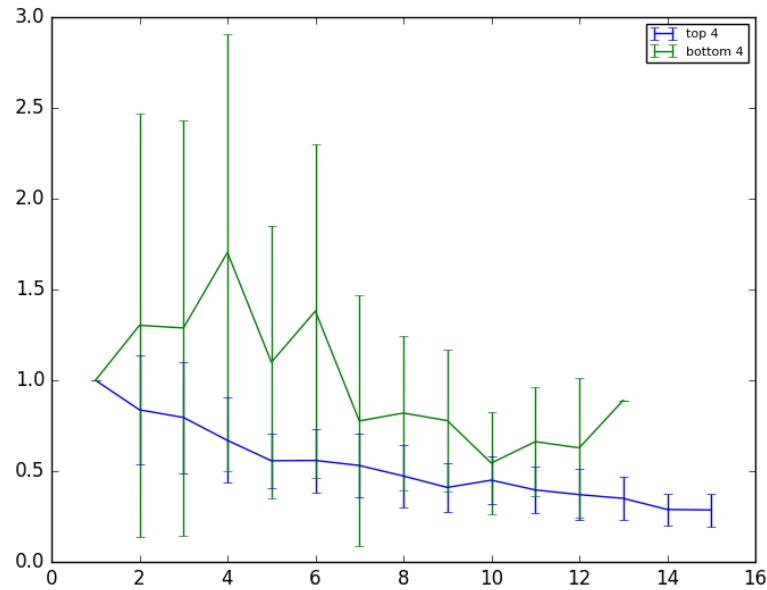
e)Subject 5



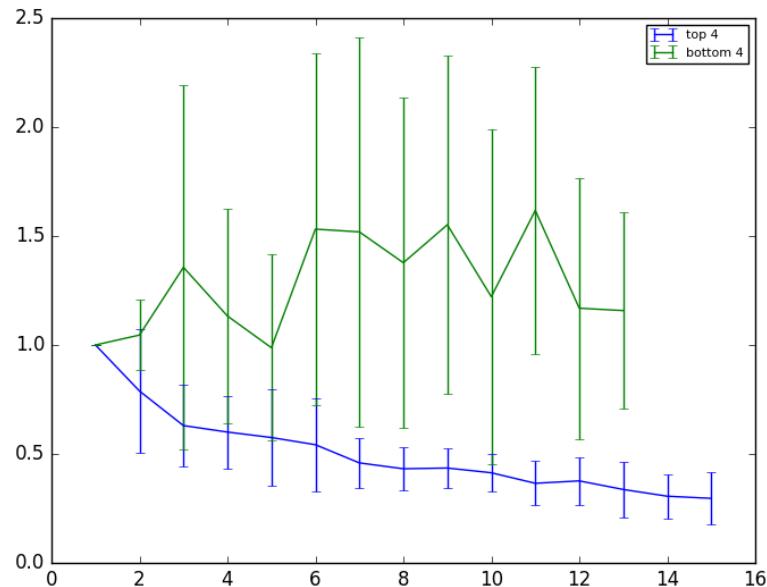
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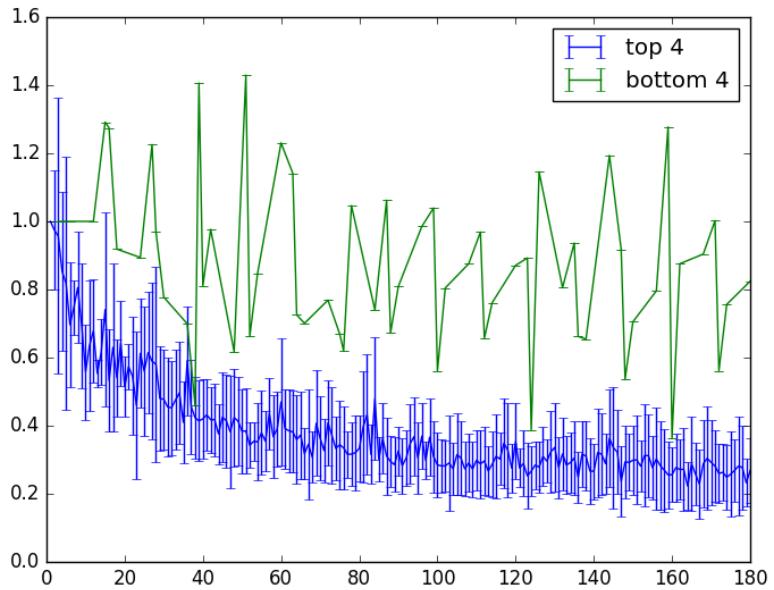
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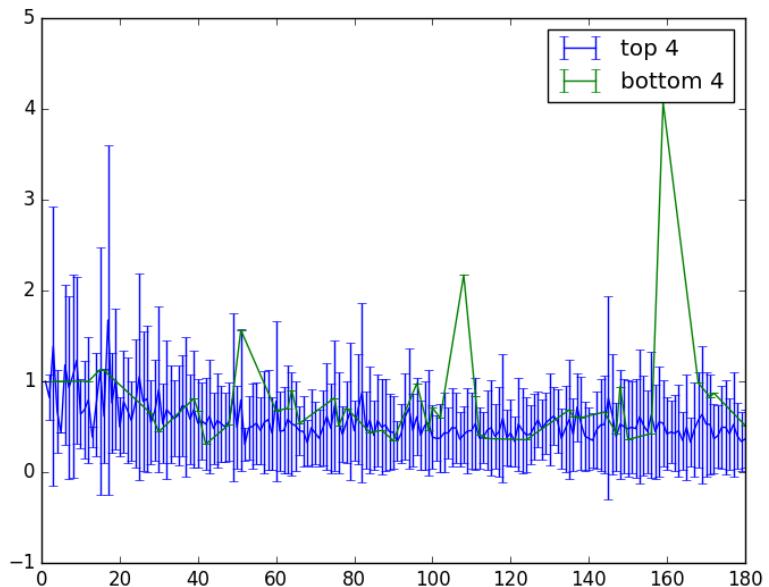
h)Subject 8



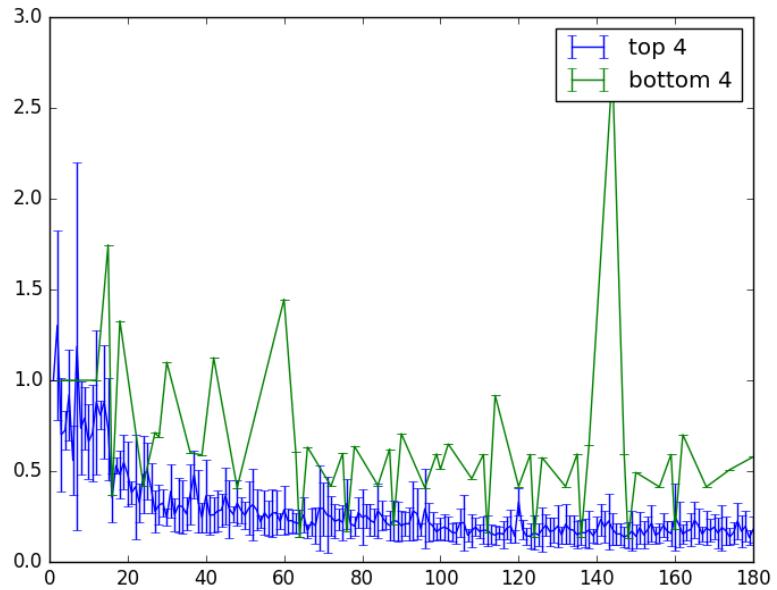
ii) Average across all subjects taken across each block



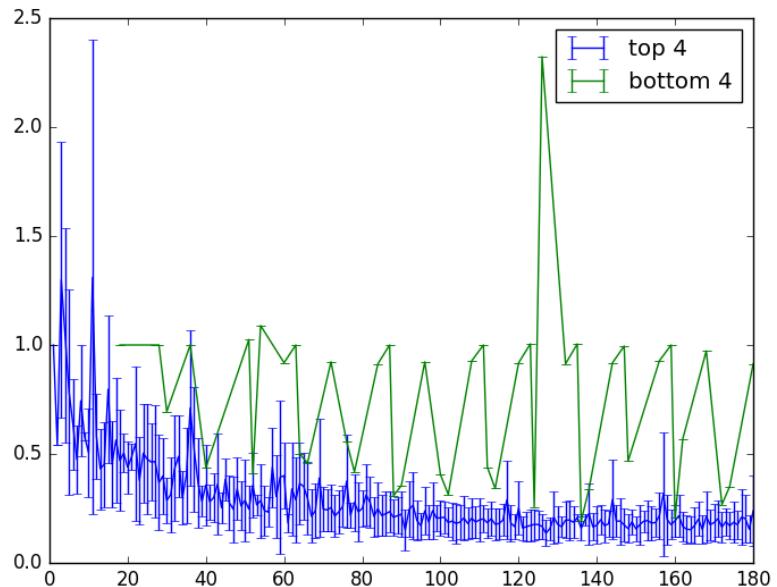
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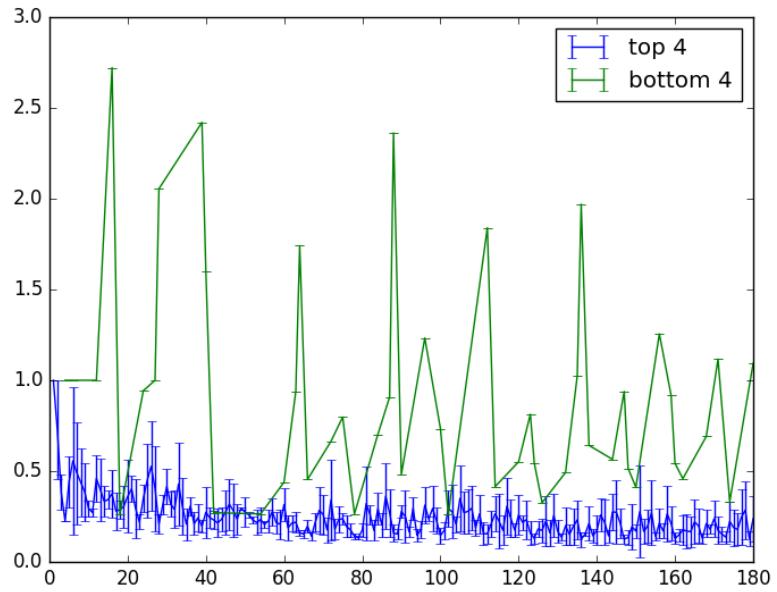
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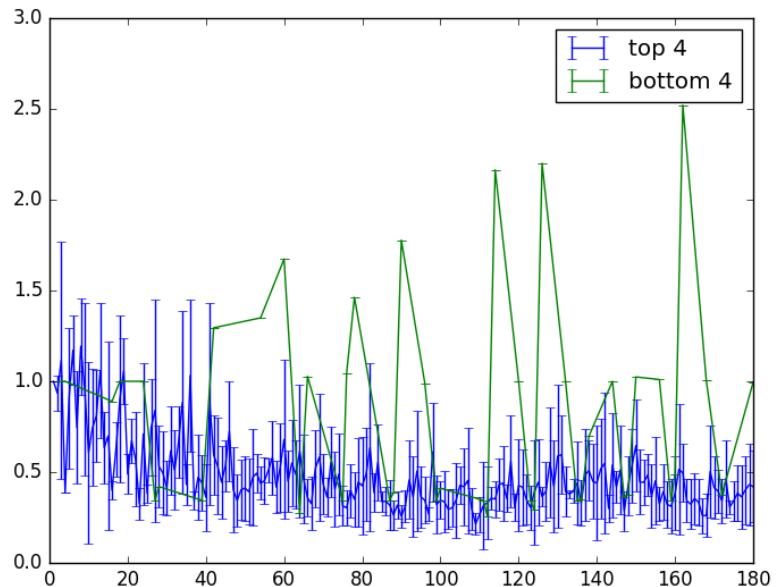
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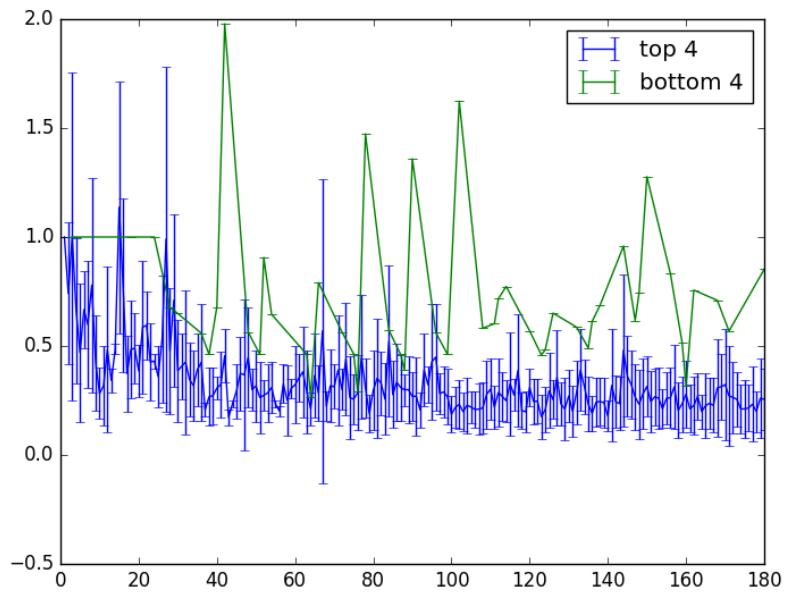
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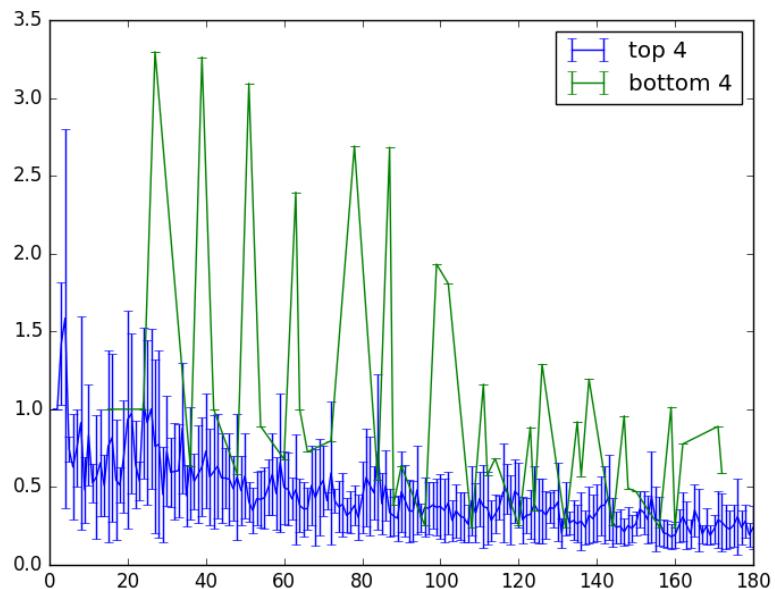
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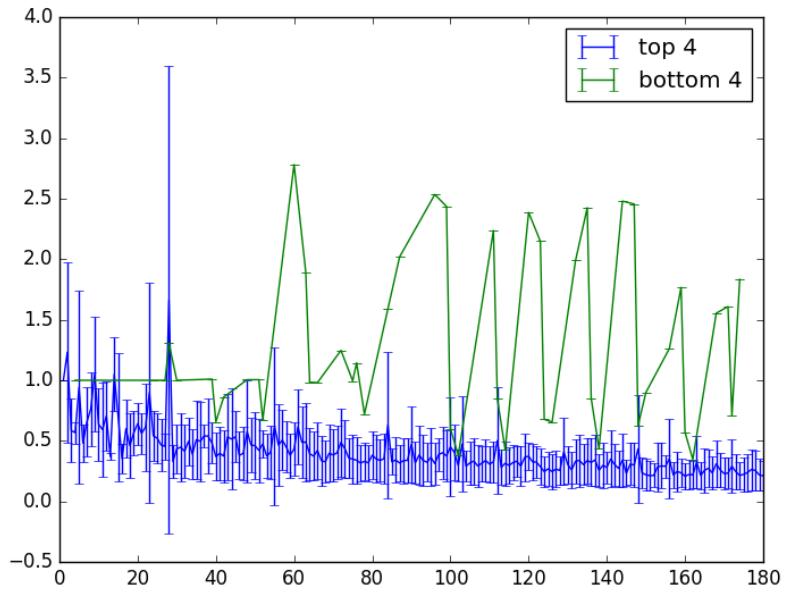
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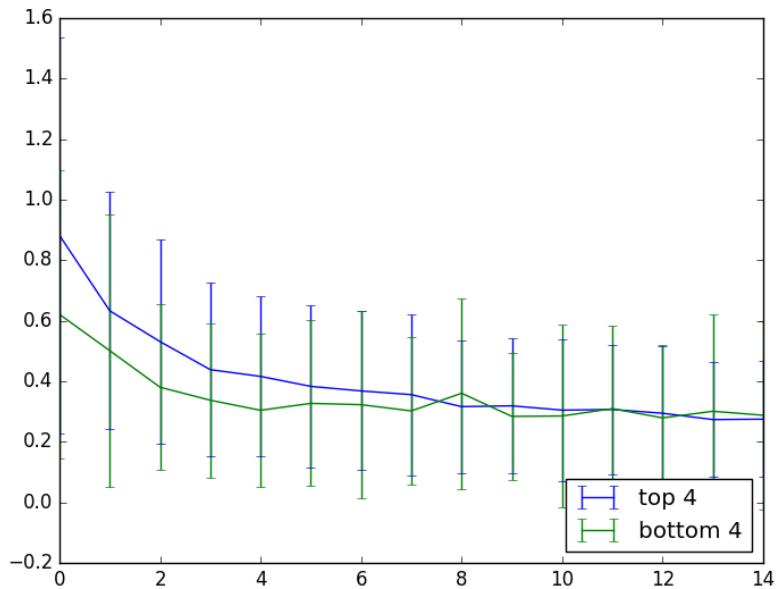


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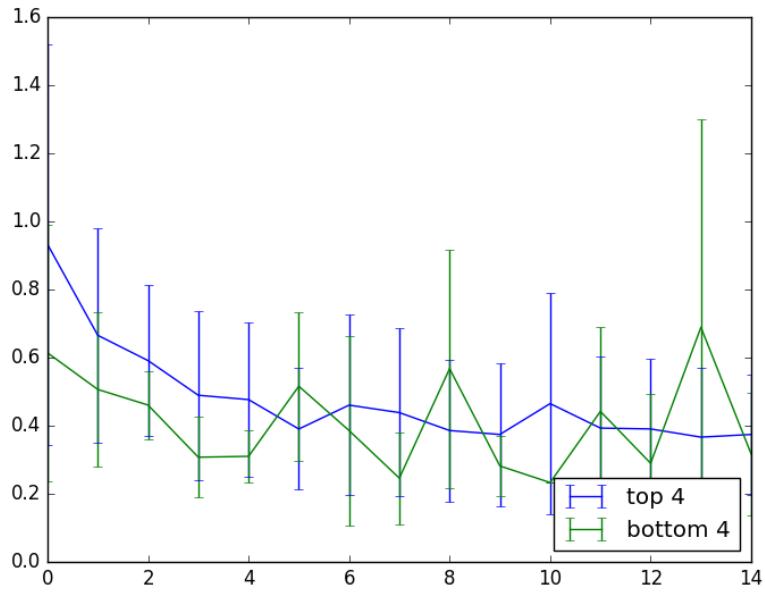


