Task Switching
And
Hand Movement Planning

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Abstract:

Moving hand involves various movement planning stages. Although we don't realize but our brain does all the complex movements just for free. Planning may involve kinematics, dynamics or both as proposed by various researchers. We intend to know whether kinematics is explicitly involved in movement planning. Participants switched frequently between fast hand movement and slow hand movement tasks. The interval between the task cue and the stimulus (target) onset varied between blocks. The task switched predictably after every four trials (alternating runs paradigm). After one trial (performance), control process get used to the resulting change as a result of task switch. Preparation reduced switch costs but not interference from irrelevant attribute. Switch cost decreased to certain extent as preparation increased but as soon as some threshold preparation is provided there is no further decrease in switch cost seen. Hand movement takes about a straight path and velocity of hand follows a bell – shaped profile. Hand movement planning explicitly involves kinematic attributes.

TASK – SWITCHING

Involves processing target in accordance with changing series of tasks.

(a) **Task – Switch** defined in relation to preceding trial, i.e., "**switch"** condition occurred when preceding trial involved a different task than the task in current trial, while **"no – switch"** condition was when task was same as in previous trial.

(b) **Response – Repetition :**
When physical response repeated from previous trial, **"response change"** occurs when physical response in previous and current trials are different.

Each task requires attention to, classification of, different attribute or element of stimulus, or retrieval of different property of the stimulus from memory based on previous experiences. Then, a stimulus is presented on series of trial and subject performs one of the tasks. Task may or may not change on the upcoming trials. There are several methods of telling the subject which task to perform.

Task Switching Paradigms

Various Task Switching Paradigms under use by many researchers to study the performance while switching the tasks and task succeeding the switch:

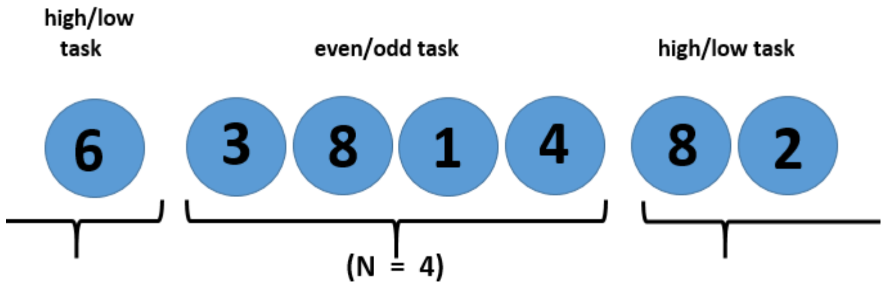
- **Pure versus Mixed Task Blocks (Jersild's Method) :**
  Blocks of trials in which subject alternate between two tasks compared to blocks in which they perform only one of the tasks ('pure blocks').
    - RT is generally longer in alternating than in pure blocks.

  E.g.: 'AABABBABA' block of trials compared with 'AAAAAAA'.

- **Pre – Specified Task Sequencing Paradigm :**
  Each task preceded by sequence of two (or more) stimuli; before sequence subject is told which task to perform corresponding to each stimuli.
    - Response is slower to the second stimulus where the change of task is required, and 'switch cost' generally reduces when more time is allowed for preparation between response to first stimulus and onset to second stimulus.
    - **Disadvantage :**
        - Additional load of remembering the task sequence.

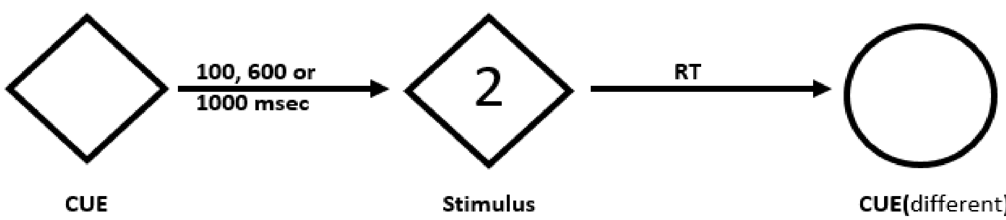
  E.g.: ABBAACC is the task sequence to be followed by subject in each trial.

- **Alternating Runs Paradigm :**
  Task changes predictably every nth trial, where n remains constant for blocks of trials.
    - Cue may or may not be provided.



- **<u>Task Cuing Paradigm</u> :**
  Each stimulus is preceded or accompanied by cue informing the subject which of two or more tasks to perform.
  - **Advantages of CUE**, cue may assist subject :
    - To keep track of what the current task is,
    - Where they are in the run, and
    - When the task is to be switched predictably.
  - **Disadvantages of CUE :**
    - Cues require more attention.
    - Interpreting more informative cue can interfere with processing of the stimulus when cue and stimulus are very close.

  E.g.: Diamond square cuing / signaling for multiplication 2 whereas circle signaling addition of 2.



- **<u>Intermittent – Instruction Paradigm</u> :**
  Subject is provided with instruction to perform one of the two (or more) tasks. Subject processes number of stimuli according to the instruction, then sees another instruction, which may specify same or other task, and then again processes a number of stimuli according to that instruction.
    - In other words, providing the subject with the instruction at any unpredictable point specifying him/her whether same task to be followed on subsequent trials or switch to different task.
    - Unlike Cuing paradigm, instruction may or may not be given with every trial.
    - **"Restart Cost" – Extra effort / time required by subject to interpret the instruction** and proceed with the task further **–** is observed on the first trial after instruction.
    - **Disadvantages :**
      - Interpreting an instruction can even constitute a distinct task in itself.
      - **'Restart cost'** seen even when the task doesn't change.

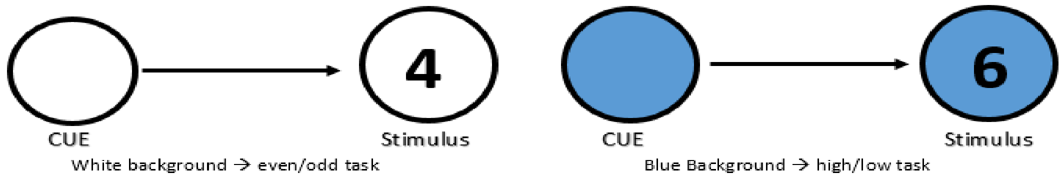
<u>Some phenomena of primary interest:</u>

Consider an example, which involves two tasks – white circle signaling even/odd task whereas blue circle signaling high/low task.

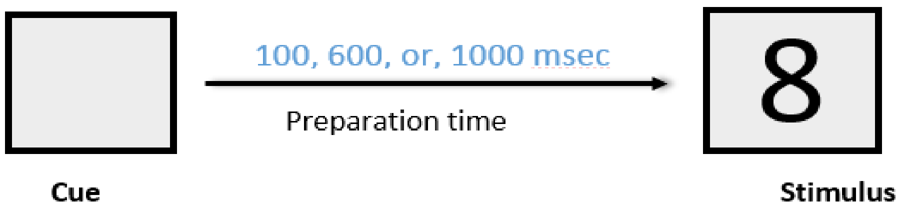
A. Switch Cost(Task Repetition benefit) :

- Extra time taken to initiate task on 'switch trial' than on 'non-switch trial' or 'task – repetition trial'.

- Time consumed by control processes that reconfigure task – set and eliminating effect of task – set from previous trials.
- Difference between the mean RT on the first (P1) and second (P2) trial of a run.



