Analysis of effect of frequency and distance of transitions on improvement in performance

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1 Introduction

Previous studies have shown that practising a sequence such as 4-1-2-3-4 showed improvement in performance in terms of speed and accuracy as a function of practise(Karni.et.al, 1995; 1996; 1998)[1][2][3]. In that context, the sequence is 4-1-2-3-4 and each number is an element. In the current study we consider meaningful words as a sequence. Consider the word 'SAINT'. Here the word 'SAINT' is a sequence and the letters are elements. The action of moving from 1 letter to the next letter is called a transition. For this word there will be 4 transitions, which are S-A, A-I, I-N and N-T. Now, these transitions are not practised independently nor as a continuous repetitive sequence. But rather they are performed as part of a sequence of other unique transitions. The performance of a transition depends on multiple factors which are the transitions preceding that transition, the positioning of the letters of the transition, the number of times the transition has been practised and the distance required to traverse that particular transition. Based on this we have the following hypothesis.

H1a) The improvement in performance of a transition will not depend on the frequency of practise alone.

H1b) The improvement in performance of a transition will depend on the distance irrespective of frequency of practise.

2 Materials and Methods

2.1 Participants

Eight healthy, right-hand dominant participants (6 males and 2 females, mean sd: Age: 26.82.6 yrs., Height: 163.56.0 cm, Weight: 66.810.5 kg) volunteered for the study. Participants had no history of any neuro-motor disorder or trauma to the hand or fingers and were nave to the purpose of the experiment. Handedness was determined using Edinburgh handedness inventory (Oldfield, 1971) and all participants those who had a handedness score above 90% (score of 90 and above indicates that participants were right hand dominant) recruited for the study. All participants provided written informed consent before participating in the experiment. The procedures carried in the experiment were endorsed by the institutional ethics committee of the Indian Institute of Technology Madras (Approval number: IEC/2016/02/VSK-12/22).

2.2 Experimental Setup

The experimental system used was a glove-based typing device that consisted of a glove with conductive key patches placed approximately at the center of each segment in the index, middle, ring and little fingers (3 segments * 4 fingers = 12 keys) and one at the distal end of the thumb. Among these 13 keys, the one on the thumb was used as a switch while the 12 on the other fingers were assigned with nine specific letters, space, backspace and caps lock. These keys were connected to a microcontroller (Teensy 2.0++) using conductive thread, metallic buttons, and cables. Fig 4.1 illustrates the experimental setup and the keymap used.
In order to type a particular key, participants had to touch the corresponding key patch on a finger with the thumb, which then closed the electrical circuit. A customized program in the microcontroller detected this event, and the program then sent the ASCII code assigned to that specific key to the computer through a USB port. For example, when the participant touched the middle phalanx of the index finger, letter S was typed on the computer screen as shown in Fig 1. These gloves were custom-made to suit the hand dimensions for each participant. The text from the glove was processed by a customized LabVIEW based program at 1000 Hz.

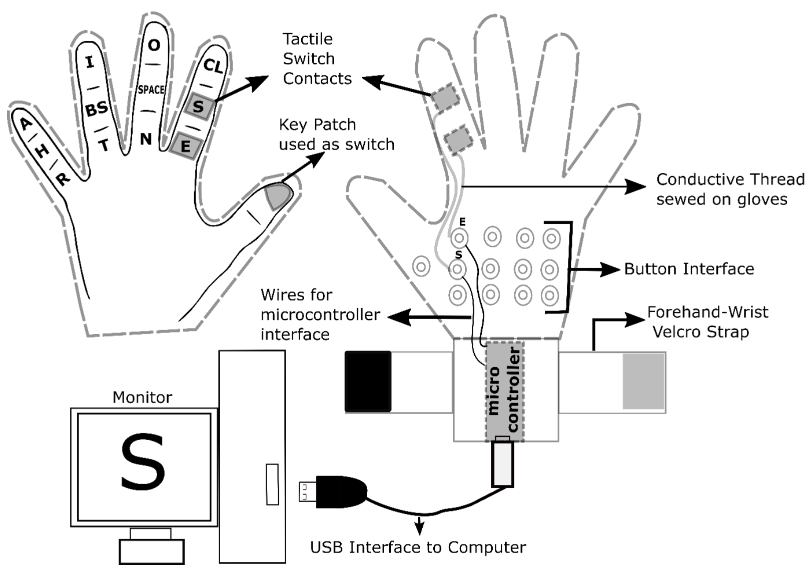

Figure 1: **Block diagram showing the functioning of the glove-based typing device-** Participants wore gloves (showed with dotted lines) such that the tactile switches on the glove faced towards the participants. Hand is represented with bold lines. Key patches (showed as square around the letters) were sewed on the dorsal side of each finger segment on the gloves. Conductive threads, sewed on the glove were used to connect the key patches to a button connector, which was used to interface with the microcontroller. When an letter patch was touched with thumb, a custom written code in the microcontroller converted the touch into text. This was shown on the computer monitor.