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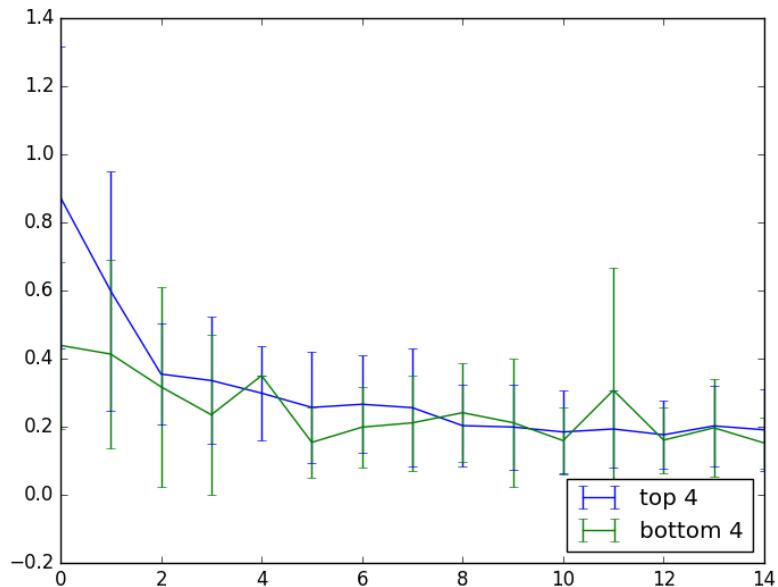
i) Average across all subjects taken across each day



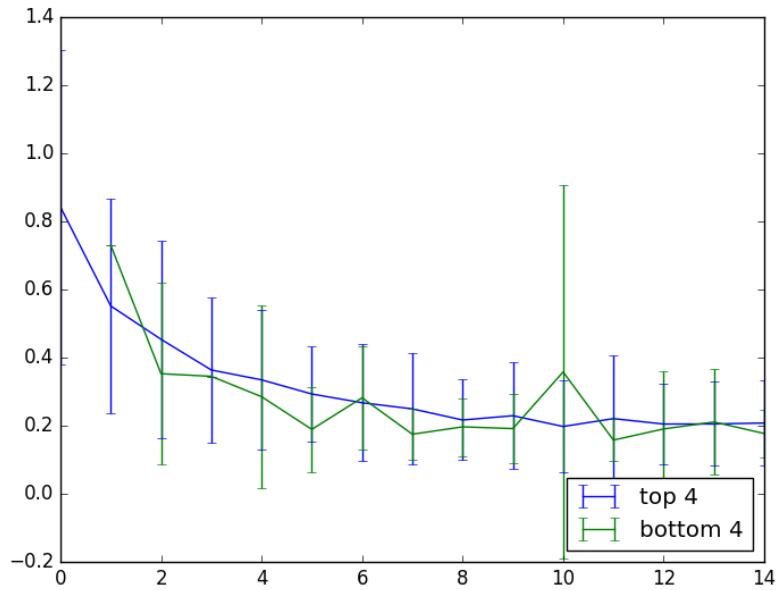
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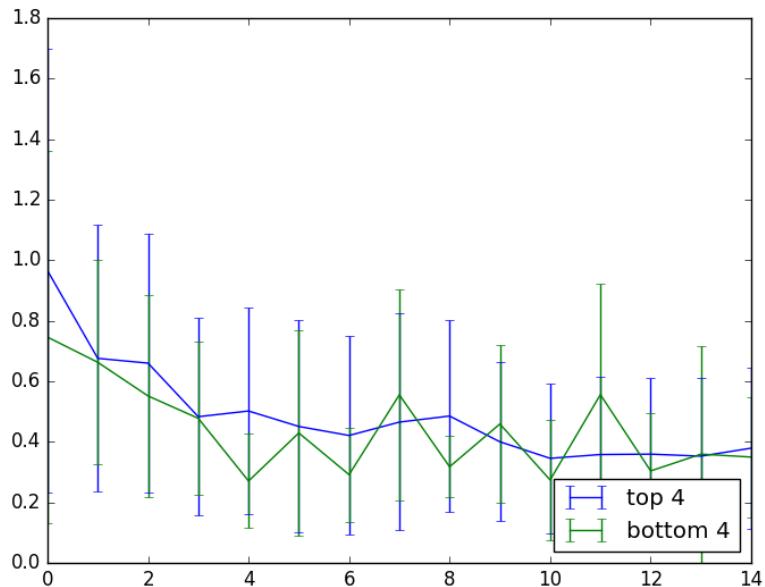
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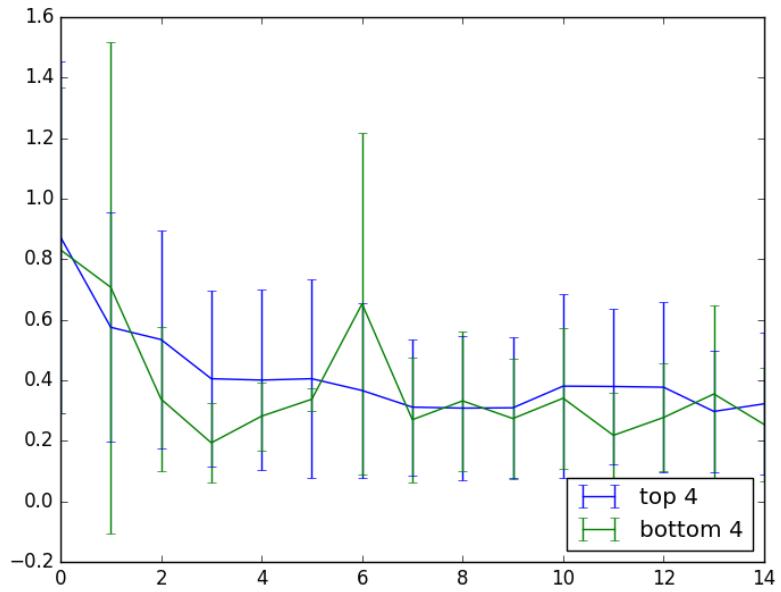
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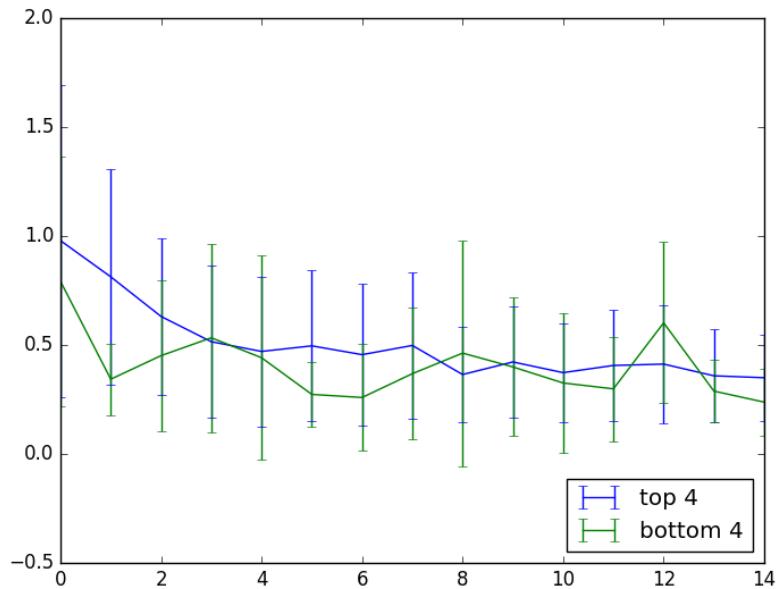
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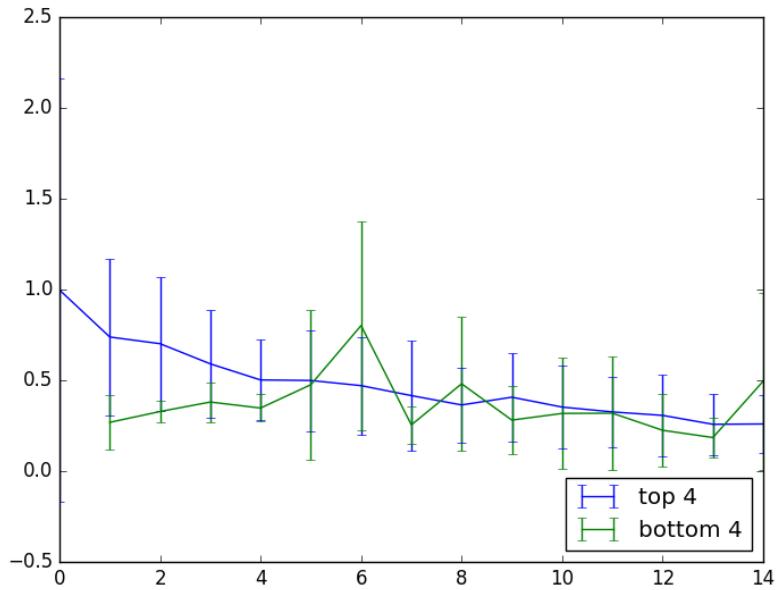
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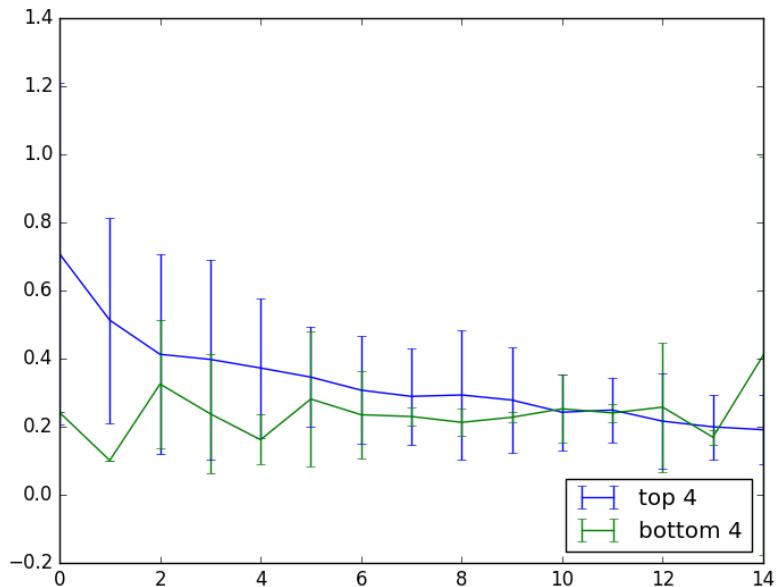
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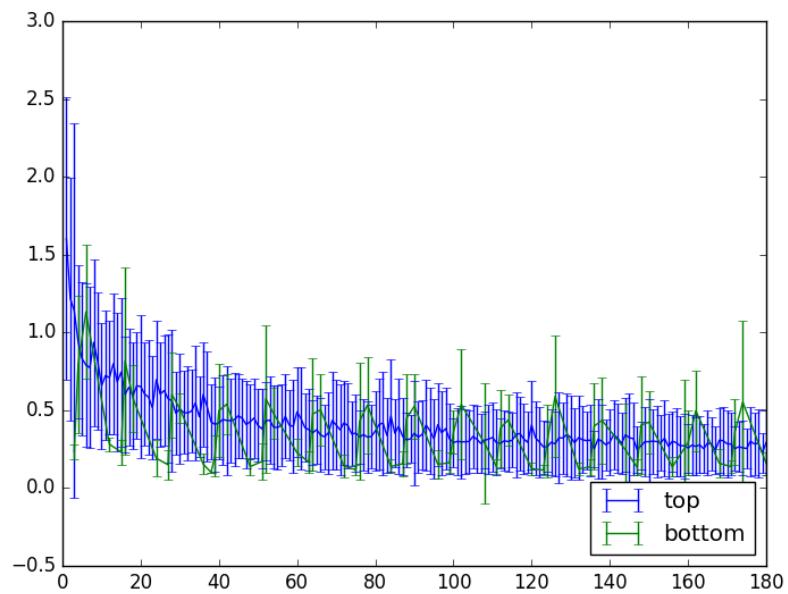
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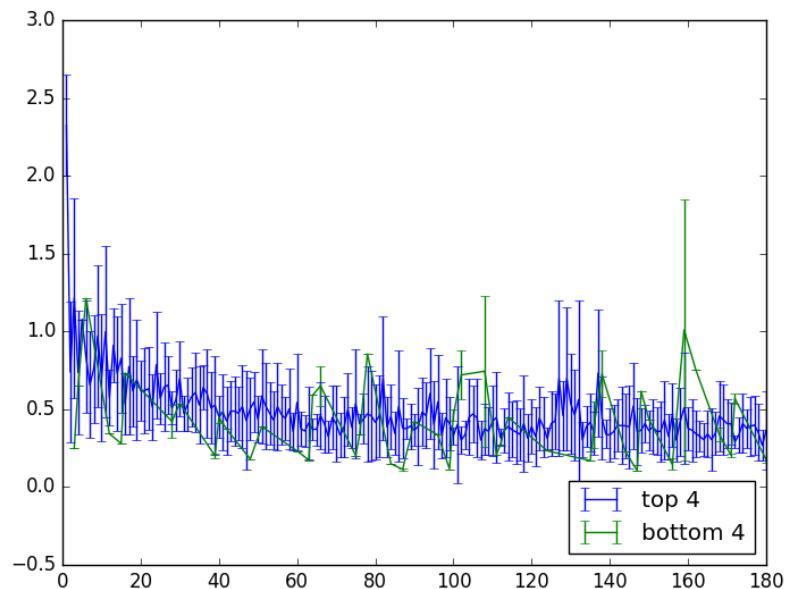
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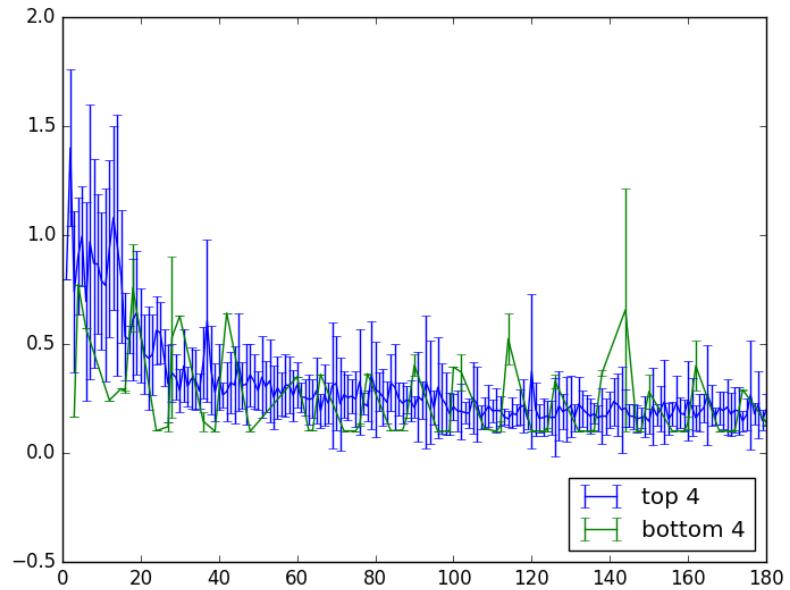
ii) Average across all subjects taken across each block