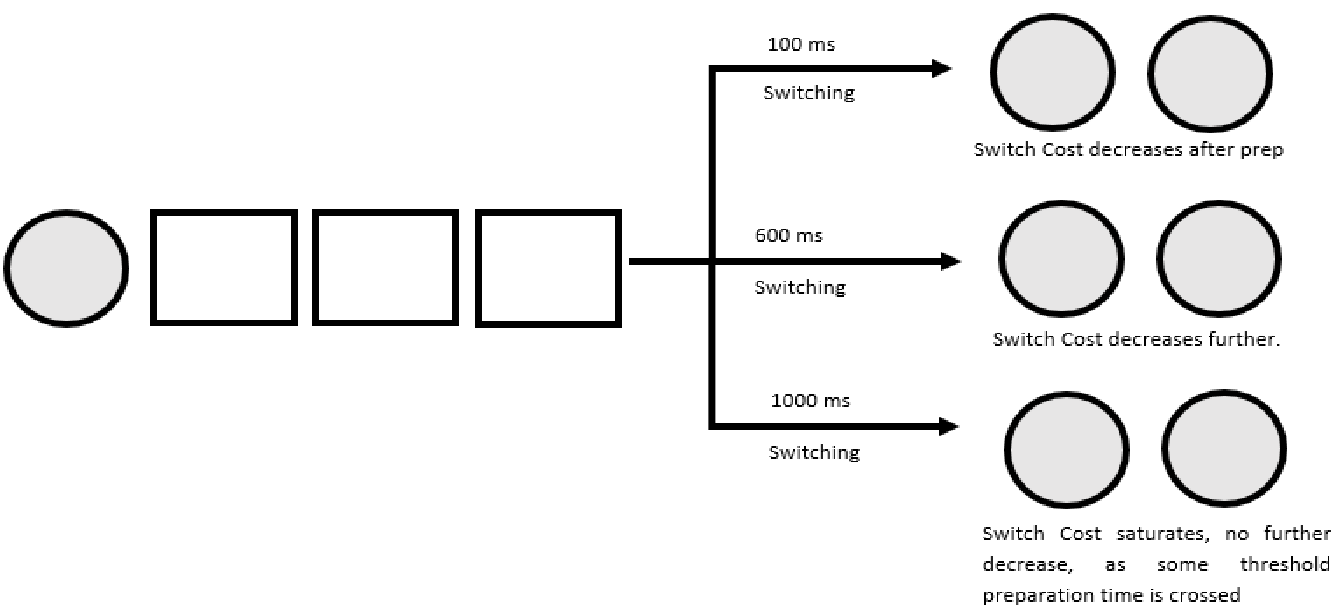
B. Preparation Effect / Time :



- Advance knowledge is provided to subject about the upcoming task (**Preparation Effect**) and the time is allowed to prepare (**Preparation Time**), thus reducing the switch cost.
- Time interval provided to the subject between response to first stimulus and onset of second stimulus to prepare for second (upcoming) task.
- Also called **"Response – Stimulus Interval (RSI)"**.

C. Residual Cost :

- The decrease in switch cost as a result of preparation effect.
- As Preparation increases, residual cost decreases, but up to certain threshold (limit) after which no effect of preparation is seen on the switch cost.



Except Jersild's method, each task switching paradigm consists runs of trials on Task A interspersed among runs of trials of Task B (and maybe Task C, D, etc.).

P → Position of trial within a run of length ***r***.

P1 → First trial of run following a change in task (switch trial)

P2 → first non – switch trial

And so on up to **P**r.

Linking our Task Switching experiment with Hand Movement Planning

The task used in our experimental setup were fast and slow hand movements. The hand movement made by subject would off course involve some movement planning. There are various kinds of kinematics and dynamics involved in hand movement planning. Our experiment involves target recognition and subject needs to infer a few things such as:

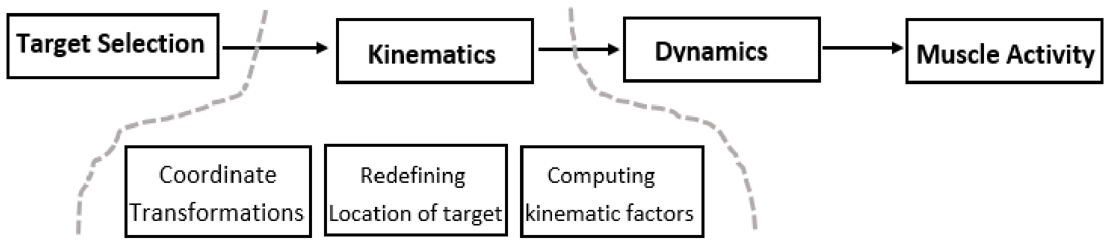
- **(a)** At what distance w.r.t. the subject himself / herself, the target is presented (location of target w.r.t subject itself),
- **(b)** Velocity required to reach the target within certain time limits, so that the movements made could be classified as slow or fast,
- **(c)** Direction of movement to be made based on the position of the target.

Our hypothesis being that all these kinematic aspects of movement are to be taken care of by the subject before he/she actually starts the movement (I.e., movement planning involves kinematic attributes). Some introduction to various models of hand movement planning, claiming kinematics and/or dynamics to be involved in hand movement planning.

Hand Movement Planning and Execution

We, in everyday life, perform each kind of reaching or pointing hand movements, i.e., bringing the hand to spatial location of object of interest. Although we consciously do not appreciate that our brain is planning the movement we are performing at each time. Various studies indicating that movement planning are likely to occur in CNS (Central Nervous System) – **Bernstein (1967)** much before the execution. Movement planning involves various stages:

1. **Selecting target** from the surroundings.
2. **Coordinate transformations**, spatial location of target first transformed from eye – centered frame of reference to desired frame (here, shoulder – centered).
3. Location is then redefined, the system **recognizes current position of the hand** in new spatial coordinates.
4. **Computation of trajectory (**configuration of arm in space / path and speed of movement where path is sequence of positions through which hand passes**)** – distance of target from hand, velocity of hand (), joint angles, etc. (**kinematic** factors) – where the Target position is converted to angles between upper arm and forearm and Target elevation to elevation angle of arm, done by the motor control system.
5. After all the movement planning has been done, factors like which muscle to be activated, what force to be generated within the muscles, torque at each joints, etc. (**Dynamics**) probably based on some optimality criterion determining the particular trajectory for hand rather than other possible trajectory.



Every movement can be thought of two stages – planning and execution. (**Kalaska & Crammond 1992**)

Planning Stage –

- Encoding the target location (visuospatial location)
- **Kinematics** refers to geometrical and time based properties of motion; variables of interest being positions (e.g. joint angles, hand Cartesian coordinates) and their corresponding velocities, acceleration and other higher derivatives like jerk.
    - **Extrinsic Kinematics –** Refers to the target location, hand path, direction of movement needed to reach the target (attributes w.r.t. target).
    - **Intrinsic Kinematics –** Defines limb's geometry during movement with attributes like joint angles, muscle length (attributes w.r.t. the subject's arm/hand).
- **Dynamics** referred to as forces required to develop motion and is linked to properties of the arm like mass, inertia, stiffness; variables of interest being joint torques, forces acting on hand, and muscle commands.