Table 1- Word Dictionary

'aeons'	'eosin'	'horns'	'oasis'	'riots'	'serer'	'snare'	'store'	'these'	'trash'
'aerie'	'erase'	'horse'	'oaths'	'risen'	'seres'	'sneer'	'taint'	'theta'	'treat'
'airer'	'error'	'hoser'	'onion'	'riser'	'setae'	'snits'	'tares'	'thine'	'trees'
'anion'	'ester'	'hoses'	'onset'	'rises'	'shahs'	'snoot'	'tarns'	'thins'	'trent'
'anise'	'ether'	'hosta'	'orate'	'rites'	'share'	'snore'	'taros'	'thorn'	'tress'
'antra'	'ethos'	'hosts'	'ortho'	'roans'	'shear'	'snort'	'tarot'	'those'	'trier'
'aorta'	'hairs'	'inane'	'other'	'roars'	'sheen'	'snots'	'tarsi'	'three'	'tries'
'areas'	'hares'	'inert'	'otter'	'roast'	'sheer'	'soars'	'tarts'	'throe'	'trios'
'arena'	'harsh'	'inner'	'rains'	'roist'	'sheet'	'sonar'	'taste'	'tiara'	'trite'
'arias'	'haste'	'inset'	'raise'	'roost'	'shier'	'soots'	'tatar'	'tiers'	'trots'
'arise'	'hater'	'inter'	'rants'	'roots'	'shies'	'sorer'	'tatoo'	'tinea'	'tsars'
'arose'	'hates'	'iotas'	'rarer'	'roses'	'shine'	'sores'	'tears'	'tines'	
'arson'	'hears'	'irate'	'rares'	'rosin'	'shins'	'sorts'	'tease'	'tints'	
'ashen'	'heart'	'irons'	'rater'	'rotor'	'shire'	'stain'	'teats'	'tires'	
'asher'	'heath'	'naira'	'rates'	'saint'	'shirt'	'stair'	'teens'	'titan'	
'ashes'	'heats'	'nares'	'ratio'	'saith'	'shish'	'stare'	'teeth'	'tithe'	
'asses'	'heirs'	'nears'	'rears'	'saner'	'shoer'	'stars'	'tenet'	'toast'	
'asset'	'heist'	'neons'	'reins'	'sanes'	'shoes'	'start'	'tenon'	'toner'	
'aster'	'henna'	'nests'	'renin'	'sarin'	'shone'	'stash'	'tenor'	'tones'	
'astir'	'heres'	'nines'	'rents'	'saris'	'shoot'	'state'	'tense'	'tonne'	
'atone'	'heron'	'ninth'	'reran'	'satan'	'shore'	'stats'	'tenth'	'tooth'	
'atria'	'heros'	'nitro'	'resat'	'sates'	'shorn'	'steer'	'tents'	'toots'	
'earns'	'hints'	'noise'	'reset'	'satin'	'short'	'stein'	'terns'	'torah'	
'earth'	'hirer'	'noons'	'resin'	'sears'	'shots'	'steno'	'terse'	'torso'	
'easer'	'hires'	'noose'	'resit'	'seats'	'sines'	'stent'	'tests'	'torte'	
'eases'	'hoist'	'norse'	'rests'	'seers'	'siren'	'stern'	'tetra'	'torts'	
'eaten'	'honer'	'north'	'retie'	'seine'	'sires'	'sties'	'thats'	'toter'	
'eater'	'hones'	'noses'	'retro'	'senna'	'sitar'	'stint'	'their'	'totes'	
'eerie'	'honor'	'notes'	'rhino'	'senor'	'sites'	'stirs'	'thens'	'train'	
'enter'	'hoots'	'oases'	'rinse'	'sense'	'sitin'	'stone'	'there'	'trait'	

2.3 Task

The goal of the participants was to type out a series of words as fast and as accurately as possible. Rather than let participants choose their self-selected speed (which might not reflect their actual maximum speed), a game interface was designed where the typing speed could be set by the experimenter, allowing to more closely probe the maximum speed of the participants. This interface is described below.