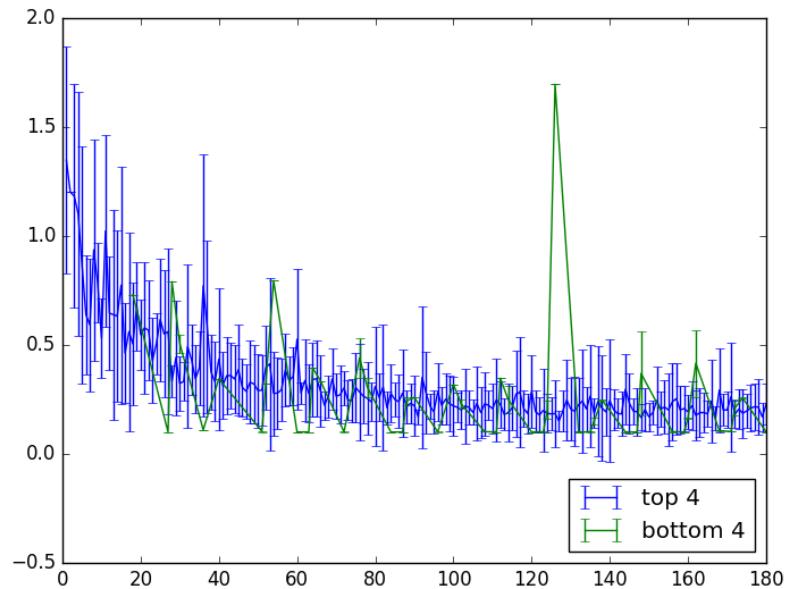
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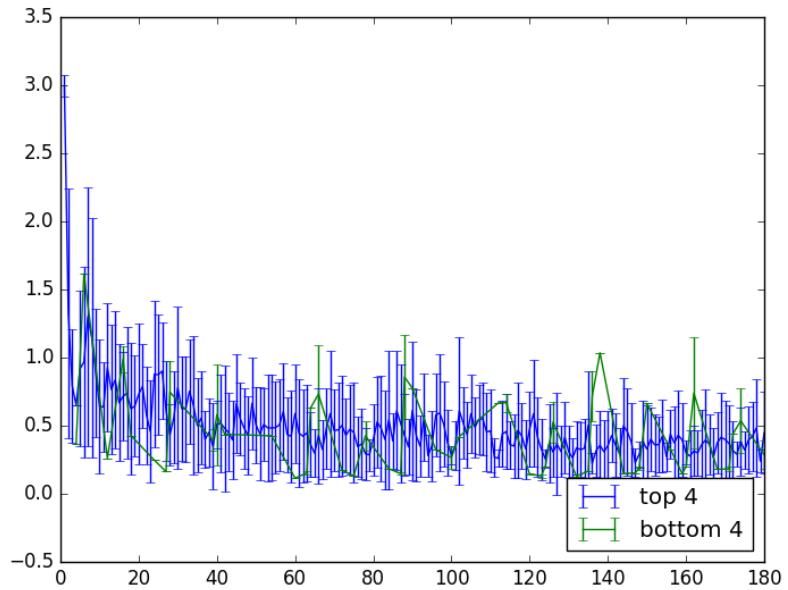
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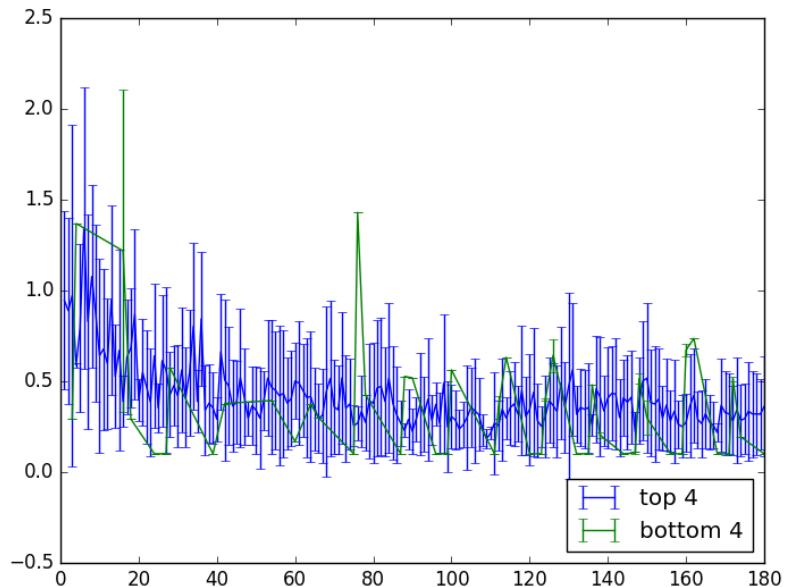
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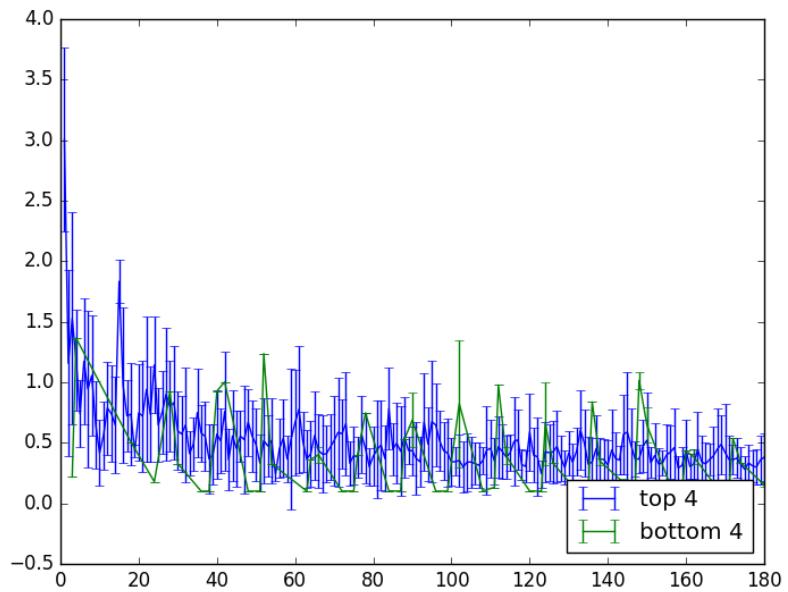
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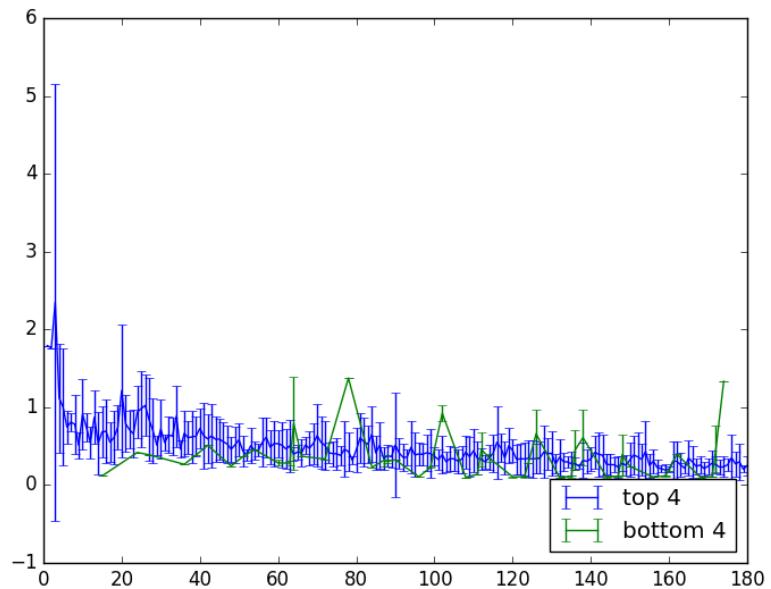
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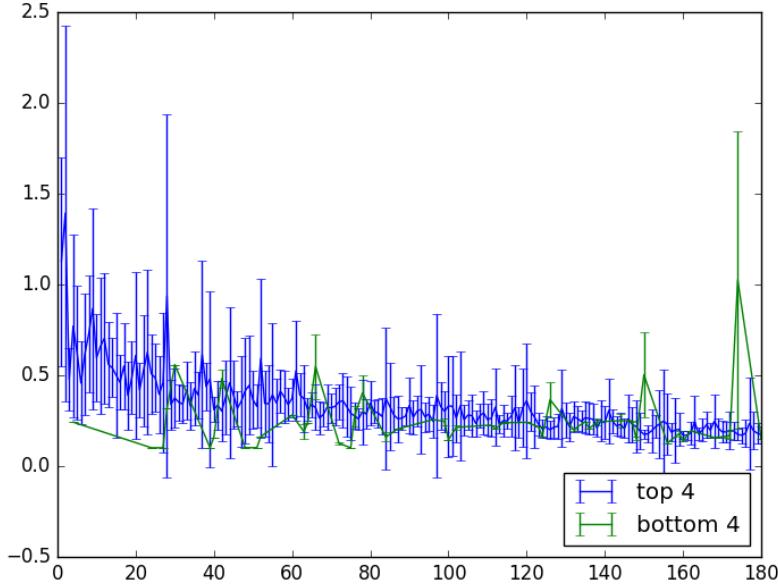
f)Subject 6



g)Subject 7



h) Subject 8



Observations:

- i) In method 1 there is a clear separation between the most and least frequent transitions when average across all subjects is considered. While, for each subject, the lines are separable but overlap at some points. This is true for both days and blocks.
- ii) In method 2 we can see that the lines are not as separable. But if we look at the extent to which the values have reduced over time in the average plots, we can see that the most frequent transitions line show a larger drop than the least frequent transitions line. This is true both across days and across blocks. Now for each subject, this is true in almost all of the subjects, although 1 or 2 plots show a different behavior. This can be attributed to the initial average movement time being less than the final average movement time.

Inference:

This is not enough to fully justify our claim although it indicates that there is motivation for performing further analysis.

5 Performance curve

Now we will analyse the drop in movement time by taking each point of the plots and dividing it by the first point of that plot.

$$\text{i.e. } r_i = p_i / p_0$$

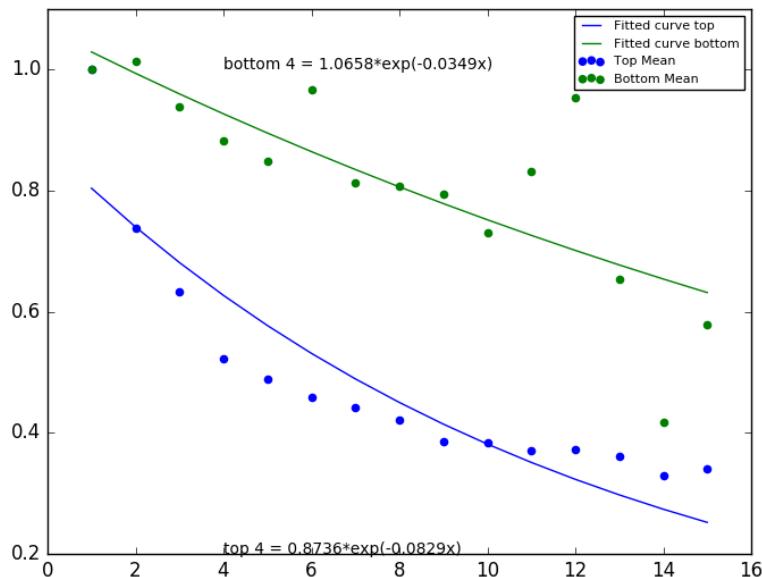
where, r_i is the new i th point, p_i is the initial i th point and p_0 is the first initial point

This will show how the average movement time varies with respect to the first day/block of

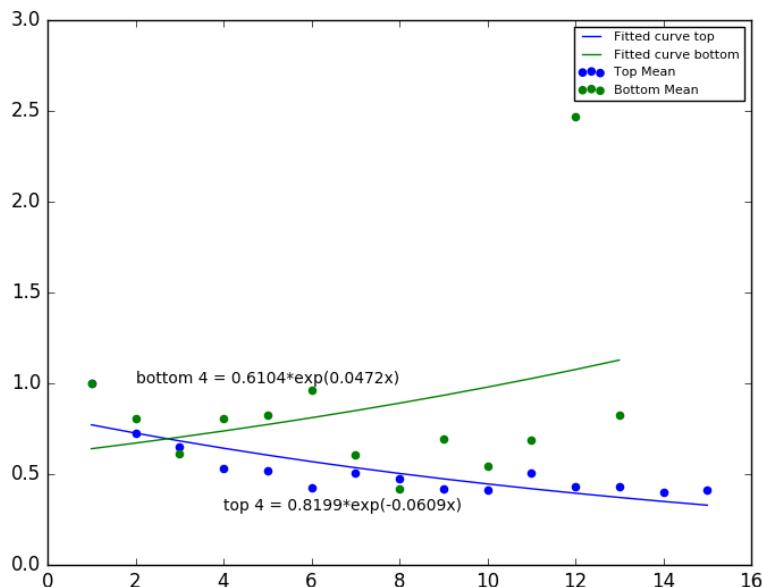
practise. In essence it will show how the performance changes over time. Then we can fit a curve to these plots to see if there's a significant difference between the most frequent transitions and least frequent transitions. We will call this as the performance curve. When we consider these points, we can see that an exponential curve will fit the data points.

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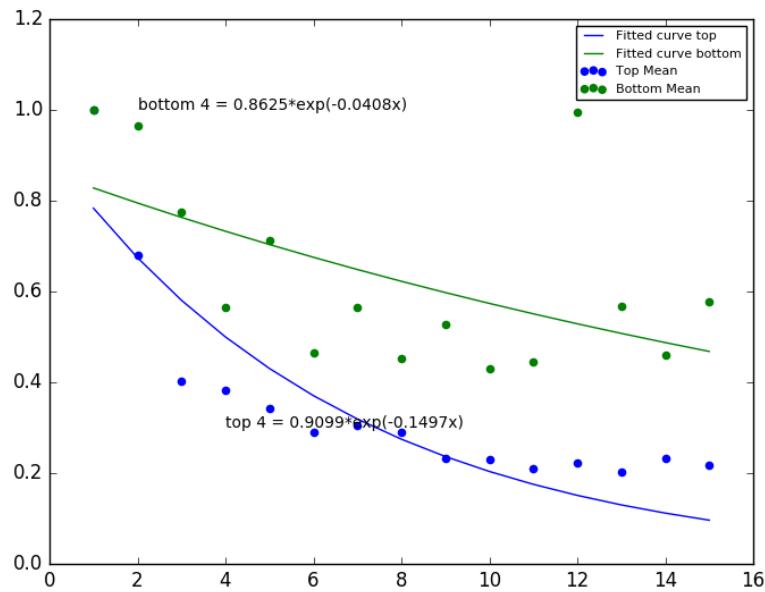
i) Average across all subjects taken across each day.



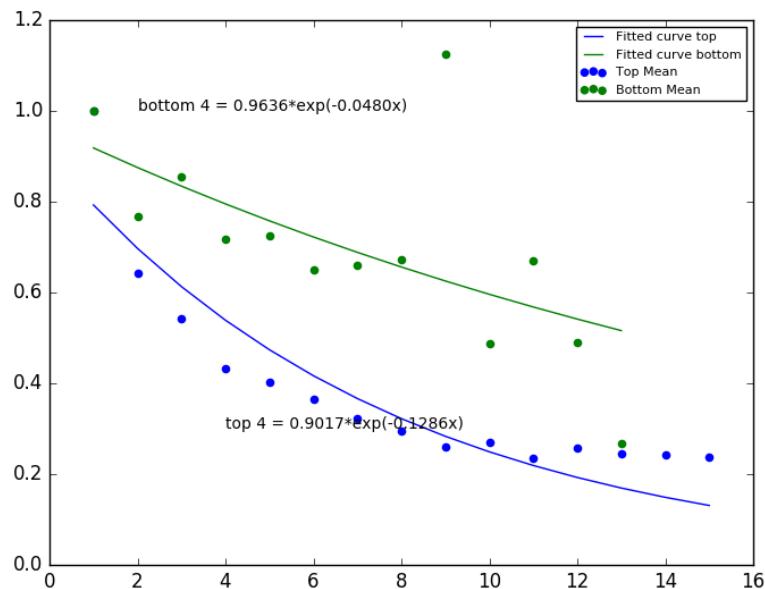
a) Subject 1



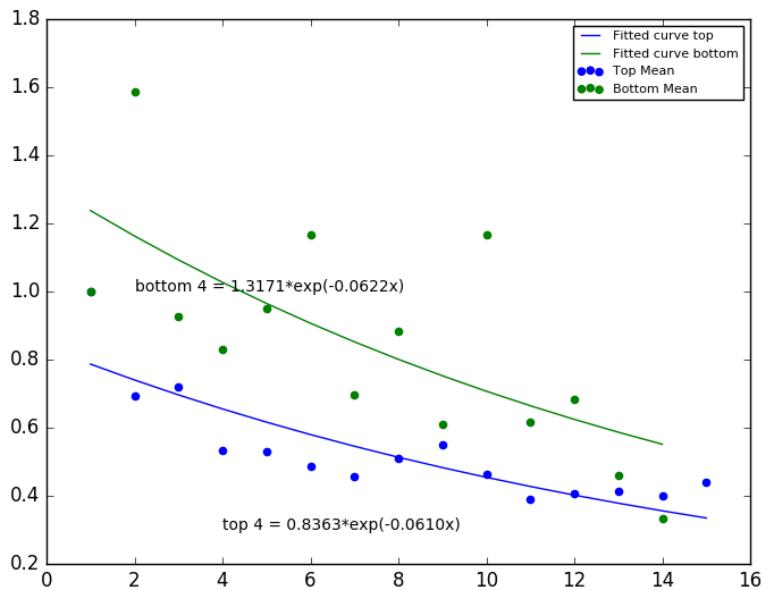
b) Subject 2



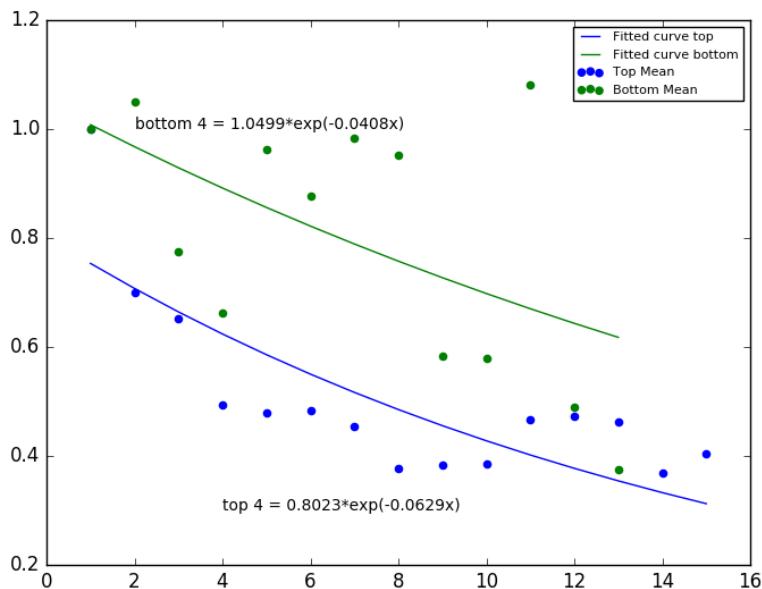
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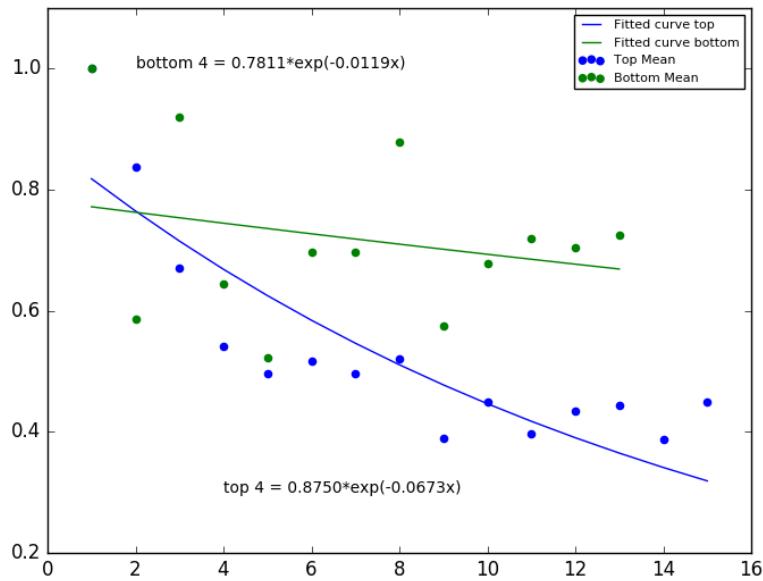
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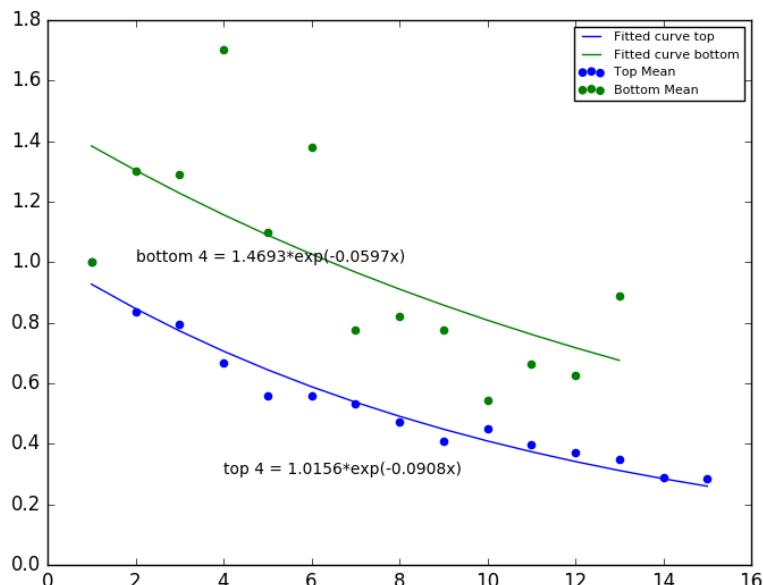
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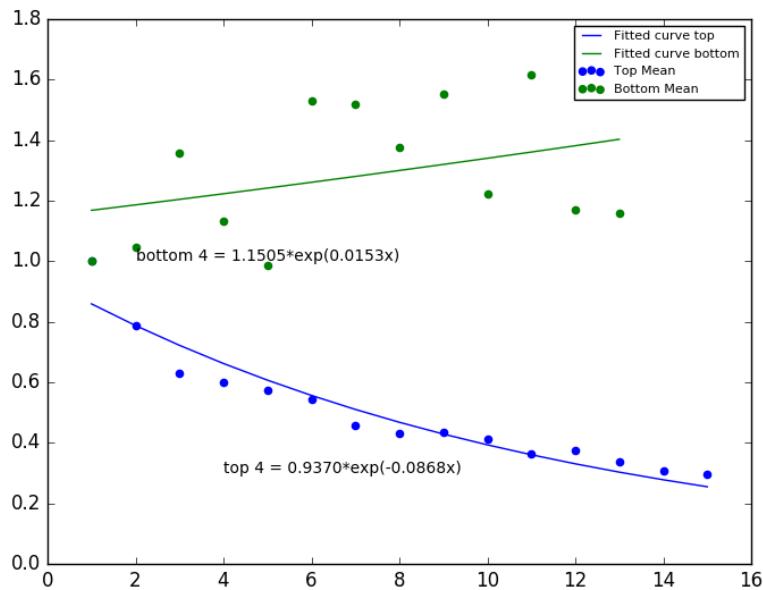
f)Subject 6