These modules / reference frames proceed in a hierarchical manner as:

- **Highest** → Extrinsic Kinematic attributes
- **Intermediate** → Intrinsic Kinematic attributes
- **Lowest** → Intrinsic Dynamic attributes

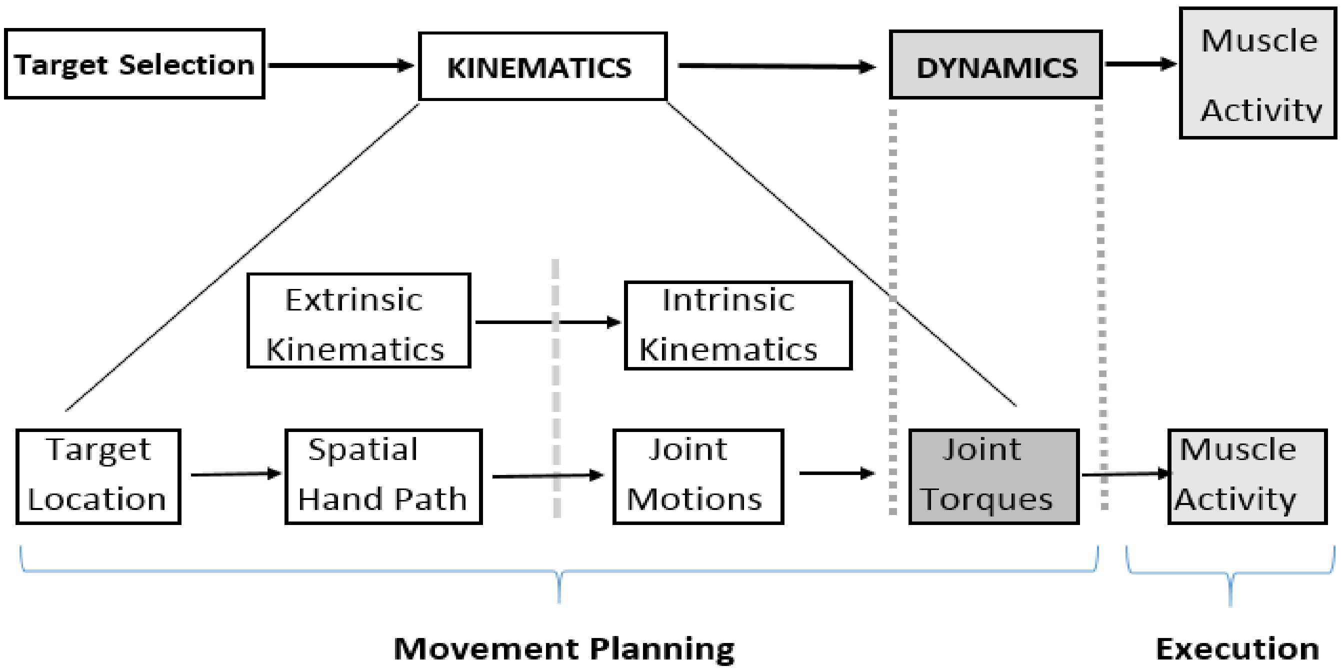


Figure 2: Schematic representation of movement planning in two stages (Planning and Execution) and their corresponding hierarchical attributes.

Kinematics proposed as intermediate in movement planning:

Morasso (1981) suggested planning of arm movements is carried out in extrinsic coordinates (that represent movement of hand in space). **Morasso** instructed human subjects to point with one hand to different visual targets that were activated randomly. His analysis showed two kinematics invariances: (1) hand trajectories were approximately straight segments, (2) hand velocity for different movements always appeared to have bell-shaped configuration – time needed to accelerate the hand approximately same as time needed to bring the hand to rest, with the maximum velocity at middle of the reaching movement.

The idea that hand movements are planned by CNS in terms of extrinsic coordinates is based on hypothesis that planning and execution constitute of two separate stages, also supported by **Flash & Hogan (1987). Flash & Hogan** provided further evidence that movements are planned in terms of hand trajectories (extrinsic kinematic coordinates) rather than joint rotations (intrinsic kinematic coordinates) and hypothesized that **minimizing jerk** (rate of change of acceleration) **optimality criterion** is used by CNS**.** According to this view, during planning brain is concerned with movement kinematics – sequence of positions that the hand is expected to occupy at different times within the extra personal space. During execution, dynamics of musculoskeletal system enforce planning of hand movements.

Figure 3: Schematic representation of movement planning in two steps

of target selection and kinematics without dynamics

Motor control involves number of computational complexities. For instance, if the goal (target) is to move the hand from initial position [A] to point [B] in space, then clearly there can be number of possible hand trajectories that could achieve this goal. Even if CNS has chosen a particular path of hand movement, its implementation is not unique, i.e., can be achieved with multiple combinations of joint motions at shoulder, elbow and wrist. Also, as there are number of muscles around each joint, the net muscular force can be generated by variety of combination of muscles. **Hollerbach and Atkeson (1987)** suggested that CNS first derives **motion of joints from planned path of limb's endpoint (inverse kinematics).** Then, CNS computes **necessary joint torques (inverse dynamics)** and distributes the torques to number of muscles. These calculations would require a large feedback loop and any slight errors in movement trajectory would lead to large motor complications based on above processes.

Dynamics proposed as intermediate in movement planning:

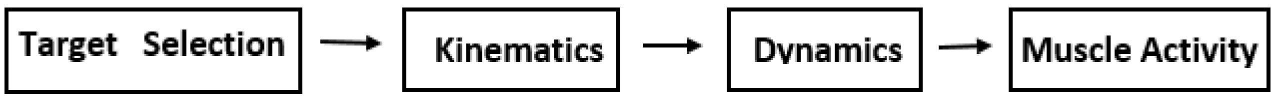
Alternative proposals that do not depend on complicated calculations of inverse dynamics have been proposed. **Bizzi et al. 1984** proposed **"equilibrium point hypothesis"** stating that CNS sees the desired hand motion as a progression of static postures (postures in which hand is at equilibrium). Movement of hand is seen as a result of different equilibrium stages. The forces needed to track the equilibrium trajectory result from the intrinsic elastic properties of the muscles (**Feldman 1974**). Spinal cord contains circuitry that, when activated, produces precisely balanced contractions in group of muscles. These synergistic contractions generate forces directing limb towards equilibrium point in space (Bizzi, Mussa-Ivaldi, and Giszter 1991).

Figure 4: Schematic representation of movement planning in two steps Of target selection and Dynamics.

Uno, Kawato & Suzuki 1989 proposed "Minimum Torque change Model" which differs from "minimum jerk change model" in that the reference trajectories (trajectory based on the optimality criterion) are dependent on dynamics of arm. Minimum Torque Model predicts same bell shaped velocity profiles. A reasonably good correlation between predictions from minimum torque model and actual trajectories was shown by **Uno et al. (1989).** Minimum jerk model suggested reference trajectory is straight line but control process via CNS gives curved paths which were as a direct result minimization of torque change suggested by minimum torque model but the shoulder and elbow torque contours from model did not match much with experimental values.

Kinematics to Dynamics Transformation:

Padoa–Shioppa et al. (2002) proposed transformation of movement information from kinematics to dynamics during movement planning stage. CNS has to solve a problem: given is a hand trajectory (desired kinematics), how to generate appropriate muscle forces (dynamics) to perform the hand movement (reach the target). How, when and where kinematics to dynamics transformation occurs are fundamental and unanswered questions? They analyzed SMA (supplementary motor areas) during the period following the instruction and prior to go signal (i.e. period of motor planning). Dynamics related neuronal activity during execution is found in M1 (primary motor cortex), SMA, PMd (dorsal premotor area), PMv (ventral premotor area), the putamen and the dentate. In addition, some dynamics related activity is seen in SMA and PMd during movement planning.