2.4 Training Words

Words used in the experiment were 5-letter words picked from a custom dictionary (Refer to Table 1). This dictionary comprised of 281 words each made up from the nine most frequently used letters (e, s, o, n, i, t, a, r, h). These letters were mapped to keys on the glove to form a key-map as shown in Fig 1 (placed on the gloves). For all participants, the same key-map was used on all days and blocks

2.5 Game Interface

The sequences were displayed to participants in a game interface (Diamond glider game in Typing Instructor Platinum 21, Individual software, CA, USA) (Fig 2). The objective of the game was to move a glider from the starting point to destination without crashing by typing the sequences quickly and accurately. Sequences to be typed appeared on the top of the screen and moved from right to left like a marquee. Once the participant starts to type the letters glider started to move towards the destination. Once a letter was typed correctly, that letter was highlighted in green, and the cursor moved to the next letter. If a wrong letter was typed, that letter was highlighted in red, and the cursor stayed on the same letter until the correct letter was typed. A distinct tone was played when an error occurred. Participants had to use SPACE (SP) to accommodate the gaps between the sequences. The game interface had an option to specify minimum typing speed for a block. This option was used by the experimenter to prescribe minimum typing speed before each block depending on performance in the previous block(s). The game algorithm chose a maximum speed, which was five sequences per minute (WPM) above this experimenter-chosen minimum speed. For all participants, the minimum speed was set to 5 WPM in the first block on Day 1 of practice. The participants were instructed to attempt to type as many sequences as possible correctly so that the glider remained above the minimum speed. If the errors made were greater than letters typed per minute or if speed was slow (as decided by the game algorithm), the glider crashed, and the game got over. Likewise, if letters were typed faster than maximum speed, the glider could hit the ceiling and crash (although this never happened in our experiments). When the participant typed below minimum speed the speed indicator displayed speed up, and when the participant was about to hit the ceiling (close to the maximum speed), the indicator displayed speed down as shown in Fig 4.2. If the experimenter observed that the participant performed well at the prescribed minimum speed and was typing close to the maximum speed continuously for one minute, the minimum speed was incremented by 5 WPM for the next block.