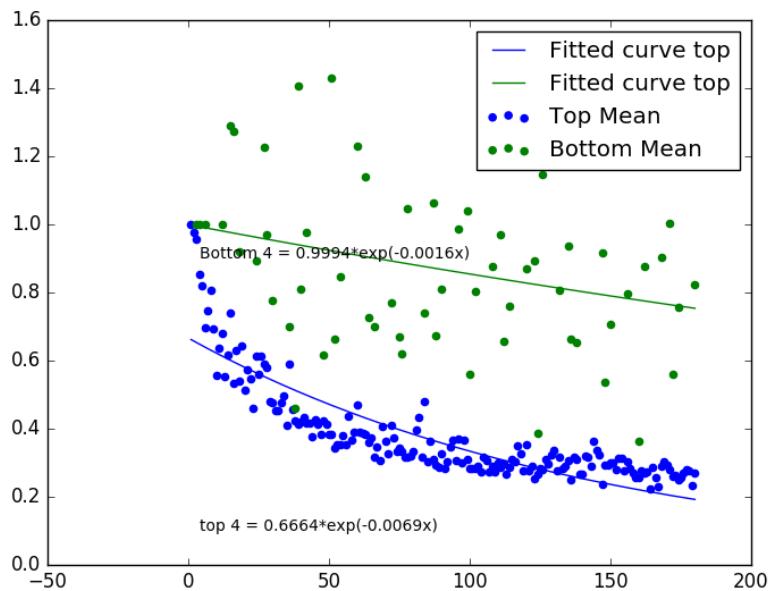
g)Subject 7



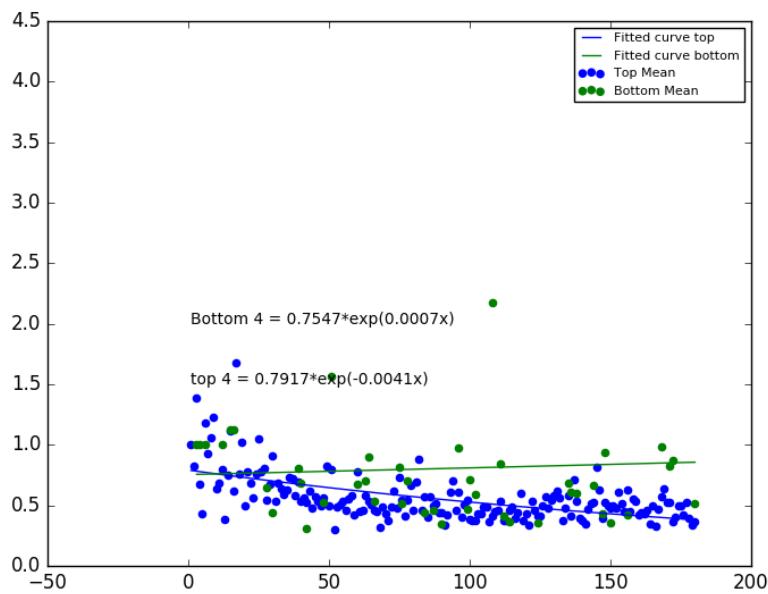
h) Subject 8



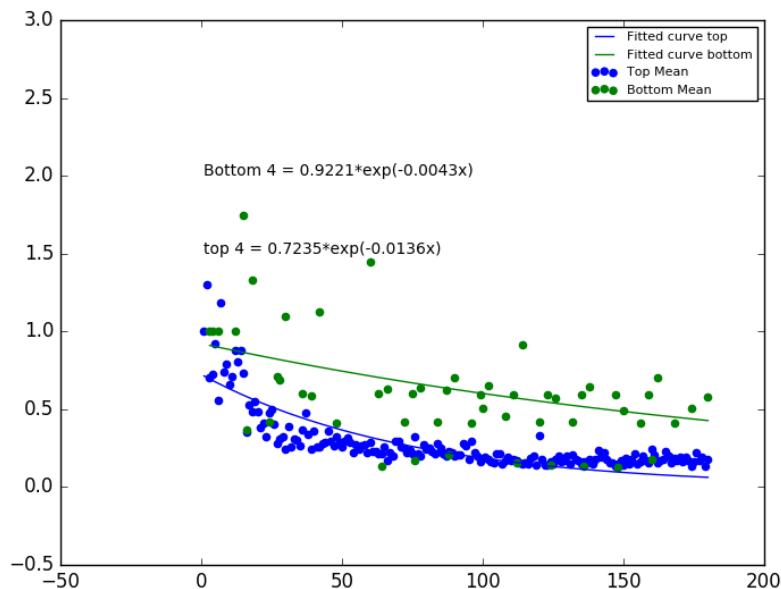
ii) Average across all subjects taken across each block



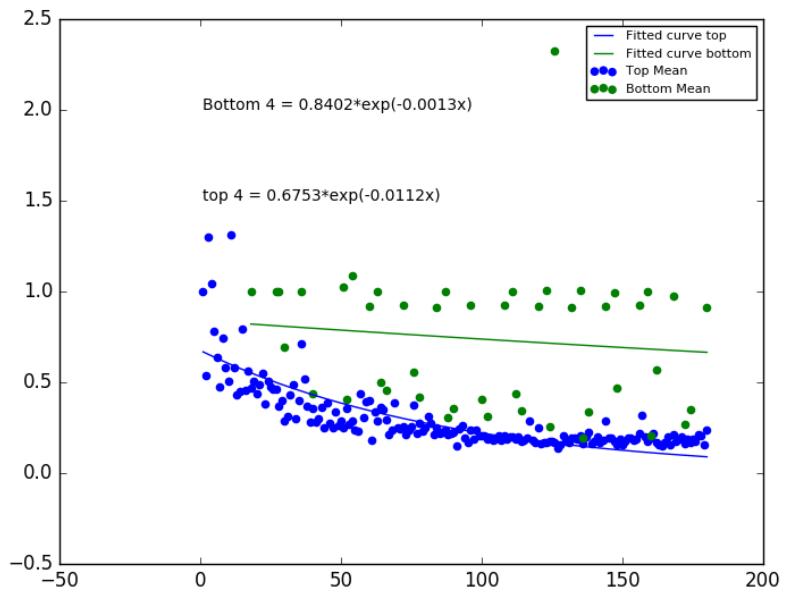
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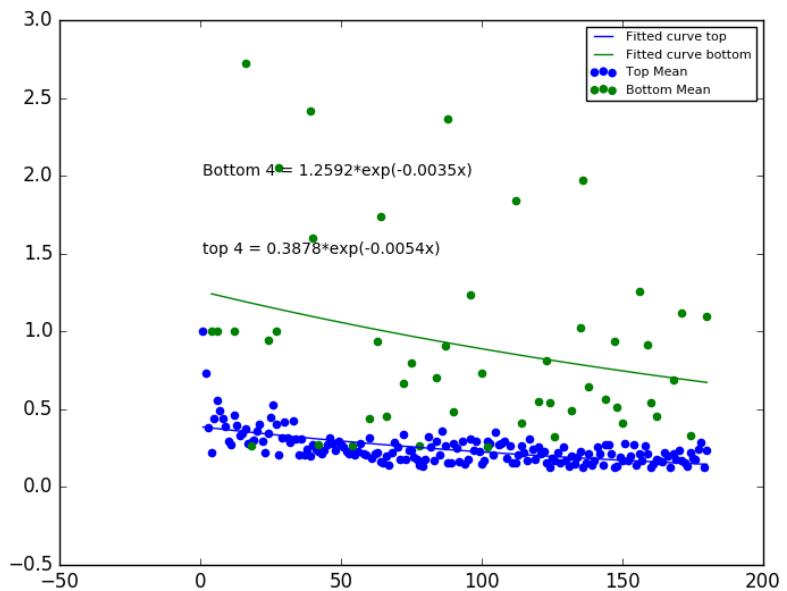
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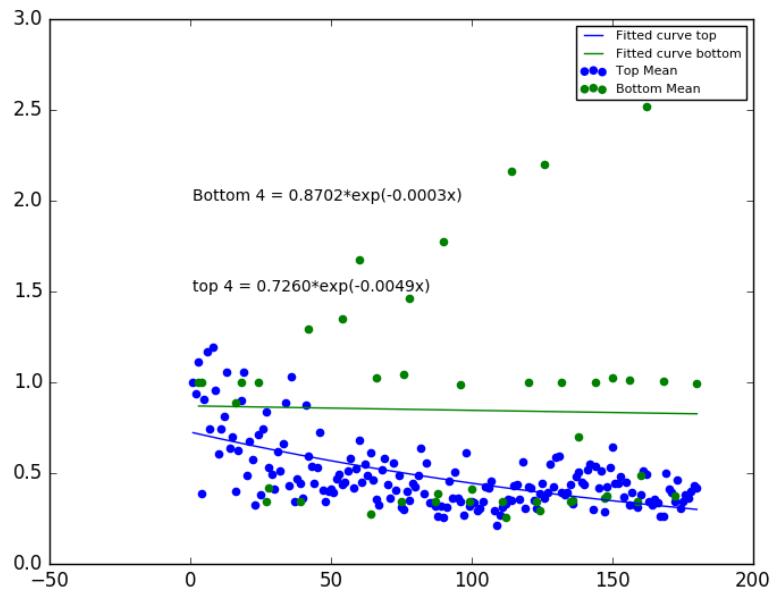
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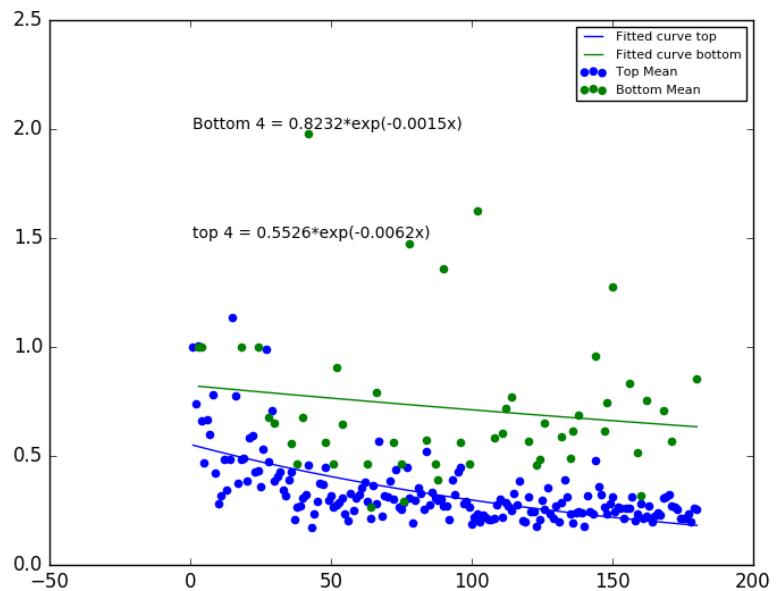
d)Subject 4



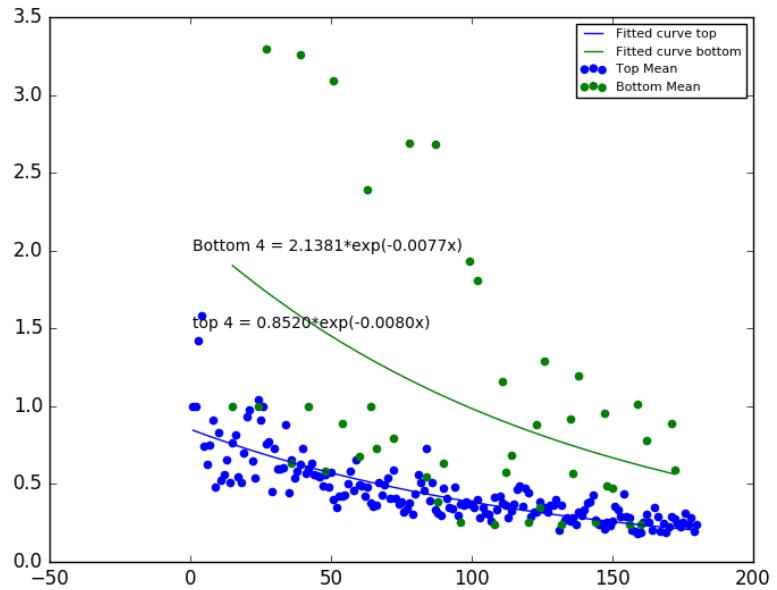
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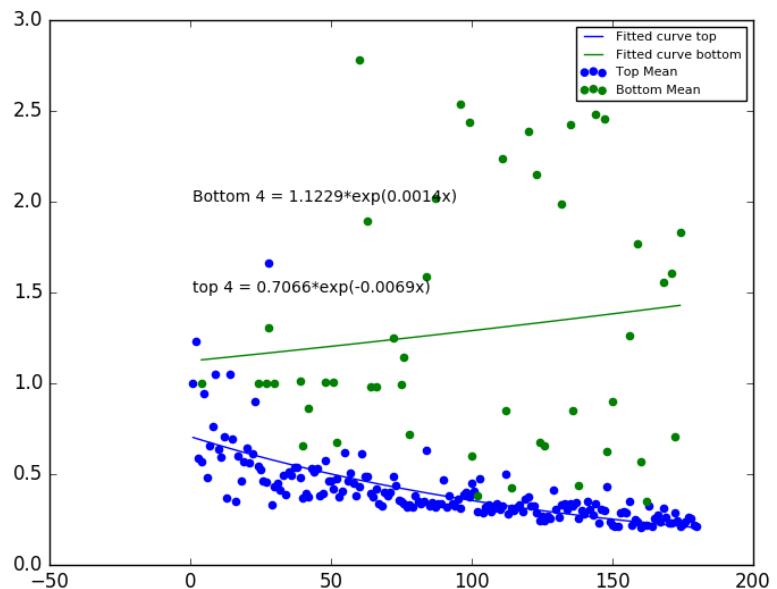
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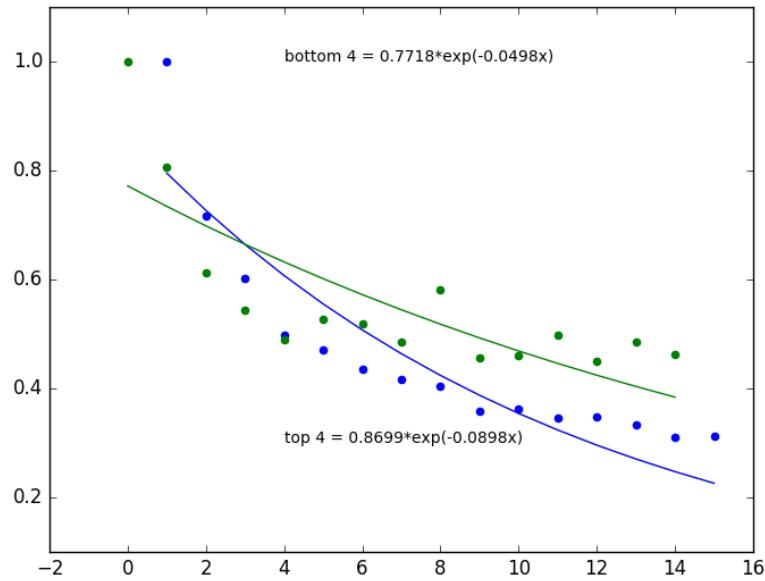
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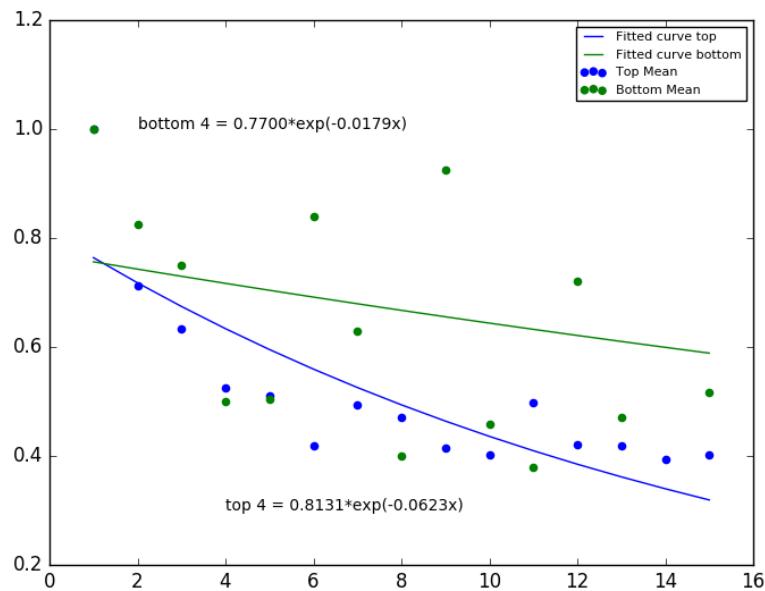
h)Subject 8