Based on models of movement planning, some of them suggesting the explicit use of kinematics and kinematic variables (hand to target distance, velocity, joint angles, etc.) whereas others suggest dynamics or both kinematics and dynamics. **I am interested to know whether there is movement planning at the level of kinematics explicitly. And if yes, what is the hierarchy of kinematic variables/parameters in movement planning?**

Pseudo Experiment using two Gaussian Distributions

Taking two Gaussian distributions – One with mean, **μ = 350** and standard deviation, **σ = 40**, and the other with mean, **μ = 400** and standard deviation, **σ = 50.** First distribution corresponds to Response Time in performing the task A whereas second corresponds to Response Time in performing the Task B. Means refer to the mean time taken for the response (time after presentation of stimulus till the start of hand movement) by the subject.

```
Mean1 = 350;
StdDev1 = 40;
Mean2 = 400;
StdDev2 = 50;
RT_1 = normrnd (Mean1, StdDev1, 1, 500);     % generates a random array of 500 trials from normal
                                               % distribution with mean 350 & standard deviation 40.
RT_2 = normrnd (Mean2, StdDev2, 1, 500);
```

In total, we would have 1000 trials, 500 from each task. These when intermixed can be dealt with different scenario:

1. Task A followed by Task A **(RT_1_1)**

2. Task B followed by Task A **(RT_2_1)**
3. Task A followed by Task B **(RT_1_2)**
4. Task B followed by Task B **(RT_2_2)**
5. Task A followed by Task A followed by Task A **(RT_1_1_1)**
6. Task B followed by Task A followed by Task A **(RT_2_1_1)**
7. Task B followed by Task B followed by Task B **(RT_2_2_2)**
8. Task A followed by Task B followed by Task B **(RT_1_2_2)**

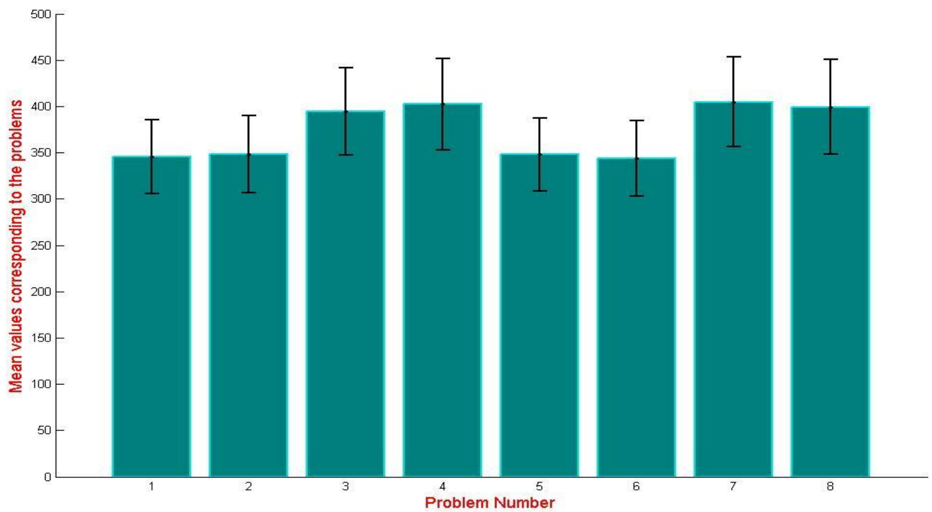


Figure: A bar plot of mean of response times is shown with its standard deviation shown as error bars against problem number.

As clearly visible, the statistical significance of the data can't be seen in the Figure above.

E.g. **"1"** and **"2"** seem to have same mean, so irrespective of the data, the viewer could have a misconception of both being same distributions.

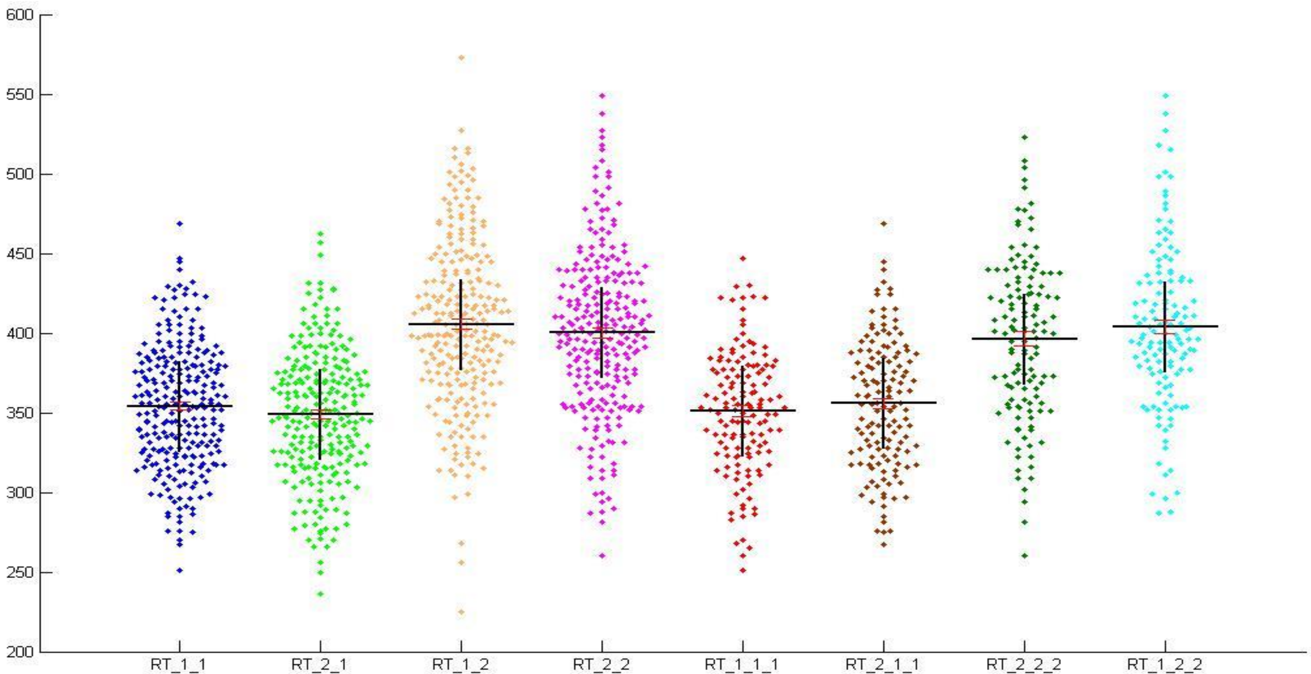


Figure: This figure illustrates the bee swarm plot of the same data displayed in the bar plot
This plot shows the statistical significance to some extent by displaying the data