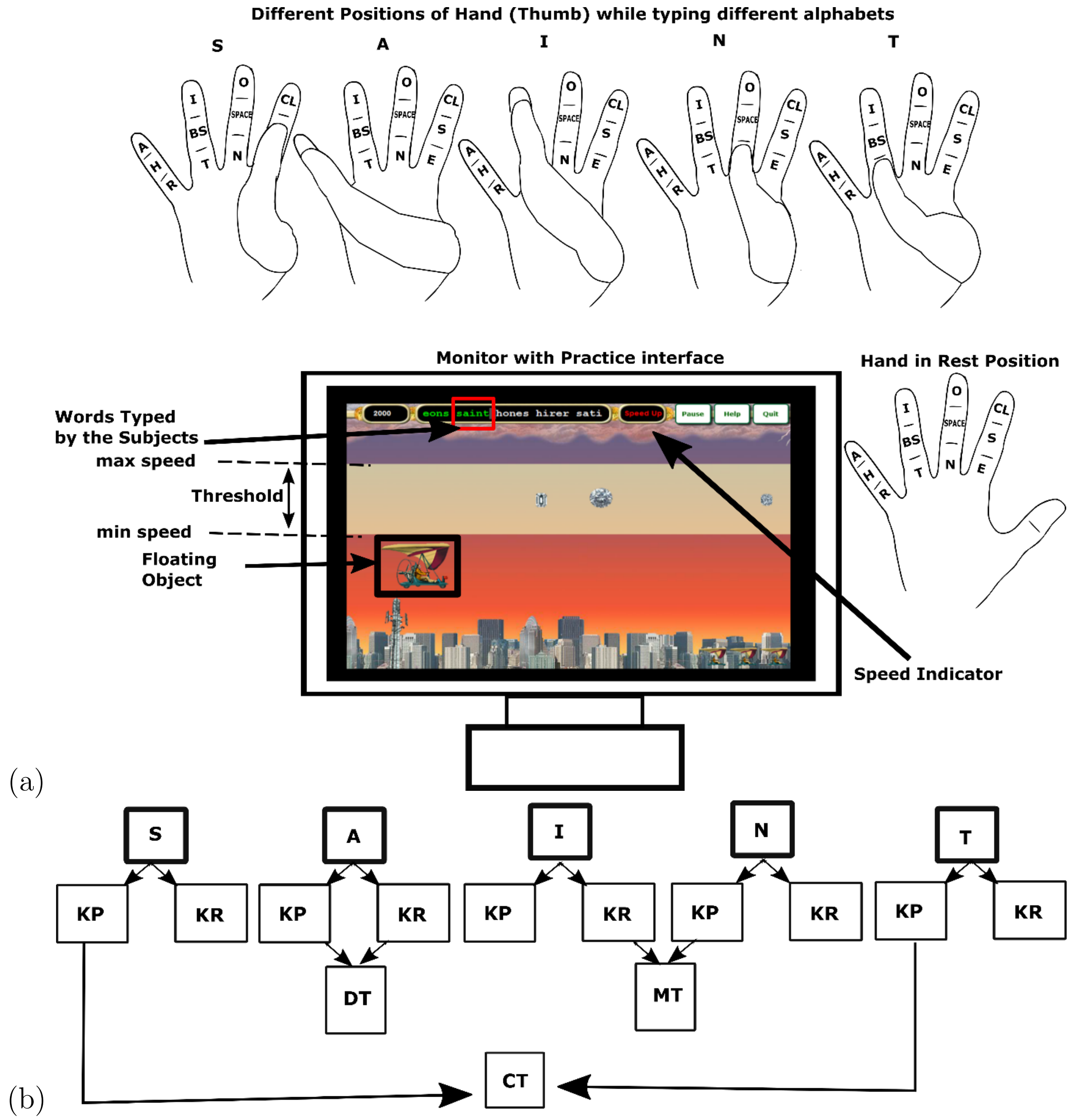

Figure 2: **Practice interface used in the experiment,**(a)Sequence of finger opposition movements performed by participants to type a word SAINT . Practice interface (Game) used in the experiment shows movement words from right to left as participants typed the words. The word SAINT shown on the game was typed correctly and hence the word was highlighted in green colour. The objective of the game was to type the words as fast and accurately as possible so that the Glider moves from left to right towards the destination. The object will lose altitude and crash with low speed and accuracy (high errors). SP, CL, BS denotes SPACE, Caps Lock, Backspace. Participants begin the experiment with hand in the rest position. (b). Each letter when typed two information are logged one is key press (KP) and another is key release (KR). The dwell time (DT) and movement time (MT) is calculated for each letter using KP and KR. completion time (CT) is calculated for a word.

2.6 Experimental Protocol

Participants practiced the experimental task for 15 consecutive days and data were collected on all days of practice. Each day/session was divided into 12 blocks of 2 mins each with 30 seconds interval between each block. Words could repeat within a block but not between blocks, and words on a given block remained the same across all days. For example, Block m was composed of the same set of words on all days but the order of word presentation may change between days; block n always had a set of words different from block m, when $m \neq n$). All blocks had approximately 23 number of words.

2.7 Data Analysis

Timing parameters like the key press and release were collected during all days of practice and analysed further using metrics defined below.

2.7.1 Key-Press Time(KP)

Key press time is defined as that time when the thumb makes contact with the tactile key patches on the finger phalanges.

2.7.2 Key-Release Time(KR)

Key release time is defined as that time when the thumb is removed from the contact with the tactile key patches on the finger phalanges. From the KP, KR information, the movement time was computed.

2.7.3 Movement Time(MT)

Movement time is defined as the time taken to reach/press a particular letter (letter) after the release of the previously typed letter (letter), which is computed as the difference between key press time of the specific letter (letter) and the key release time of the previously typed letter as shown in Fig 2b.

2.8 Performance Curve Model

All the movement time values were normalised. Consider the transition T-A. Say that through the course of the experiment, the transition is practised a total of 800 times. Let this set of values be called p. Now each value is normalised by the formula,

$$y_i = p_i / max(p)$$

This normalised movement time is taken on the y-axis and the index of practise is taken on the x-axis. There were 3 categories for index of practise.