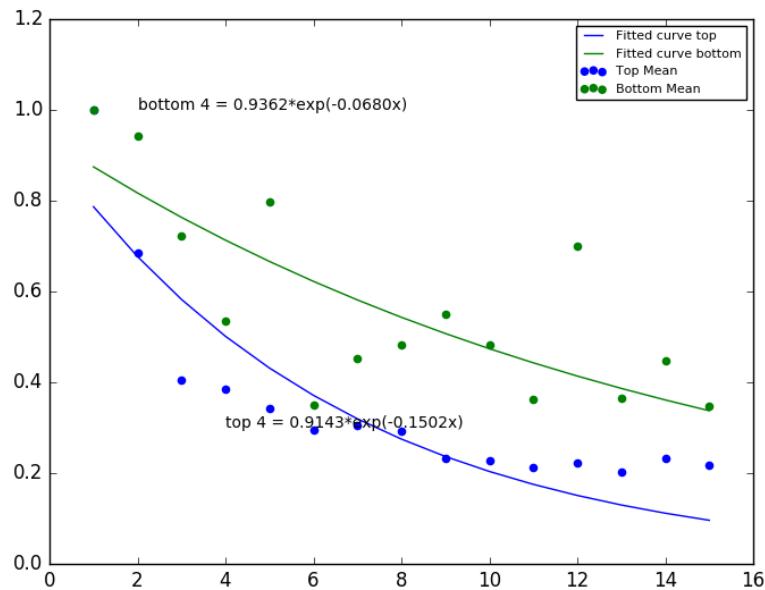
- 2) Method 2:
 i) Average across all subjects taken across each day



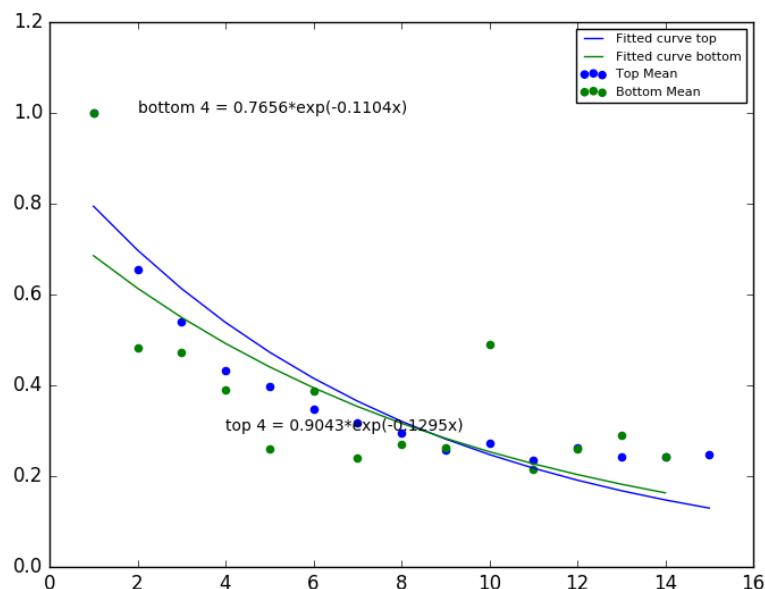
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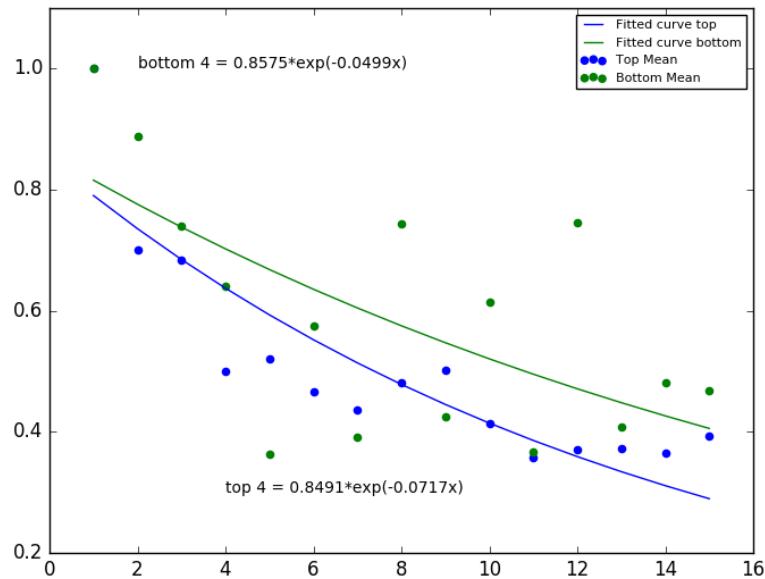
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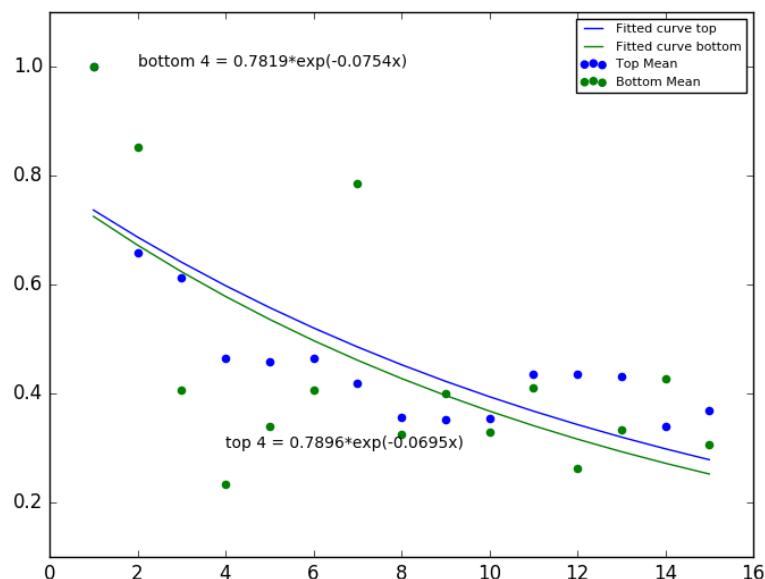
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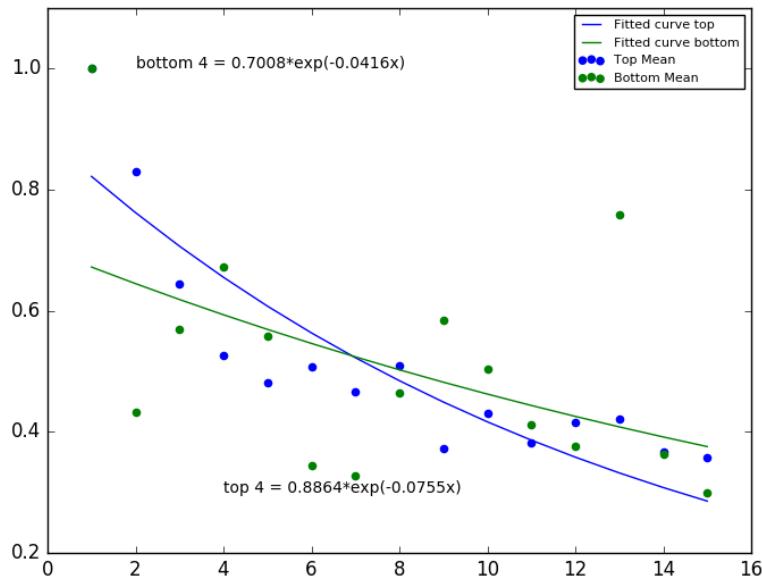
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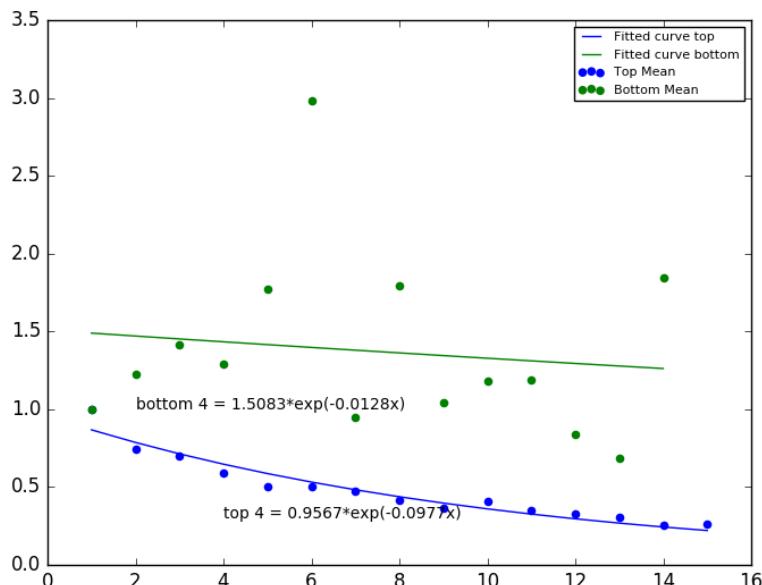
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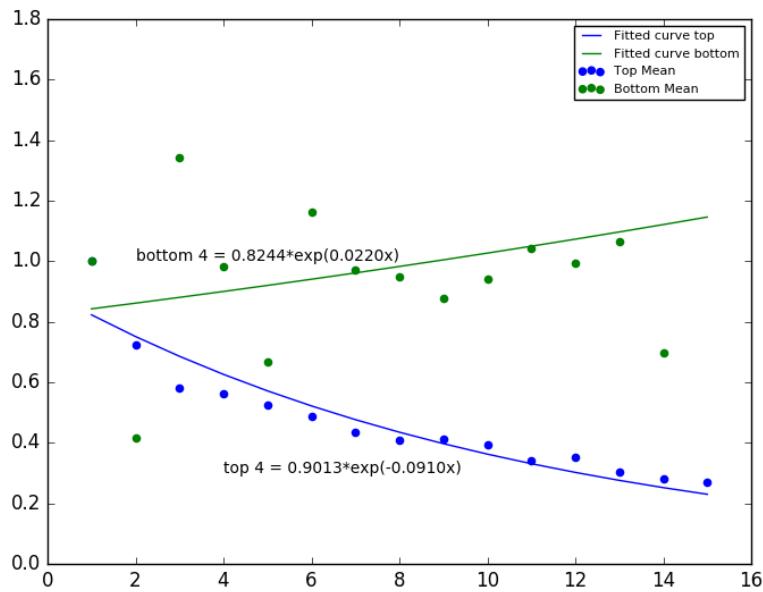
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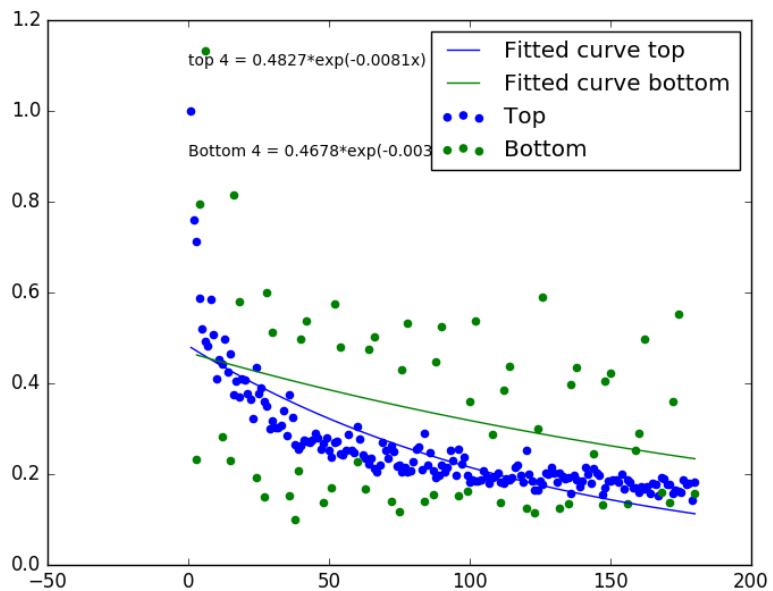
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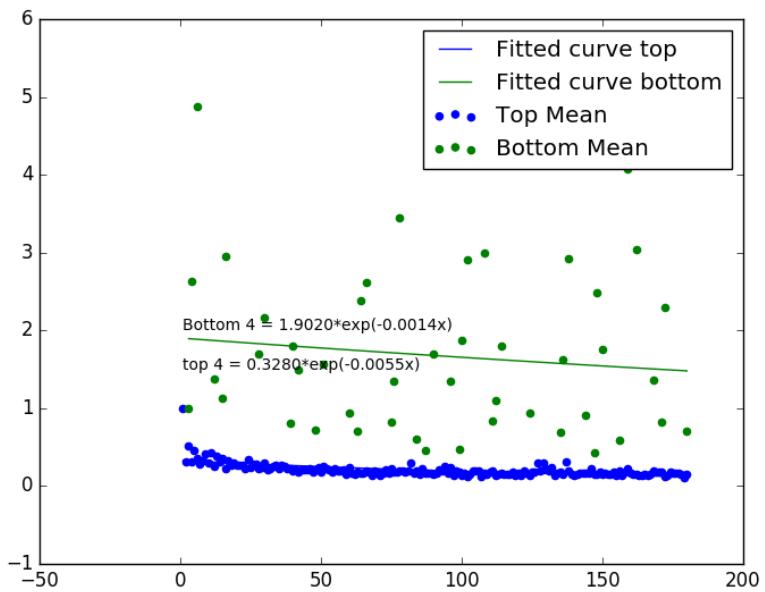
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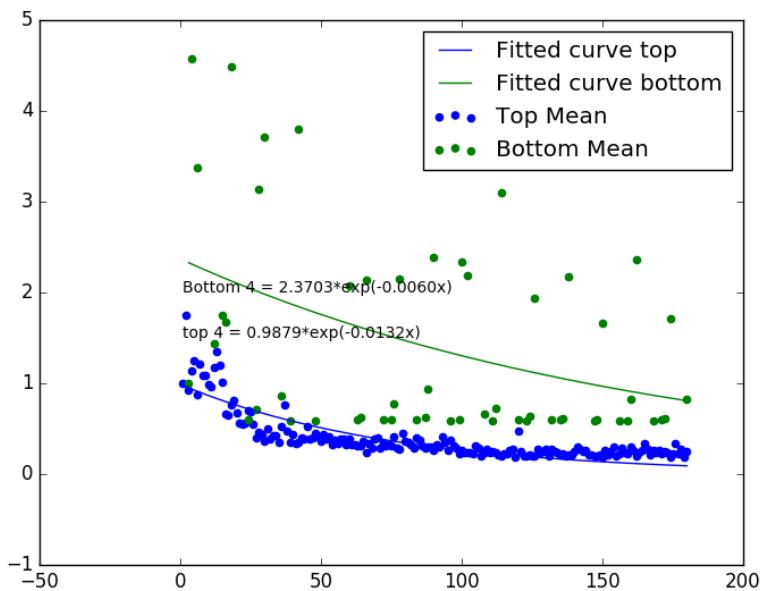
ii) Average across all subjects taken across each block



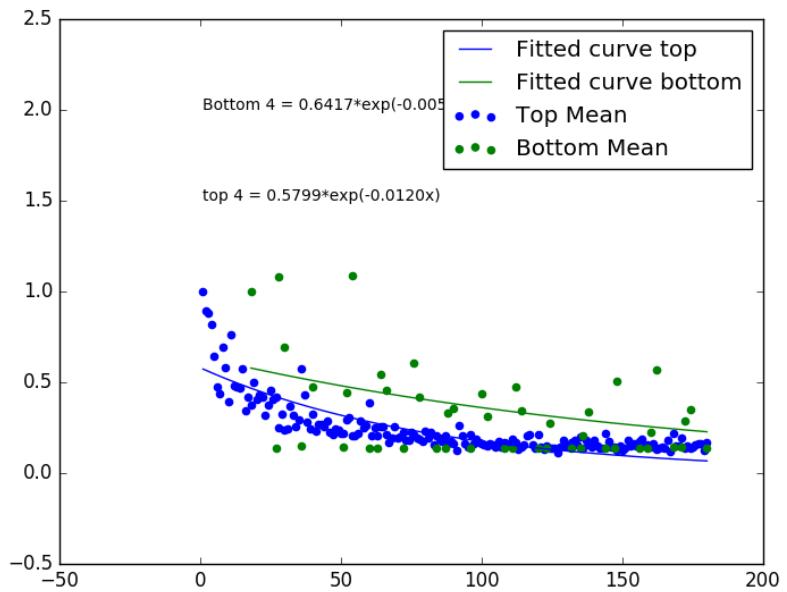
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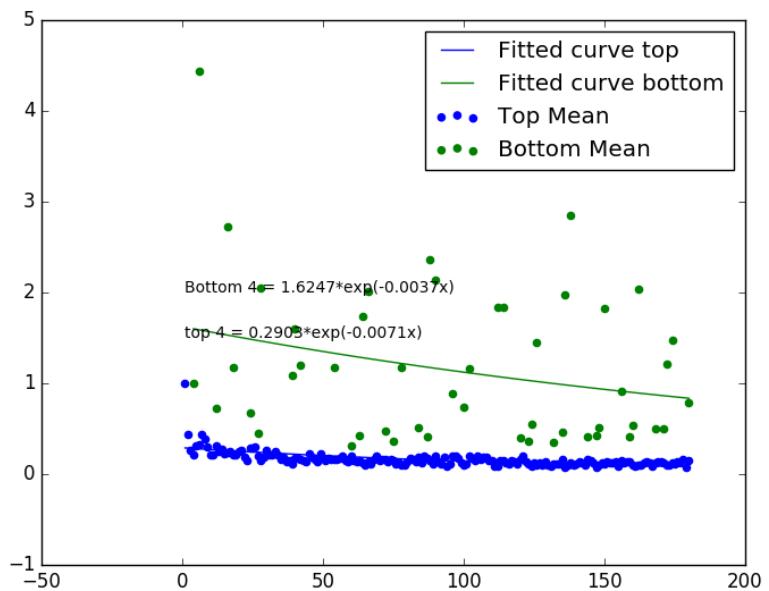
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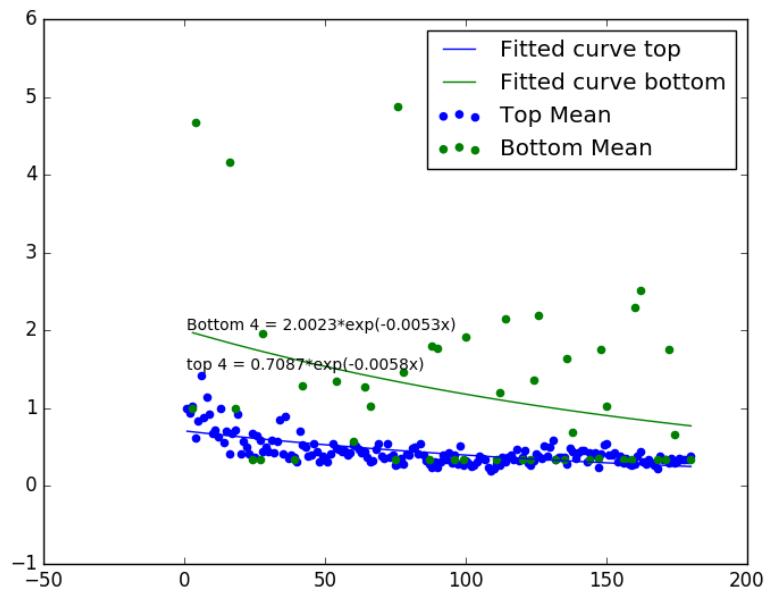
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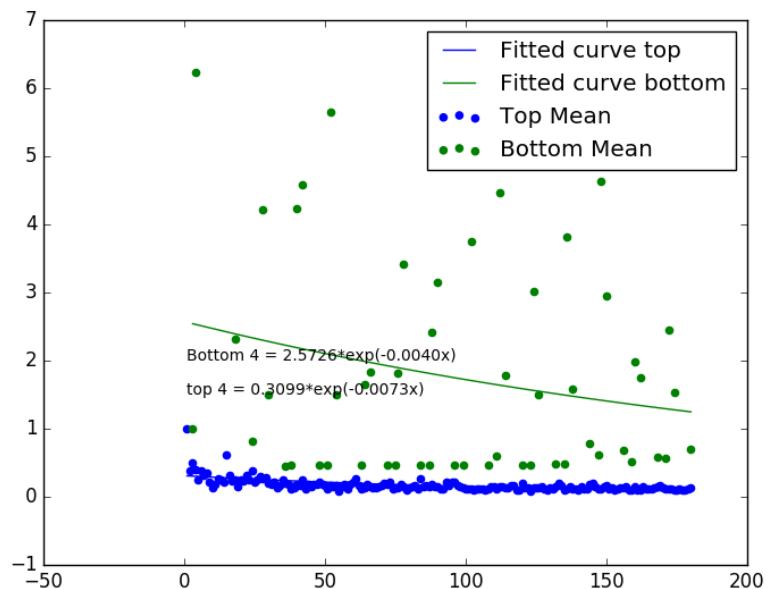
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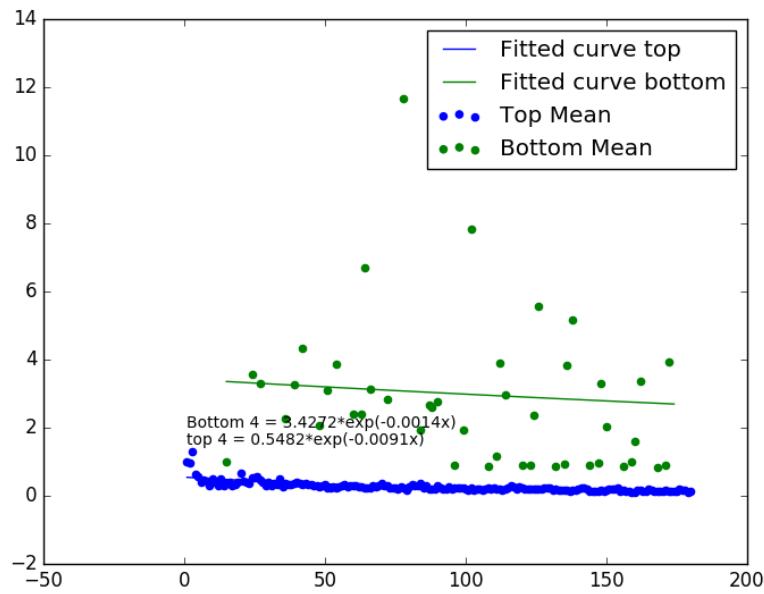
e)Subject 5