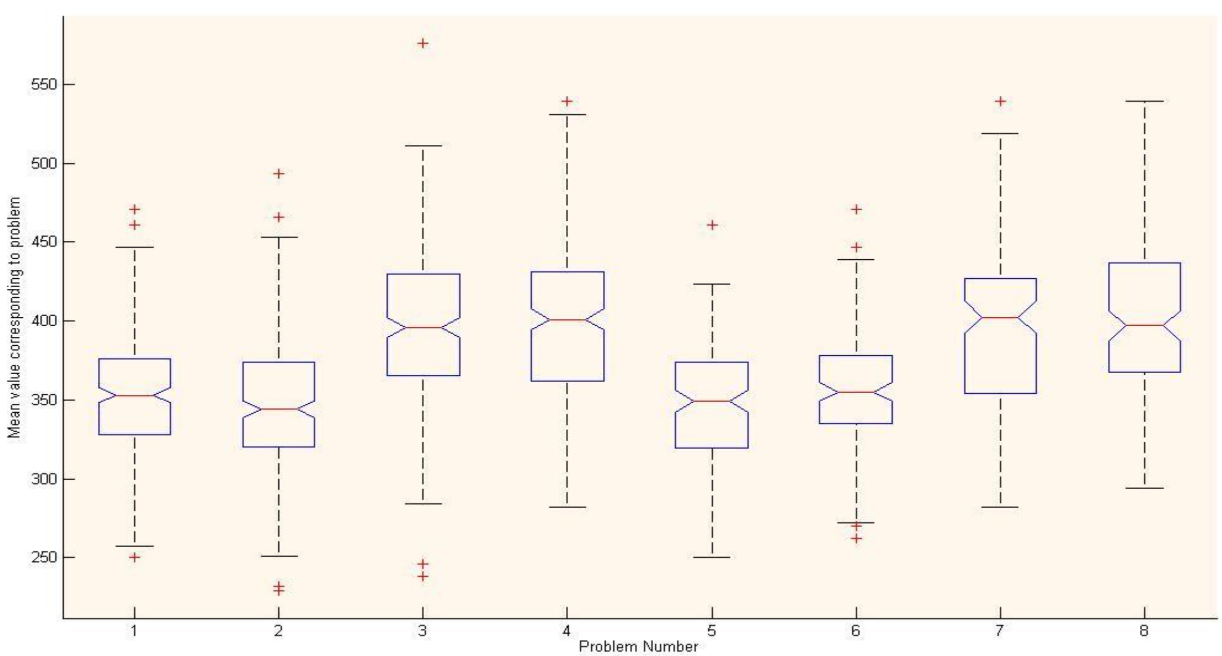


Figure: This figure represents the box plot of the same data showing the distribution of data around the mean.
Say, the data in problem 1, is almost uniformly distributed on both sides around the mean.
Similarly, in problem 2, the data is more on right of mean than on left of the mean.

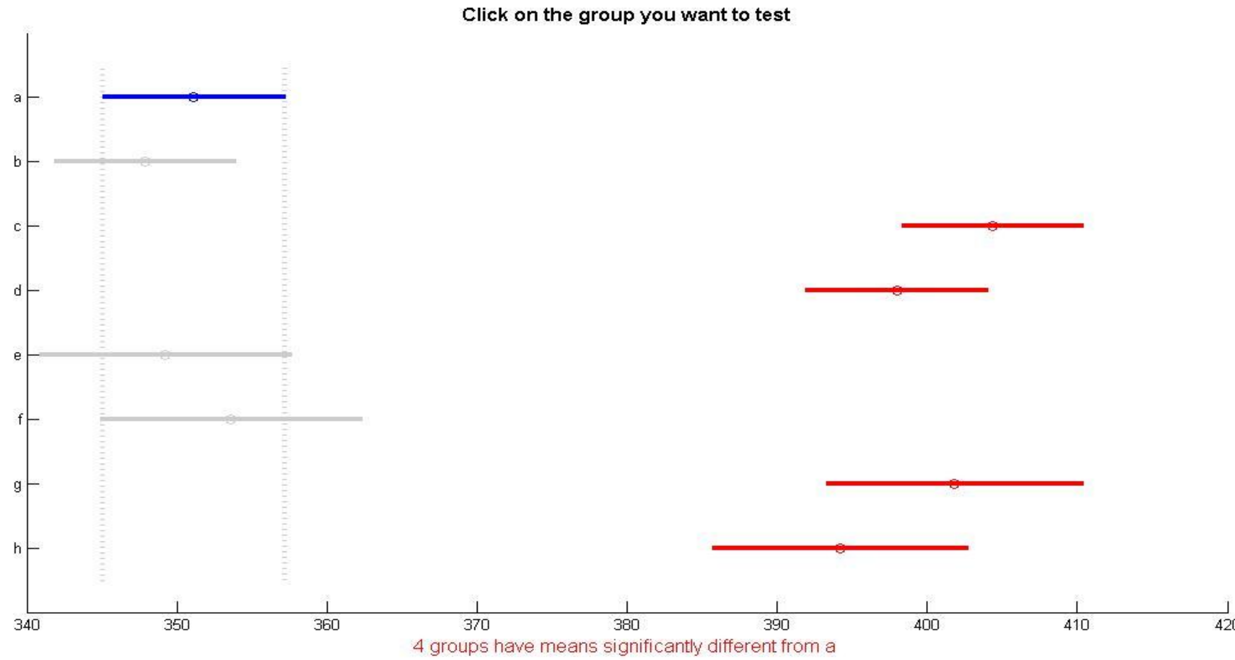
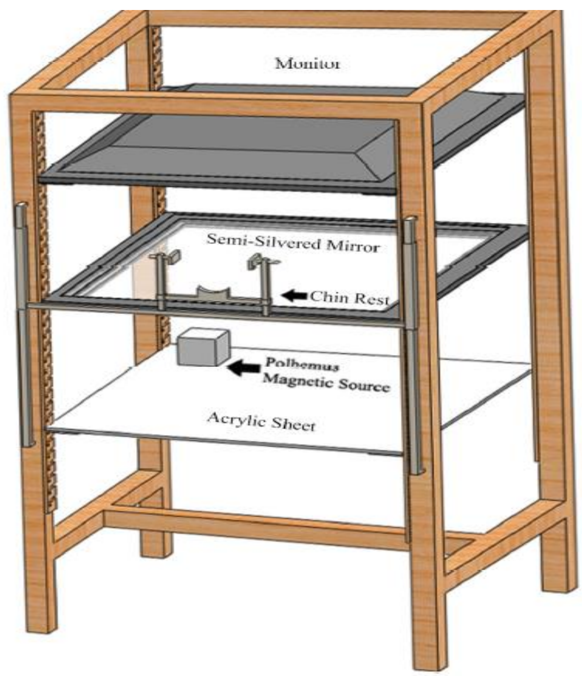


Figure: The blue line represents the corresponding group is statistically different from the groups corresponding to the red lines but statistically similar to the groups those corresponding to grey lines and the grey vertical dotted represent the confidence interval of that group.

Methods:

Experimental Setup:

All experiments were performed using TEMPO software that displayed visual stimuli, sampled and stored hand movement data and other behavioral parameters in real time. Hand position was recorded using a tracking device by means of small sensor placed on tip of pointing finger, which interfered with TEMPO in real time. Subjects were seated on chair with their heads stabilized by means of chin and head bars shown in the figure. The targets, fix, etc. visual information was displayed to subjects via LCD monitor located above semitransparent mirror through which the subjects looked at the targets and made unrestricted hand movements on the plane below the mirror at the level of their waist. All recordings were done in a dark room. A small LED placed on finger of subject gave the visual feedback about the hand position.



Procedure:

All subjects performed 80-100 practice trials before the experiment and were allowed to take rest whenever they felt like. An auditory feedback (beep sound) was given to indicate the subject performed the particular trial correctly. This would act as a motivation to decrease the errors in the experiment. A trial typically started with presentation of fixate (or cue) at the center of the screen and target was randomly presented at one of the peripherally arranged positions equally spaced on imaginary circle of radius 22 cm (@ 45, 90, 135, 180, 225, 270, and 315 degrees).

The experiment consisted of 6 types of blocks each with 160 trials (the combination of RSI and random vs. predictable switching). The block type alternated between random and predictable and RSI changed every two blocks. The 160 trials for each predictable – switching block type comprised 40 trials per combination of task and P (position in run). Thus, for predictable – switching blocks, over two set of blocks, the subjects received 40 trials in each combination of RSI × Task × run position yielding a total of 480 predictable – switching block trials.