1. All MT: Each normalised movement time is plotted without taking any average.

2. Across Blocks: Considers the average of movement times over each block. Say that the transition T-A is practised 10 times in block 1, then the average of these normalised movement times is taken and that value will be the movement time corresponding to block 1. Since there are 180 blocks, there will be 180 mean movement time points.

3. Across Days: Considers the average of movement times over each day. Say that the transition T-A is practised 70 times in day 1, then the average of these normalised movement times is taken and that value will be the movement time corresponding to day 1. Since there are 15 days, there will be 15 mean movement time points.

Curve fitting: A logarithmic curve of the form

$$y = a * log(x)$$

was fitted to each plot. This curve was chosen as it best represented the the distribution of the data points. Refer to the Reference, section 1, page no. 1-119, for these plots.

2.8.1 Improvement as a function of Frequency

The improvement in movement time was found for each transition for each subject. To find the improvement, the percentage difference between the 2 extremes of the fitted curve of a particular transition were taken. Say that the first point in the curve, which is equivalent to the movement time of the first index of practise is $y[first]$ and the last point in the curve, which is equivalent to the movement time of the last index of practise is $y[last]$, then the improvement metric (IM) is calculated as

$$\text{IM}=y[last] - y[first]$$

Now, consider the transitions in decreasing order of frequency. The corresponding IM values are taken on the y-axis and the rank of the transition is taken on the x-axis. So if the most frequent transition for a subject is E-R, then E-R will have rank 1 and it's IM will be the first point. This plot is obtained for each subject in each category. A line of the form $y = mx + c$ is fitted to these plots. Refer to the Reference, section 2, page no. 120-124, for these plots.

2.8.2 Improvement as a function of Distance

To find the distance between transitions, each letter was assigned an (x,y) coordinate. From Fig 1, the coordinates are as follows:

'E':(1,1),'N':(2,1),'T':(3,1),'R':(4,1),'S':(1,2),'H':(4,2), 'O':(2,3),'I':(3,3),'A':(4,3)

The Euclidean distance between the two letters of a transition will give the distance required for the transition. The transitions were rank ordered in terms of decreasing value of distance. As we have done in the previous section with frequency, the plots of the IM versus the rank were obtained for each subject and linearly fitted. Refer to the Reference, section 3, page no. 124-129, for these plots.

2.8.3 Improvement as a function of Distance and Frequency

For each transition, the distance was rounded off to the nearest integer and transitions which had distance 0 such as E-E were not considered. So, there are 3 distance values i.e. 1, 2 and 3. For highly frequent transitions we will consider all transitions which have frequency greater than the 90th percentile of the maximum frequency of a subject. For least frequent transitions, all transitions having frequency less than the 10th percentile of the maximum frequency of a subject were considered. The mean and standard deviation of the IM of the transitions of a given frequency (high/low) were found for each distance. Say if there are 5 highly frequent transitions having distance 3, then the mean of the IM of these 5 transitions would be taken as the improvement mean for distance 3. This was done for all subjects. Average was taken across subjects. These values are found in the Reference, section 4, page no. 129-132.

3 Results

3.1 Frequency as a Factor

All subjects showed consistent behavior i.e the linear fit curve always had a negative slope. The average across the 8 subjects plots were obtained and similar to per subject plots, a linear curve was fitted. The 2 extremes of this linear model were considered and are shown in Fig 3. The left most extreme point is the value on the linear model of the most frequently performed transition and the right most extreme point is the value on the linear model of the least frequently performed transition. We can see that there is a significant difference between most frequent and least frequently practised transitions. Most frequently practised transitions show higher improvement than less frequently practised transitions.