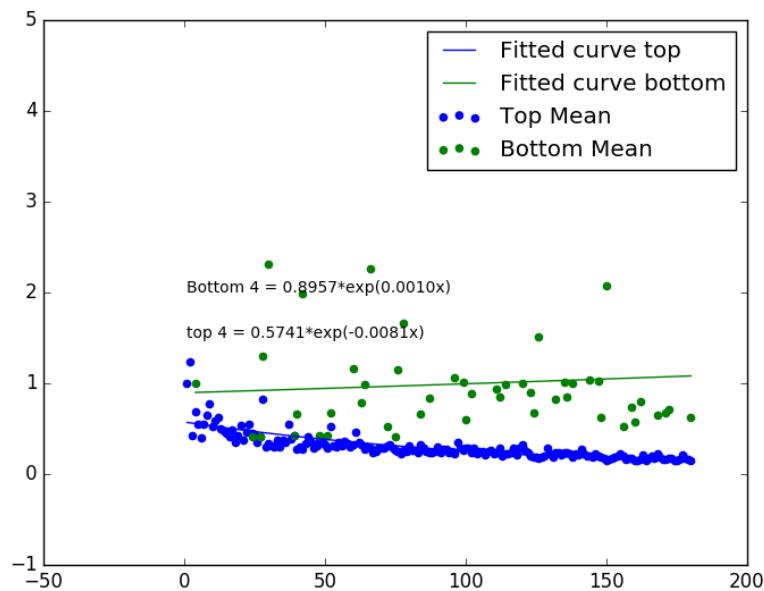
f)Subject 6



g)Subject 7



h)Subject 8



The rate of decay is given below for each plot along with the drop in movement time. The drop in movement time is calculated by substituting the first and last day/block of practise into the exponential equation to get the calculated movement time as per the function and then calculating the difference between these two values. This gives the drop in movement time as per the fitted curve.

Method 1- Across Days				
Plot	Rate of Decay		Percentage Drop	
	Most Frequent	Least Frequent	Most Frequent	Least Frequent
All Subjects	-0.0829	-0.0349	48.80	36.22
Subject 1	-0.0609	0.0472	39.69	-45.69
Subject 2	-0.1497	-0.0408	57.81	32.69
Subject 3	-0.1286	-0.0480	56.62	35.92
Subject 4	-0.0622	-0.0610	40.53	61.16
Subject 5	-0.0629	-0.0408	39.50	34.99
Subject 6	-0.0673	-0.0119	44.59	9.36
Subject 7	-0.0908	-0.0597	58.68	62.78
Subject 8	-0.0868	0.0153	53.28	-21.67

Method 1- Across Blocks				
Plot	Rate of Decay		Percentage Drop	
	Most Frequent	Least Frequent	Most Frequent	Least Frequent
All Subjects	-0.0069	-0.0016	46.49	23.95
Subject 1	-0.0041	0.0007	40.45	-9.97
Subject 2	-0.0136	-0.0043	64.16	47.90
Subject 3	-0.0112	-0.0013	57.05	14.61
Subject 4	-0.0054	-0.0035	23.72	56.08
Subject 5	-0.0049	-0.0003	41.87	4.26
Subject 6	-0.0062	-0.0015	35.44	18.46
Subject 7	-0.0080	-0.0077	63.52	121.1
Subject 8	-0.0069	0.0014	49.23	-26.83

Method 2- Across Days				
Plot	Rate of Decay		Percentage Drop	
	Most Frequent	Least Frequent	Most Frequent	Least Frequent
All Subjects	-0.0898	-0.0498	50.08	35.01
Subject 1	-0.0623	-0.0179	39.85	15.42
Subject 2	-0.1502	-0.0680	58.09	47.96
Subject 3	-0.1295	-0.1104	56.83	45.07
Subject 4	-0.0717	-0.0499	44.60	37.03
Subject 5	-0.0695	-0.0754	40.87	42.01
Subject 6	-0.0755	-0.0416	47.66	26.92
Subject 7	-0.0977	-0.0128	56.59	20.86
Subject 8	-0.0910	0.0220	52.12	-28.45

Method 2- Across Blocks				
Plot	Rate of Decay		Percentage Drop	
	Most Frequent	Least Frequent	Most Frequent	Least Frequent
All Subjects	-0.0081	-0.0038	36.22	22.68
Subject 1	-0.0055	-0.0014	20.27	41.11
Subject 2	-0.0132	-0.0060	87.08	150.6
Subject 3	-0.0120	-0.0052	49.90	32.17
Subject 4	-0.0071	-0.0037	20.47	75.37
Subject 5	-0.0058	-0.0053	44.95	118.6
Subject 6	-0.0073	-0.0040	22.20	128.4
Subject 7	-0.0091	-0.0014	43.18	61.98
Subject 8	-0.0081	0.0010	43.21	-16.28

Observations:

- i) In method 1, we can see that the most frequent transitions line always has a higher rate of decay as compared to the least frequent transitions line. This is true for each subject and in the average of the subjects across days and blocks. In method 2 the most frequent transitions line had a higher rate of decay in almost all the cases.
- ii) In method 1, there is clear separability between the 2 fitted lines in all the cases. In method 2, there is separability in almost all the cases.
- iii) The drop is greater in case of most frequent transitions in method 1 for almost all cases. While, in method 2 we see that there are a lot of cases where the drop is greater for less frequent transitions. This can be attributed to the fact that the points have been plotted by taking the ratio of the actual average with the average of the first day/block. If the first day/block average is very low and almost all the other point are greater than it, the fitted line ends up having a greater rate of decay and a higher drop as we are taking the drop with respect to the fitted line although in absolute terms the movement time on the last day may be less/greater than that on the first day.

Inference: There does seem to be a greater improvement in movement time for more frequent transitions. But we have not been able to show any distinct correlation between frequency of a transition and drop in movement time as we have taken only the most and the least occurring transitions. So in order to observe this correlation, we will consider all of the transitions. Additionally, the curve fitting equation may need to be modified so as to fit the data points better.

6 All Transitions

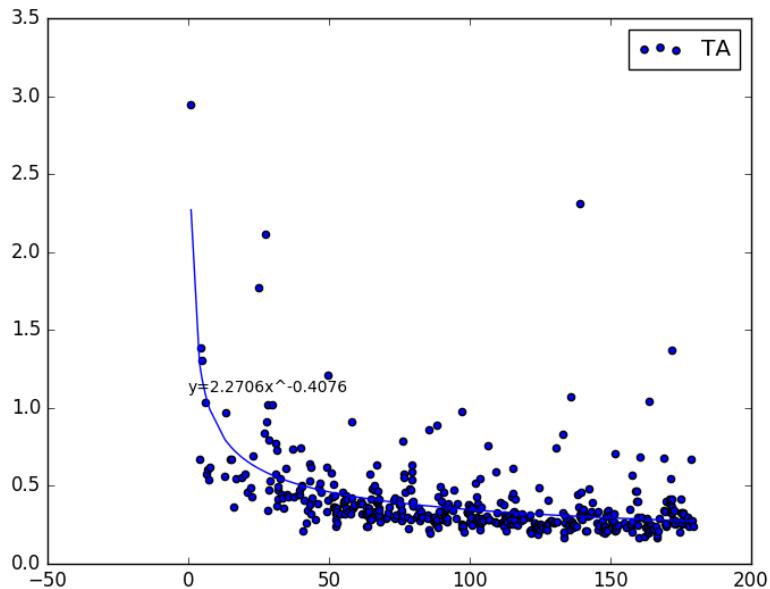
Out of 81 possible transitions, 69 exist in the dictionary set of words. The movement times of each transition was plotted for each subject without taking any average as well as by averaging across days and across blocks. So for each person there are 3 categories which are, all movement times, averaging across days and averaging across blocks. In each category there are 69 plots. Now each

plot was fitted with an exponential function of the form

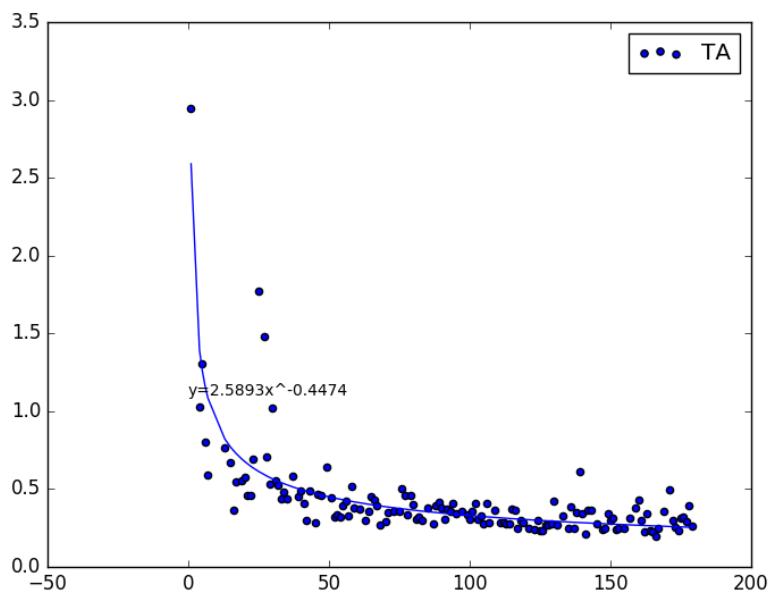
$$y = a * x^b$$

where b is the learning curve factor and a is the movement time corresponding to the first instance. This curve has a better fit with the data. Below we see the transition T-A for Person 1 for all movement times, across blocks and across days.

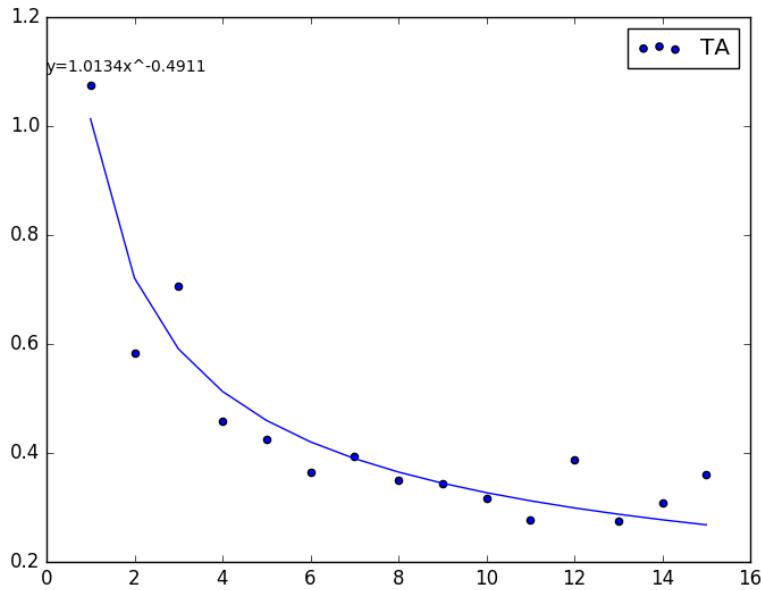
i) All Movement Times



ii) Across Blocks

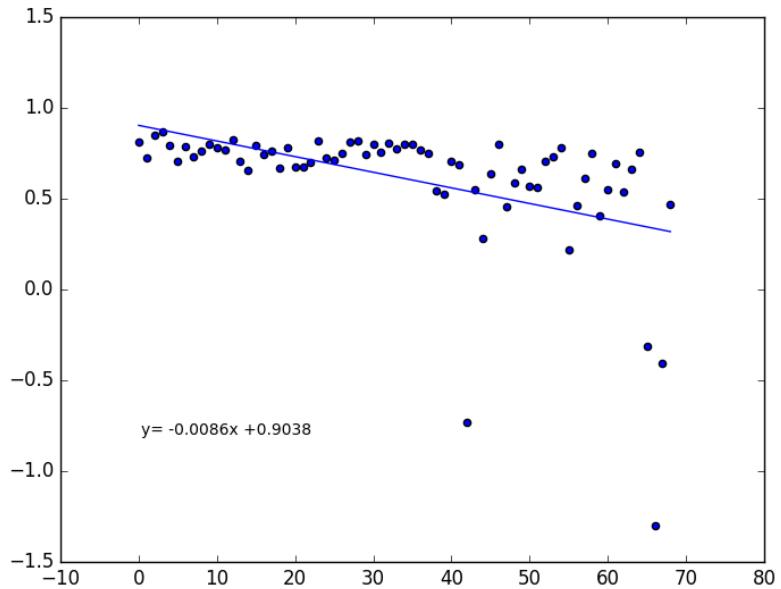


iii) Across Days

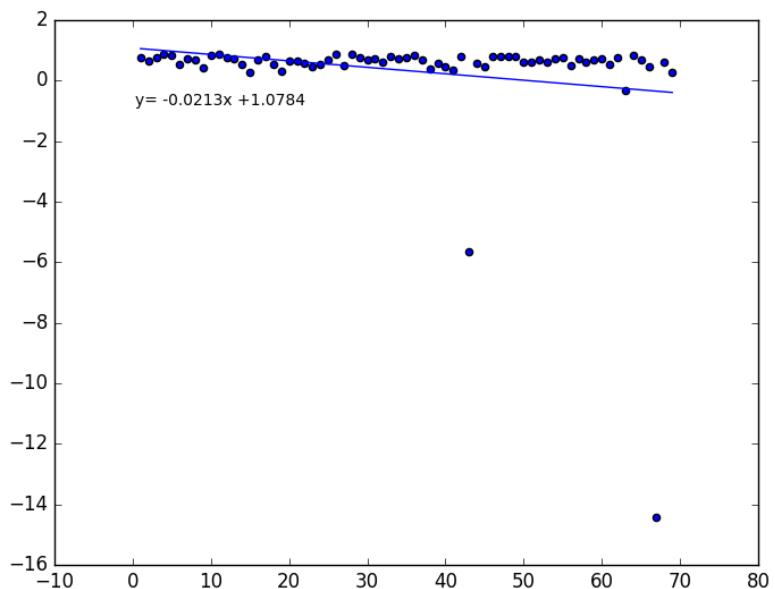


The percentage drop was calculated by substituting the first and last instance of practise in the curve equation and then finding the percentage decrease between these 2 values. This drop was found for each transition and then plotted. This was done for each subject in the 3 categories and then the average was taken across subjects. Each plot was then linearly fit inorder to observe the trend in the data points. In these plots the x-axis is the rank of the transition i.e the most frequent transition will have rank 1 and so on.