Experimental Schema:

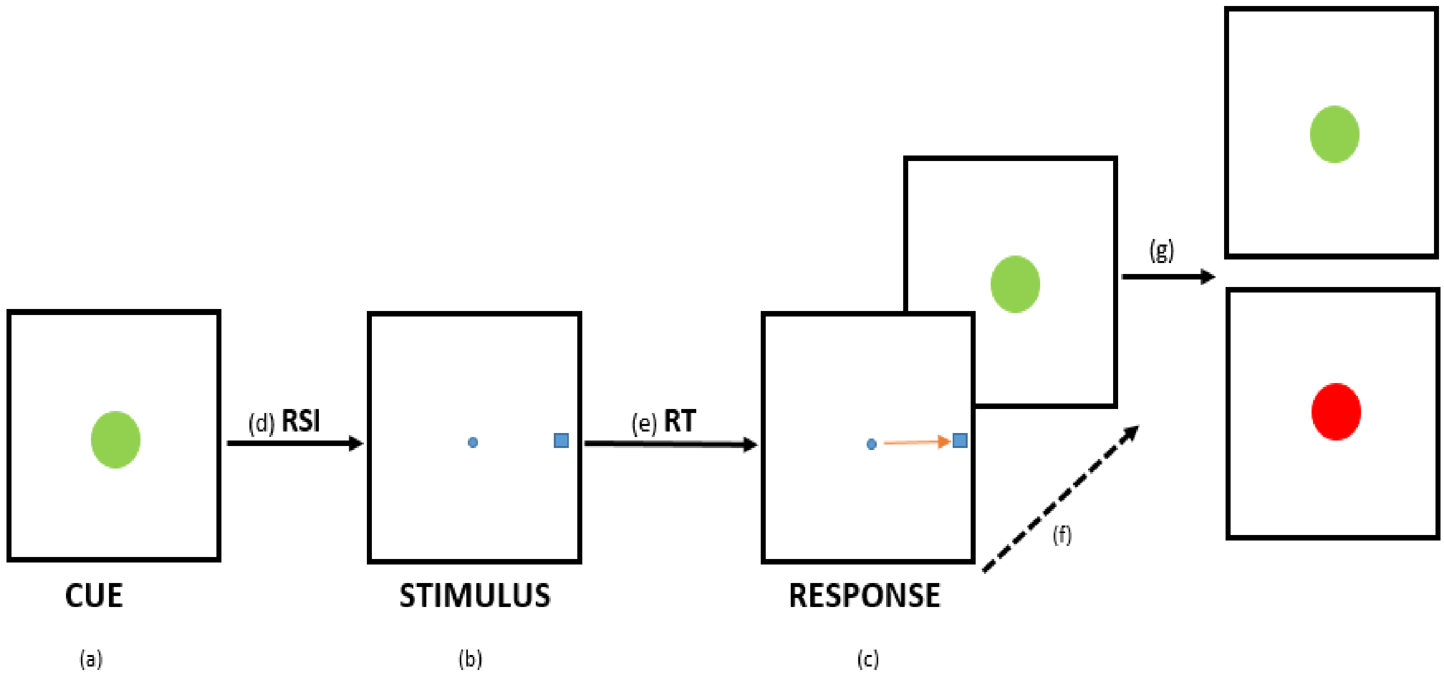


Figure: Schematic representation of task switching paradigm to be followed during experiment.

(a) CUE – Green / Red colored circles displayed at the center at beginning of every trial.

(b) STIMULUS - Target presentation (maybe Blue block)
Target presentation assisted with a fixate dot at the center.

(c) RESPONSE – Fast or Slow Hand Movement → Fast Movement if cue is Green circle.
→ Slow Movement if cue is Red circle.

(d) RSI – Response Stimulus Interval

(e) RT – Response Time: Time interval between the Stimulus (or target) onset and beginning of hand movement.

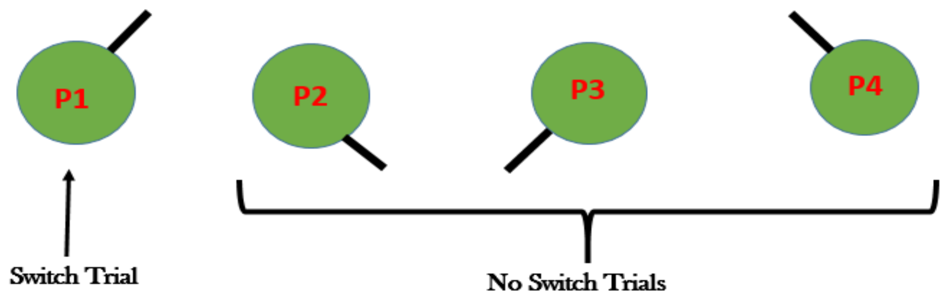
(f) After Response, when the subject brings back the hand to fixate, the target disappears leaving behind only fixate (cue) on the screen. This time may also be called as **inter – trial time interval** which remains fixed throughout the experiment.

(g) After inter – trial interval, next trial starts with presentation of fixate (cue), maybe also called as fixation time but we are using it as **RSI** in our experiment.

How are Cues used in our experimental setup?

Cues are used to help subject know whereabouts of the task and in case of any error, the subject could again follow the task instead of wasting some trials just to figure out the task but such a cuing pattern may cause subject to do more processing for interpreting the additional element in the cue and may even get mixed with the task itself. Although we are mentioned the method that may be used but these our avoided in our experiment.

To help participant to keep track of position in a run, a line projecting from the circumference of cue was rotated clockwise from northeast (P1) to southeast (P2) to southwest (P3) to northwest (P4). This scheme is shown below:



P1 → Switch Trial;
P4 → last no – switch trial, to be followed by task switch.

Analysis:

The data analysis was done in MATLAB (MathWorks) software which helped in making various kind of plots and analyzing the data for statistical significance using ANOVA, t-test, z-test, etc.

For the reasons and existing theories shown below, we hypothesize that **(1) there is some RT switch cost involved at every switch trial, (2) this switch cost decreases with the position in run, and that (3) Switch cost decrease as the preparation time interval (response – stimulus interval) increases.**

Theories of task – switching costs

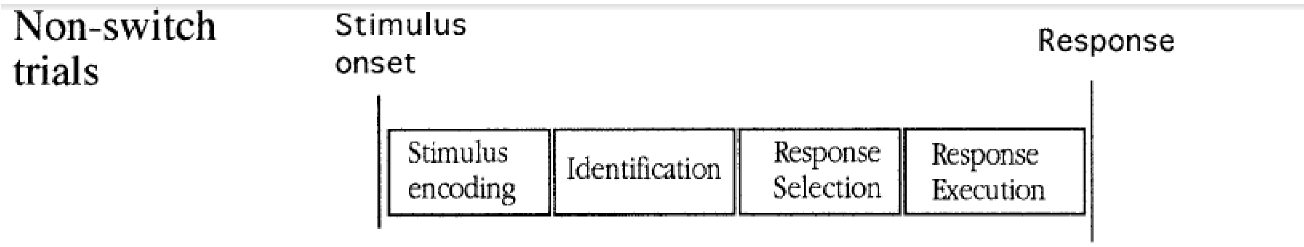
There are lot of theories exciting. One of them says that the effect of RT switch cost seen on switch trials is attributed to a process called **Task – Set Reconfiguration (TSR)** which occurs only on switch trials. If a task switch occurs predictably every *r* trials, and *r* > 1 (i.e., alternating runs paradigm), the participant knows that, having reconfigured task set on switch trial, he/she will not have to reconfigure it again immediately. The inability of subjects to completely perform this process may presumably lead to errors on switch trials. Hence, a most effective "recovery" from task change. Some theories of voluntary control of task – set readiness are discussed here. **Norman and Shalice's (1986)** framework is ancestor of number of current theories: (1) *endogenous control input* (processes occurring within our brain just after the task before another task to start to eliminate the effect of previous task), (2) consequence of recency and frequency of task on switch cost (*autogenous priming* – recency of the task causes a decrease in switch cost), and (3) *exogenous driving or triggering,* refers to presence of external elements like cue, instruction, etc.