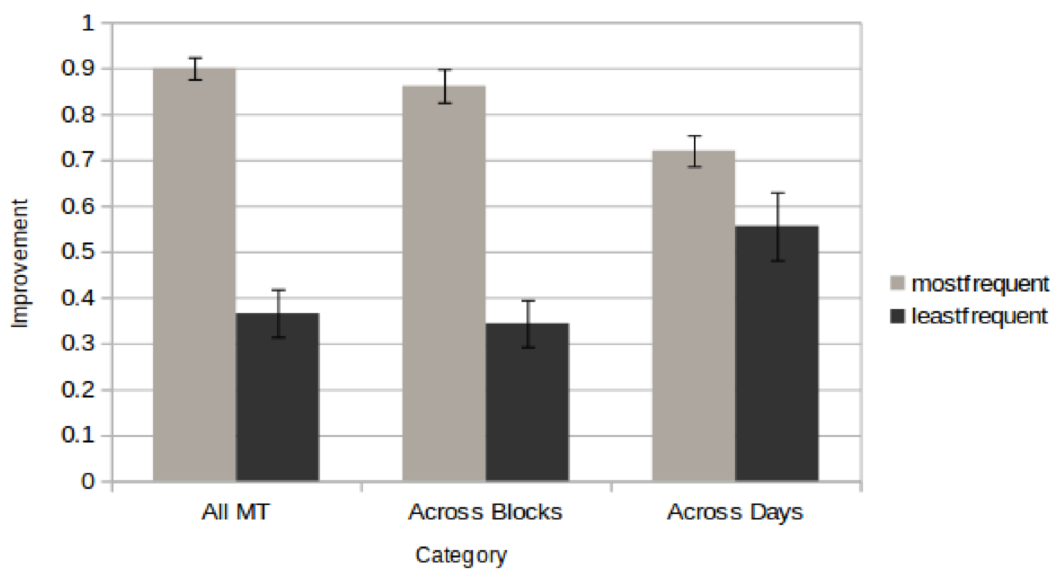

Figure 3: Improvement of most frequently and least frequently performed transitions across each category

3.2 Distance as a factor

It was found that the linear model did not always have a negative slope and was not consistent across subjects.

3.3 Frequency and Distance as factors

Fig 4 shows the improvement mean for most frequent and least frequent transitions averaged across subjects.

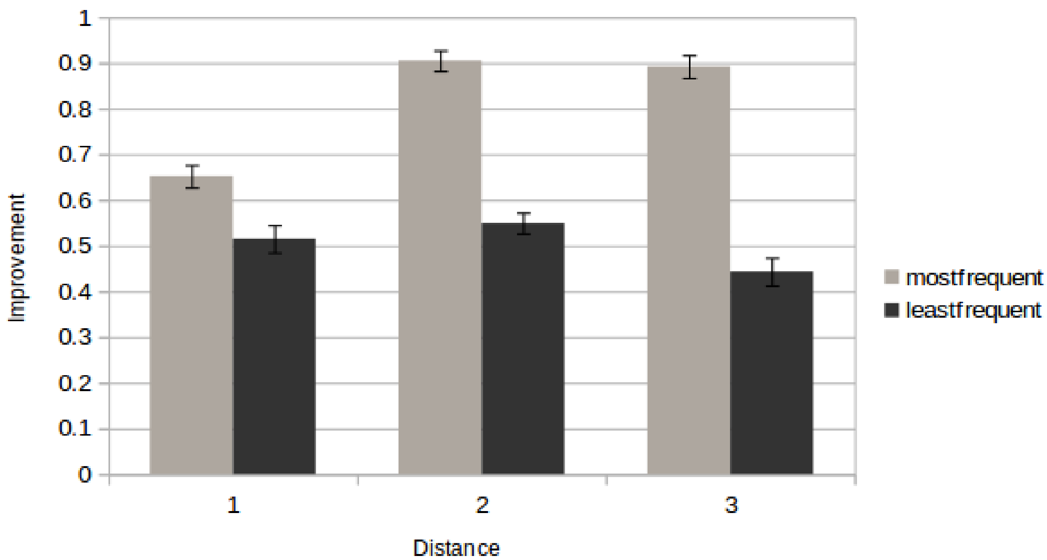

Figure 4: Improvement means of most frequently and least frequently performed transitions for each distance averaged across subjects

The p values were found between these distances. It was seen that, for frequently practised transitions, between 1 and 2 and between 1 and 3, the p value was less than 0.001, while between 2 and 3, the p value was 0.36. Refer to the Reference, section 4.3, page no. 132, for these values.

4 Conclusion

The analysis on frequency shows that transitions which are practised more frequently show better improvement when compared to transitions practised less frequently. This rejects the first part of the hypothesis, H1a. The analysis on frequency and distance shows that for highly frequent transitions, the distance will not affect the improvement while the improvement of less frequently practised transitions depend on the distance, rejecting the second part of the hypothesis, H1b.

References

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[3] **Karni, A., Meyer, G., Rey-Hipolito, C., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G.** (1998) The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex. *Proceedings of the National Academy of Sciences*, **95(3)**, 861-868.