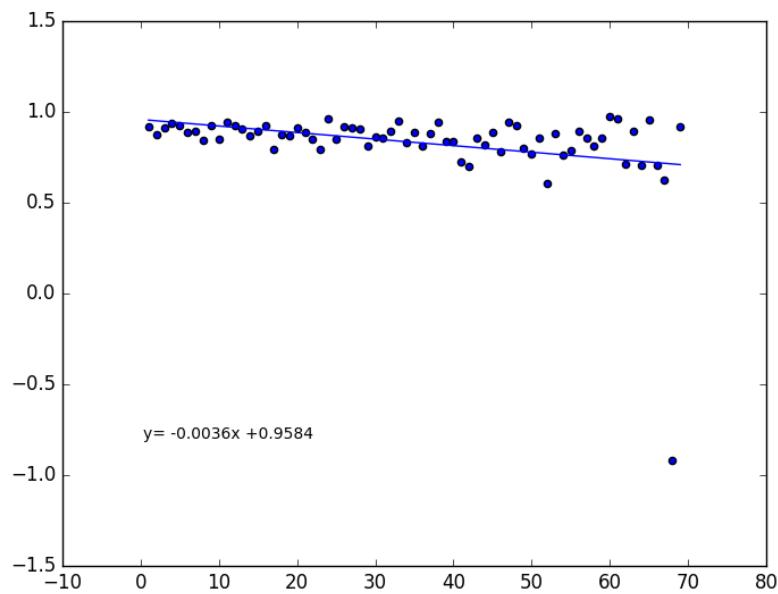
I)All Movement Times
i)Average across subjects