The *endogenous* control should be just sufficient to suppress the competitor task and perform the appropriate task. The application of just enough endogenous control to get appropriate task correctly performed is a feature of few current theories (**Gilbert & Shallice, 2002**).

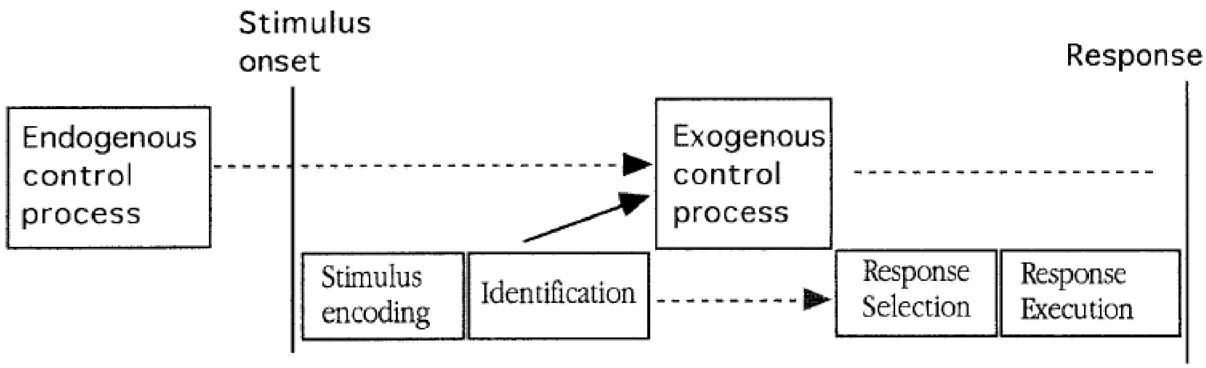
Allport et al., 1994 attributed this additional difficulty observed on switch – trials to interference with "normal" processing on the switch trials. The interference results from carry-over of positive priming of "now irrelevant task" from its exercise on previous trials.

Task – Set Interference, priming. If stimulus affords two tasks task A and task B, and subject has just performed task A and now has to switch to task B, the task – set for task A remains active – positively primed – and this makes it difficult for the system to response for the task B. If, to perform task A on previous trial, a competing task B has to be inhibited/suppressed, the suppression can carry over to next trial – negative priming – and makes it difficult to activate task-set B on switch trial.

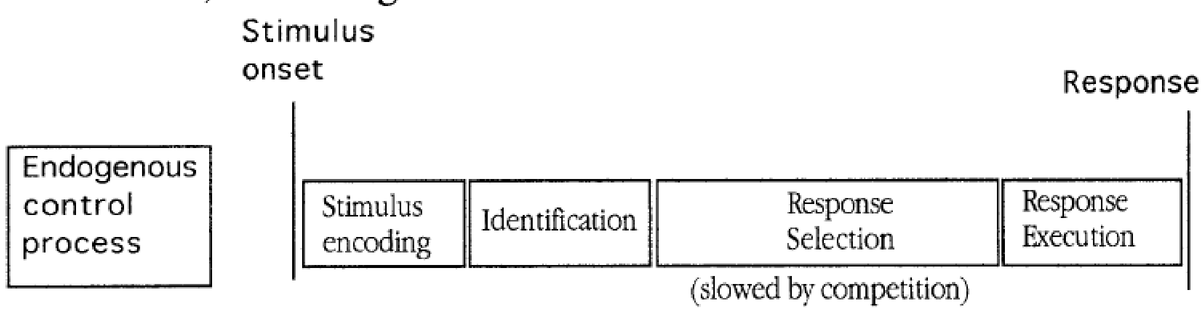
Post-Stimulus control process. TSR consists of two parts – exogenous and endogenous. Rogers and Monsell (1995) attributed residual cost to a control process, required to complete TSR (task-set reconfiguration), that could be carried out only after presentation of stimulus .



A. Switch trials, according to post-stimulus control process model:



B. Switch trials, according to task-set interference model:



DISCUSSION:

The basic result of the experiment shown below giving one evidence of existence of kinematics as a part of movement planning.

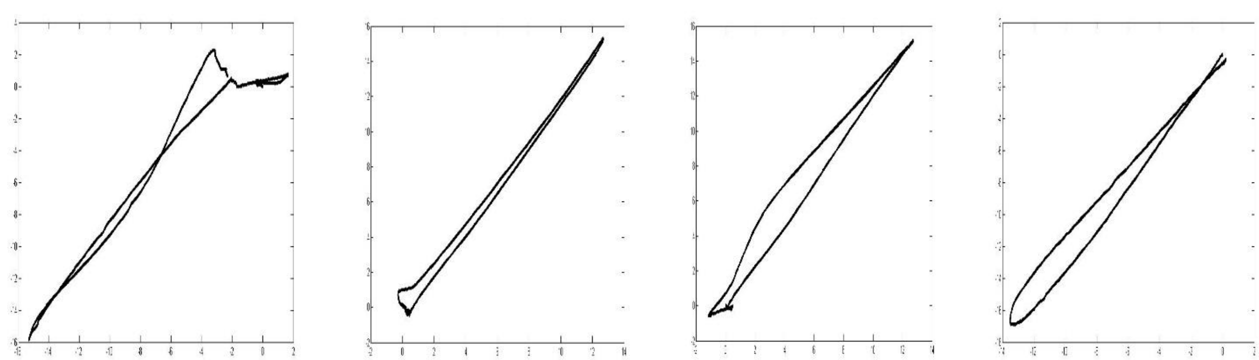


Figure: The plots show the pointing hand movement paths (trajectories) in transverse plane. These plots are shown for green cued four trials (randomly selected).

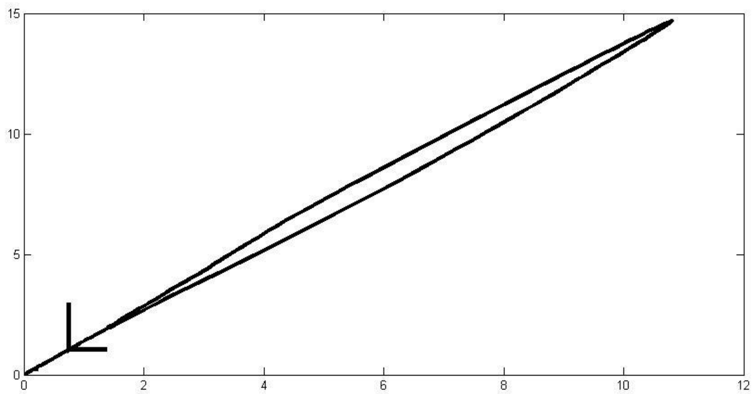


Figure: This figure shown the mean hand displacement in y – direction plotted against mean hand displacement in x – direction, i.e., mean of pointing hand movement paths from all the green cued trials. The vertical and horizontal intersecting line near origin shows the average starting point of hand movement.

The above figures showed the hand movement paths to be almost straight line paths.
One may also argue whether inhibition of the hand movement (not completely), may change hand movement path from almost straight path to otherwise a curved or zig-zag path. As red cued trials involve making a slow hand movement, so one has to inhibit or slow down the movement of hand intentionally.