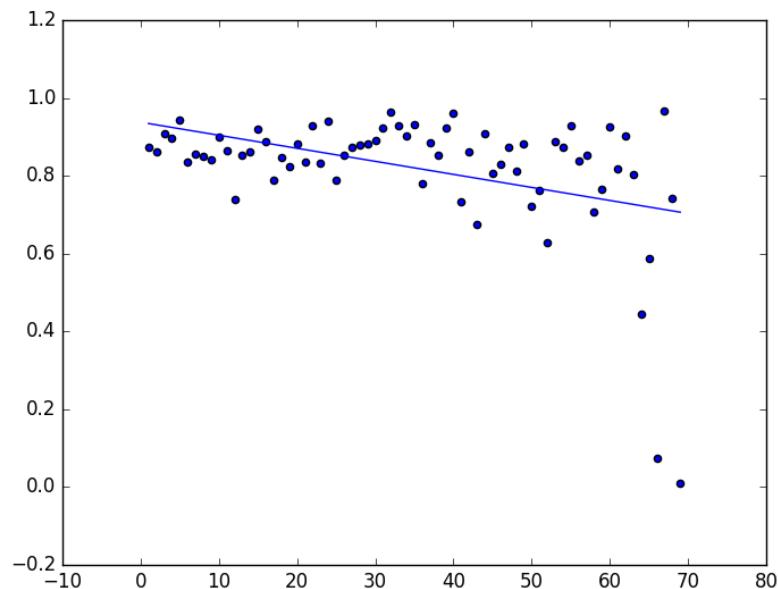
ii)Subject 1



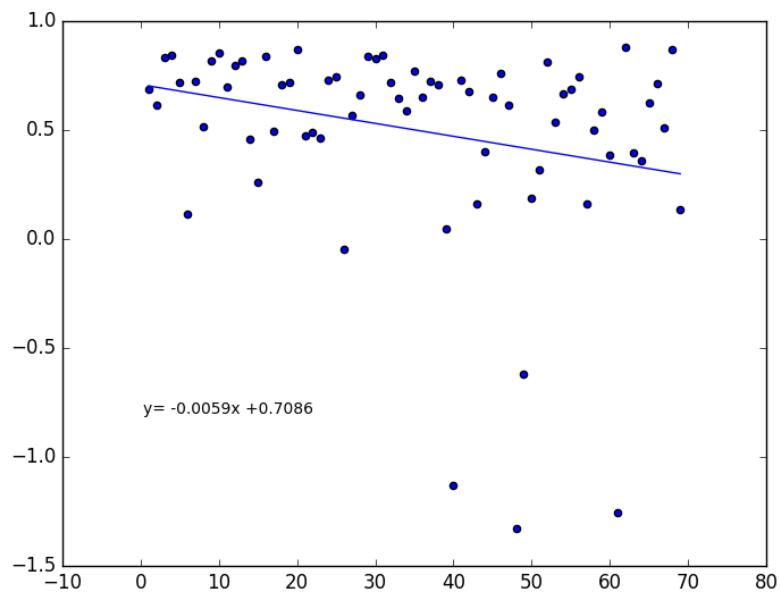
iii) Subject 2



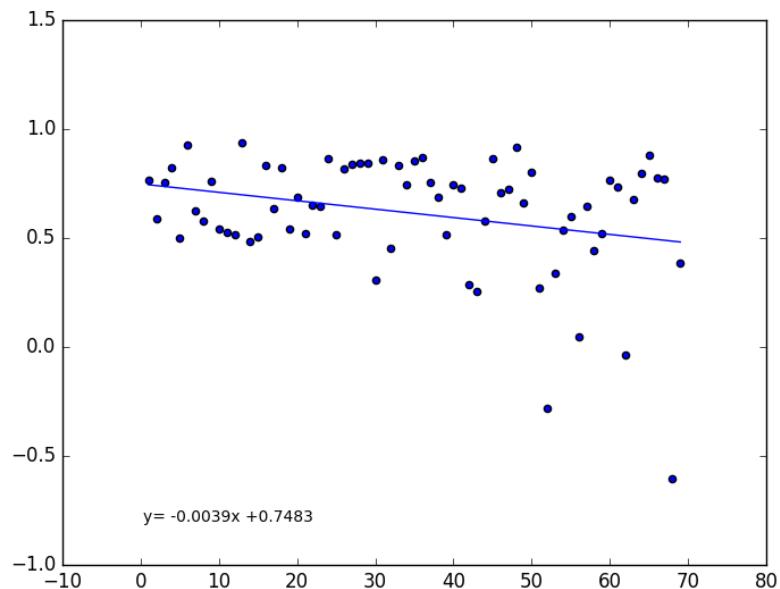
iv) Subject 3



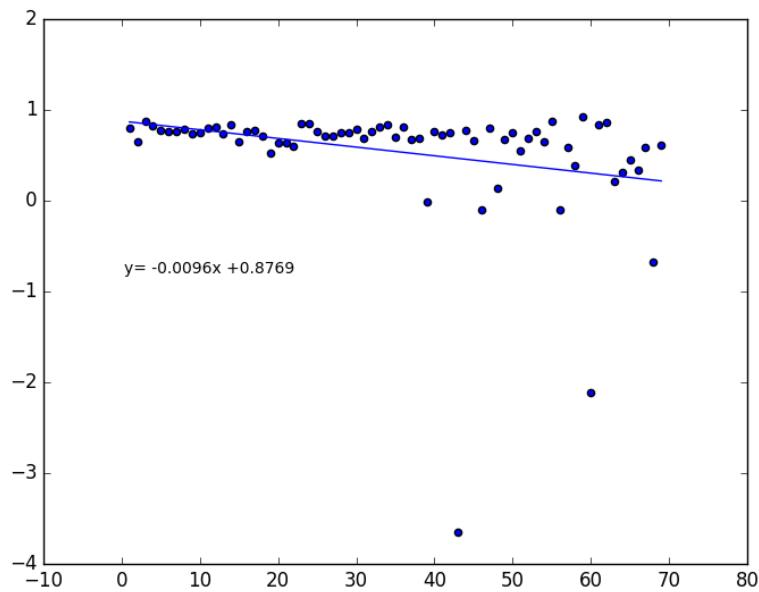
v) Subject 4



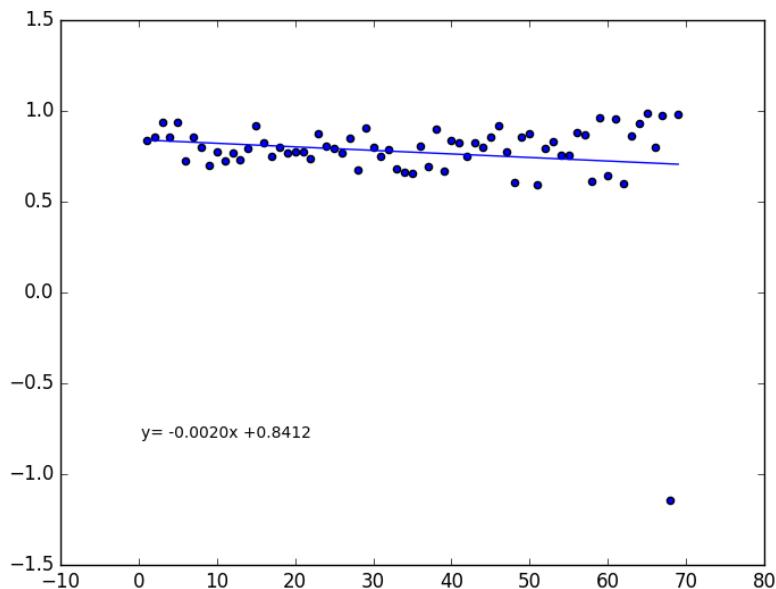
vi) Subject 5



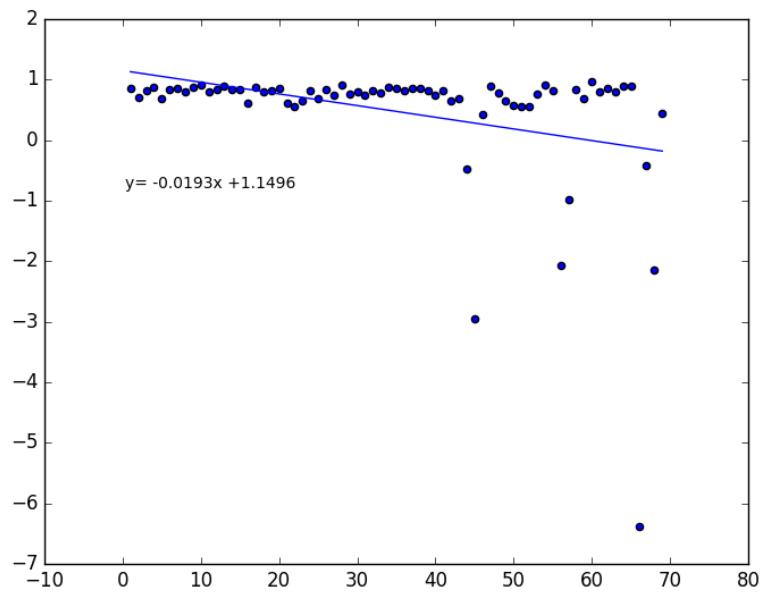
vii) Subject 6



viii) Subject 7

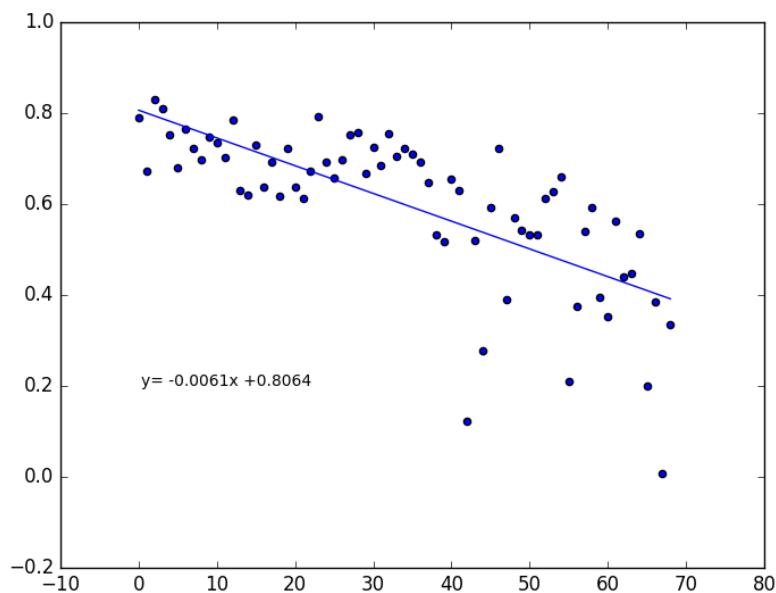


ix) Subject 8

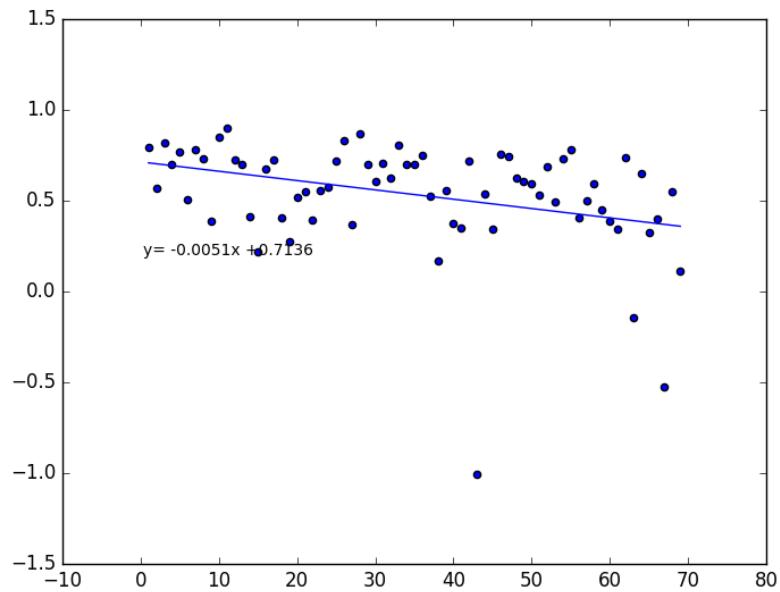


II) Across Blocks

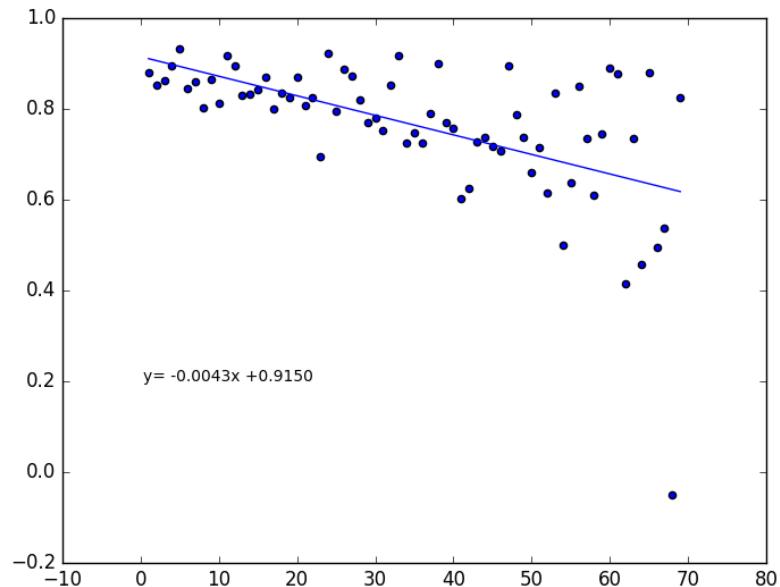
i) Average across subjects



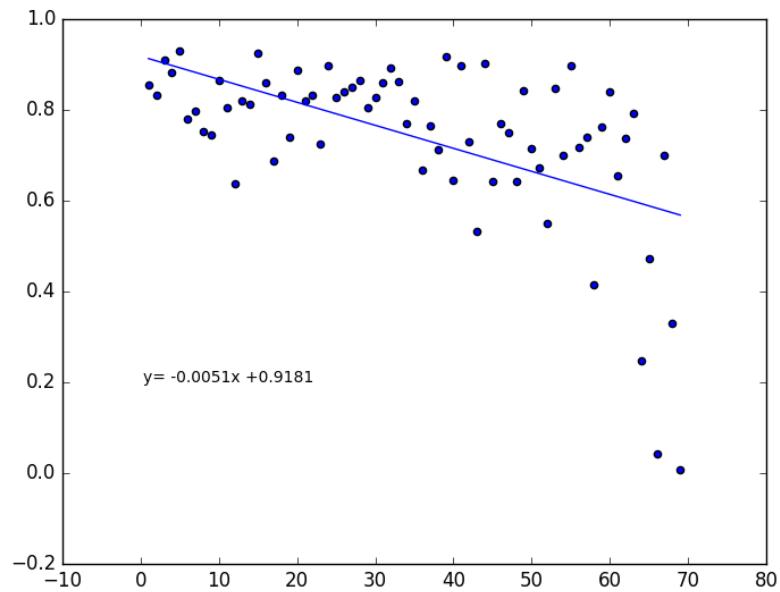
ii) Subject 1



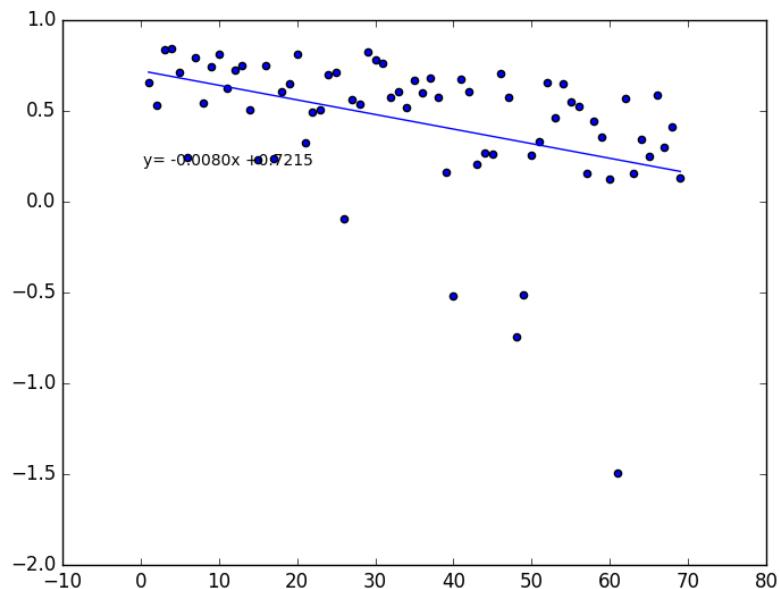
iii) Subject 2



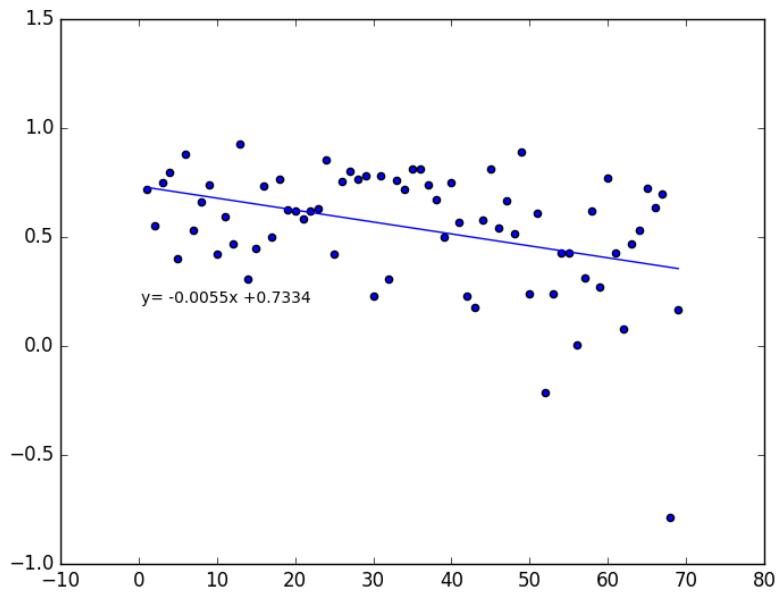
iv) Subject 3



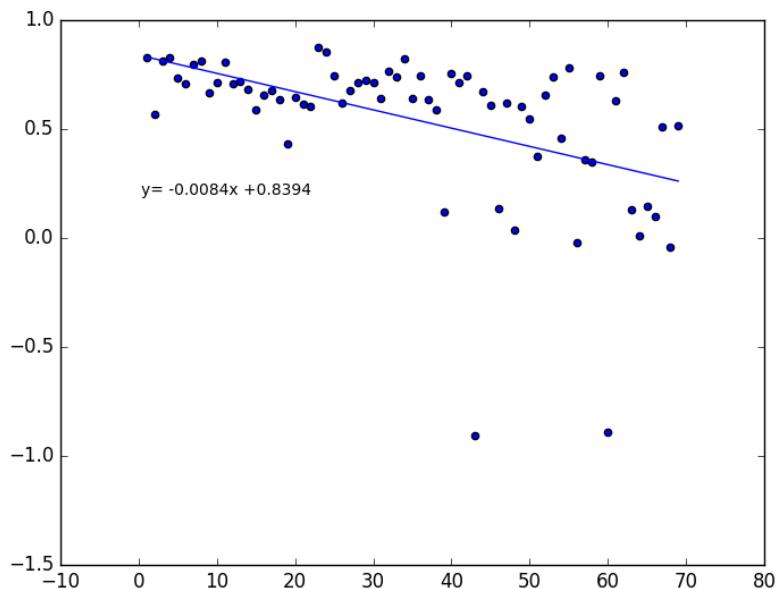
v) Subject 4



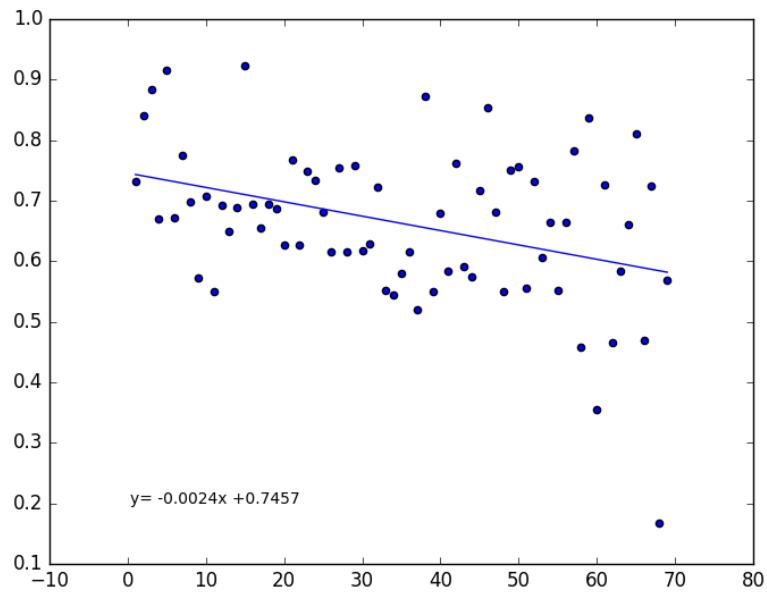
vi) Subject 5



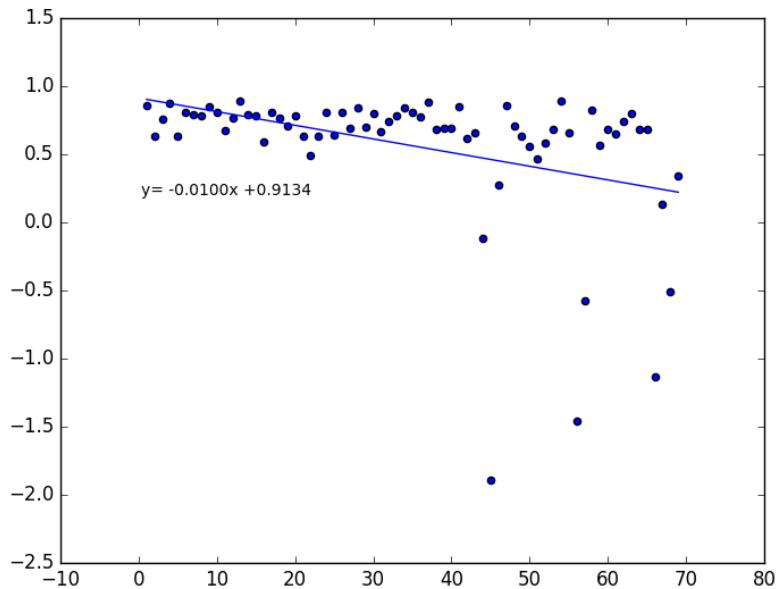
vii) Subject 6



viii) Subject 7

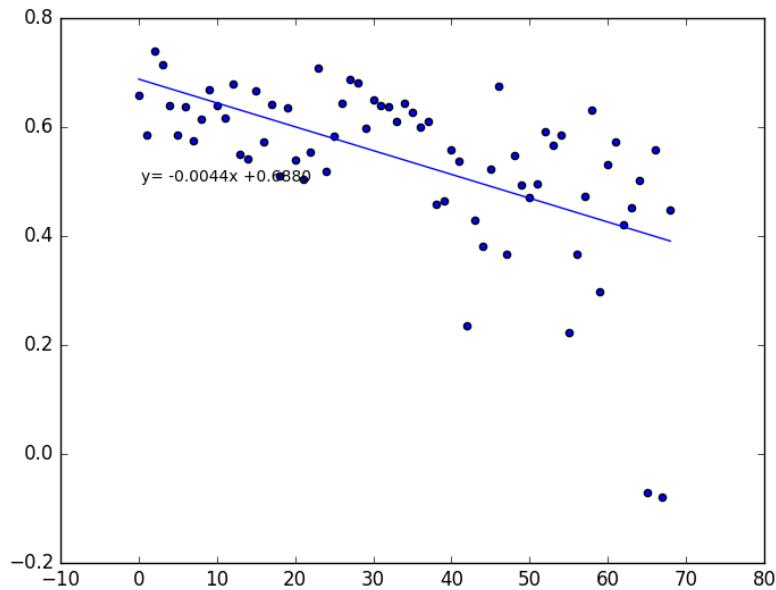


ix) Subject 8

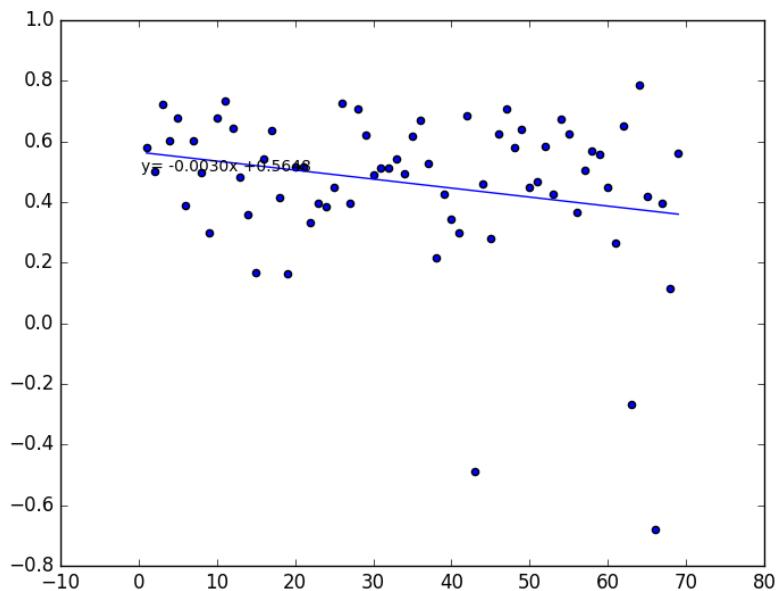


III) Across Days

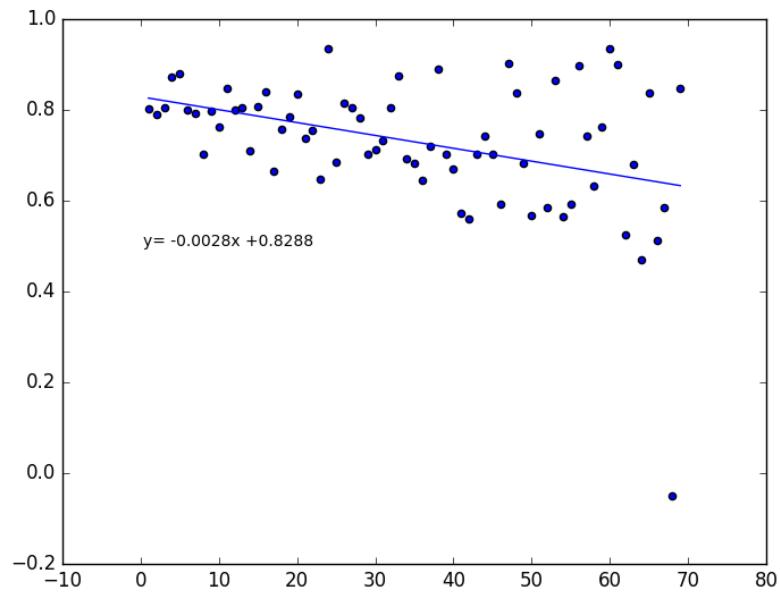
i) Average across subjects



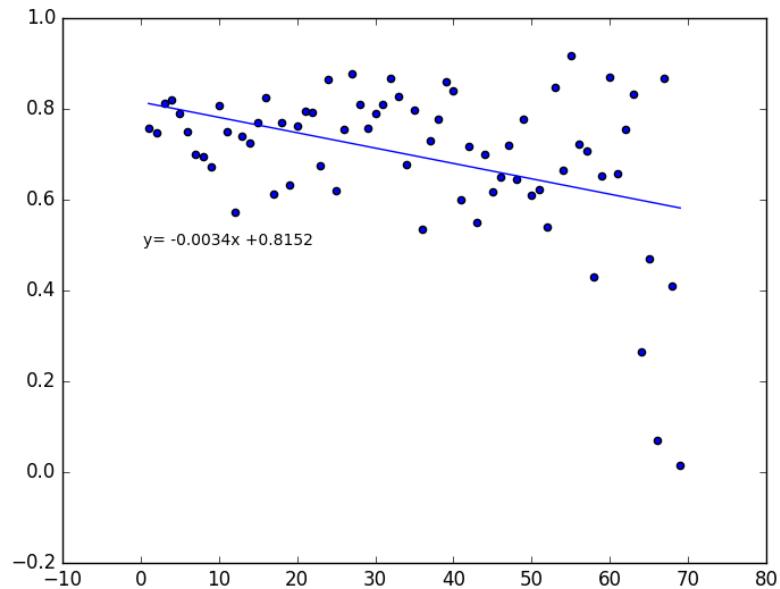
ii) Subject 1



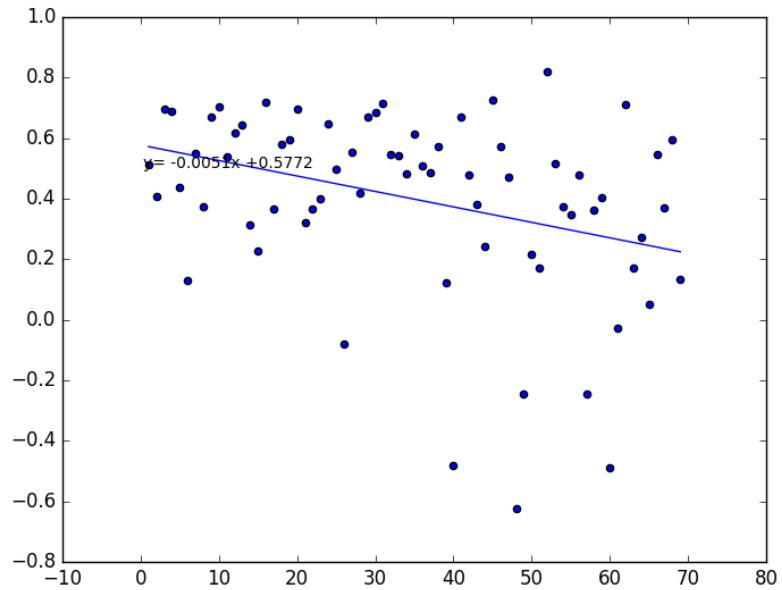
iii) Subject 2



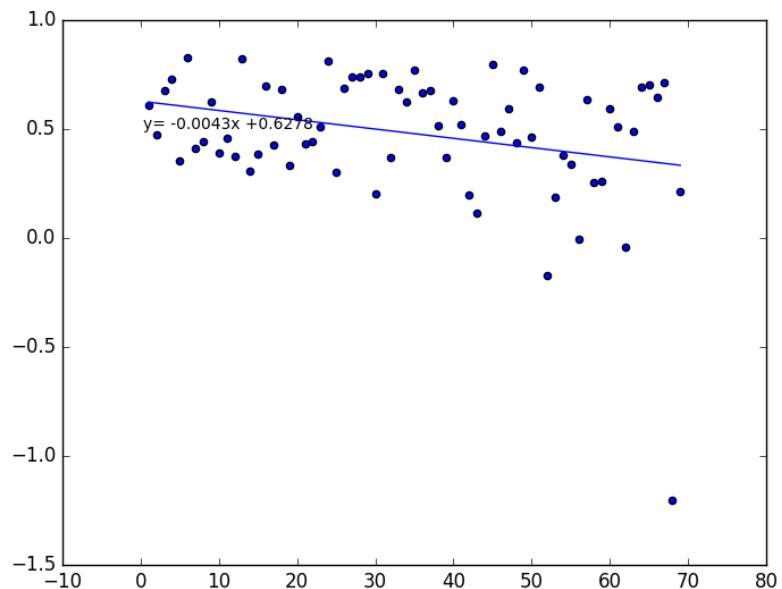
iv) Subject 3



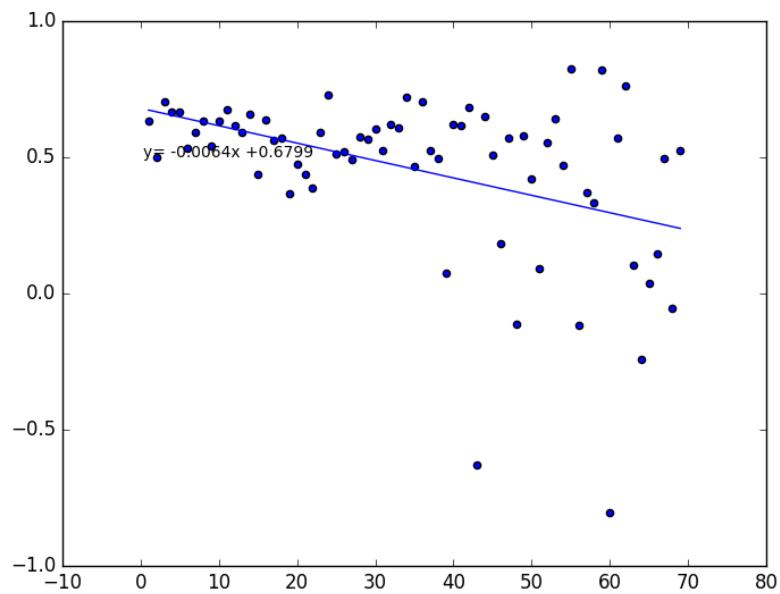
v) Subject 4



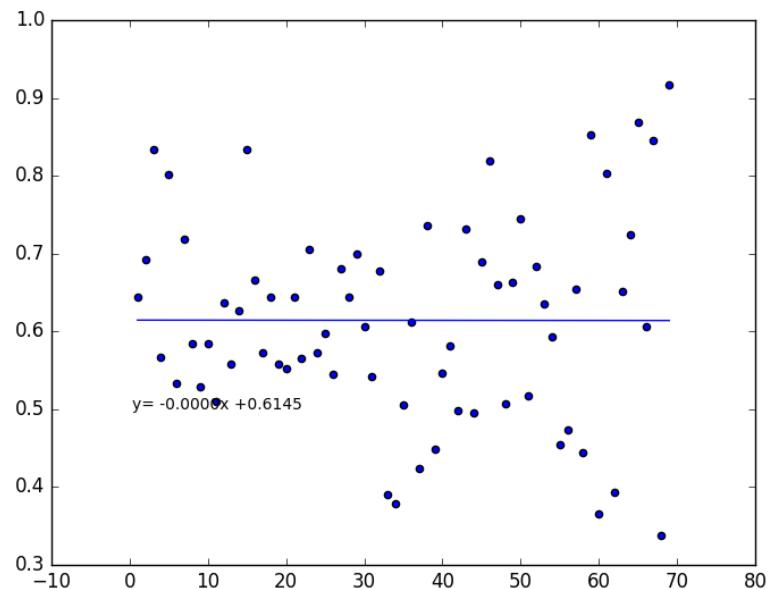
vi) Subject 5



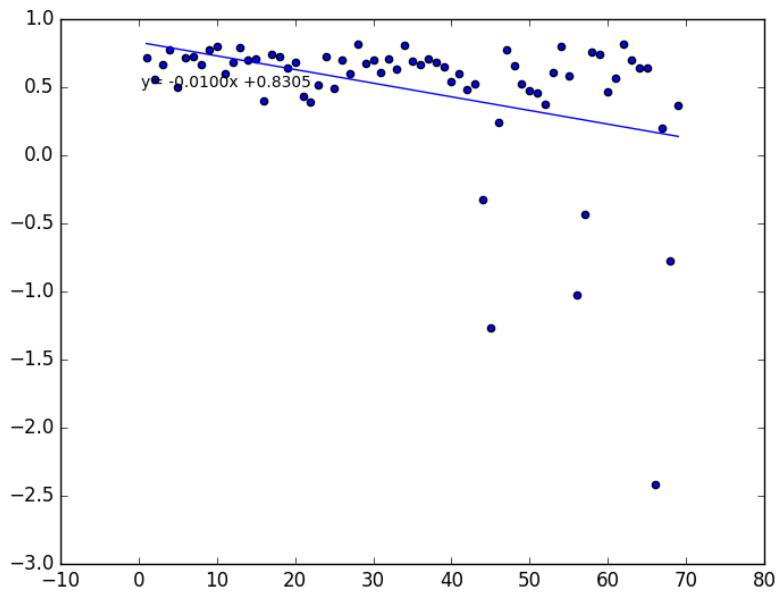
vii) Subject 6



viii) Subject 7



ix) Subject 8



From these plots we can find the percentage difference of the most frequent transition to the least frequent transition. This is done in order to observe the difference in improvement. This is done by finding the difference between the 2 extremes of the fitted line and multiplying by 100.

All Movement Times	
Plot	Percentage Difference
Average Plot	57.99
Subject 1	141.02
Subject 2	24.51
Subject 3	22.95
Subject 4	39.86
Subject 5	26.29
Subject 6	64.96
Subject 7	13.29
Subject 8	131.98

Across Days	
Plot	Percentage Difference
Average Plot	29.76
Subject 1	20.43
Subject 2	19.27
Subject 3	23.20
Subject 4	34.75
Subject 5	29.05
Subject 6	43.43
Subject 7	0.079
Subject 8	68.10

Across Blocks	
Plot	Percentage Difference
Average Plot	41.42
Subject 1	34.72
Subject 2	29.27
Subject 3	34.69
Subject 4	54.20
Subject 5	37.27
Subject 6	56.99
Subject 7	16.10
Subject 8	68.17

Inference: From these plots we can see that as the rank increases there is a reduction in the drop time. This is a clear indication that frequently practised transitions show more improvement in movement time as compared to less frequently practised transitions. On average the percentage drop between the most frequent and least frequent transition is 43.05%. This shows a significant difference between improvement in movement time for most frequently practised transitions and least frequently practised transitions.