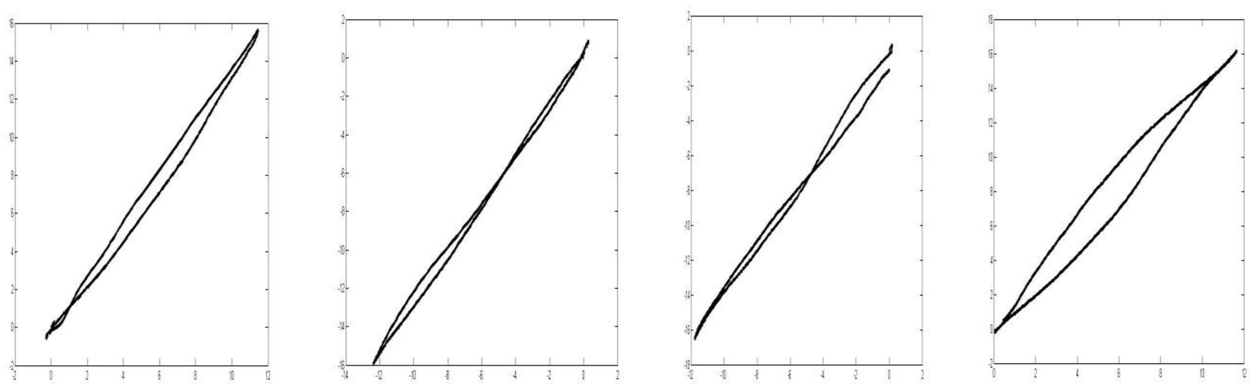


Figure: The plots show the pointing hand movement paths (trajectories) in transverse plane. These plots are shown for red cued randomly selected four trials.

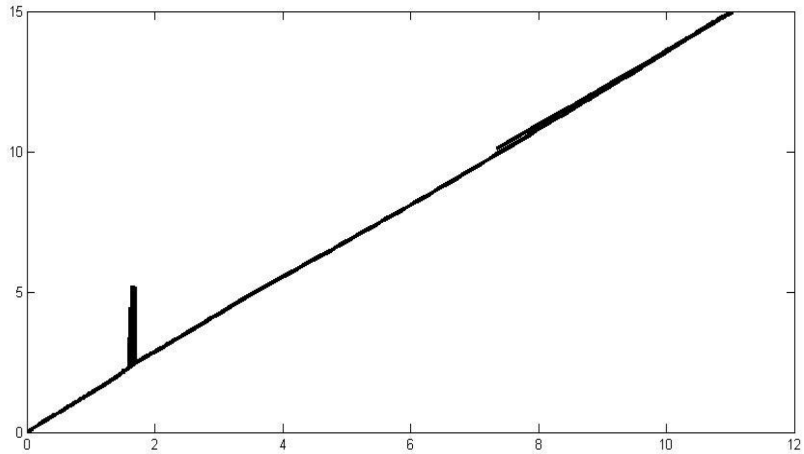


Figure: This figure shown the mean hand displacement in y – direction plotted against mean hand displacement in x – direction, i.e., mean of pointing hand movement paths from all the red cued trials.
The vertical line near origin shows the averagestarting point of hand movement.

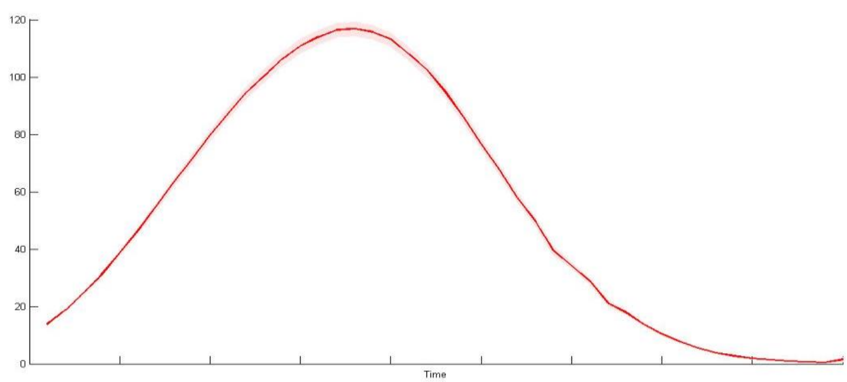


Figure: The plot shows mean velocity over all the trials. The velocity profile above shows that Velocity during reaching hand movement has a bell – shaped profile.

The basic effect of Response – Stimulus Interval (RSI) or preparation time is shown in the figure below. There was a sufficient amount of drop in RT between the first trial and second trial of run. There was no further decrease (reduction) in RT in later trials (P > 2). Recovery from a task switch appears complete after one trial.

We excluded from our analysis warm-up / practice trials, error trials, and trials with mean correct RT > 1000 msec. We conducted analysis of variance (ANOVAs) on mean correct RTs for two positions (P1 and P2) with an additional factor of RSI (100, 200, 500 msec). To access trends in performance beyond the second trial of run, we also conducted separate ANOVAs for r=4 with factor RSI.

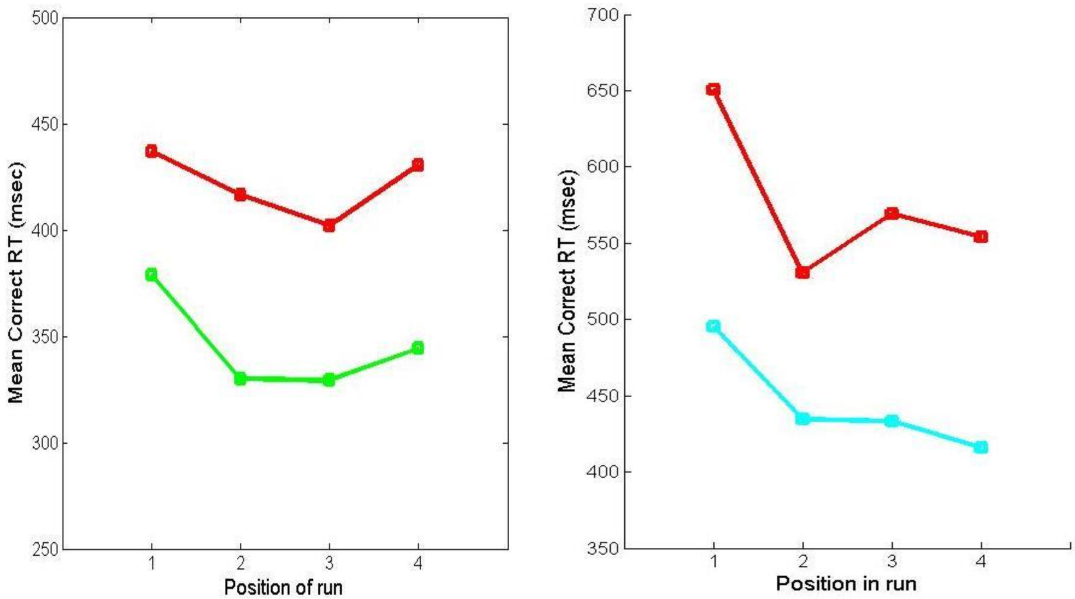


Figure: The figure shows effect of RSI on Mean RT at different positions of run. Left figure being green cued (red line denotes RSI = 100 ms, and green denotes RSI = 200 ms).Right figure being red cued (red line denotes RSI = 100 ms, and blue denotes RSI = 200 ms).

We hypothesize that the **time taken for the hand movement is more in slow movements than in fast movements**. This is because one tends to reach the target as soon as possible which is seen in fast hand movements, whereas in slow hand movement there occurs a partial inhibition of the response (although not completely but relevant inhibition) as subjects were instructed to make a movement such that hand reaches the target after 500 ms but before 1000ms, and foe fast movements subjects were instructed to make movement such that target is achieved within 200 ms.

The mean Response Time for green cued trials, i.e, for fast pointing hand movements is 370.6 ms whereas for red cued trials (slow pointing hand movements) is 501.26 ms showing that the fast hand movement is easier than slow hand movements.

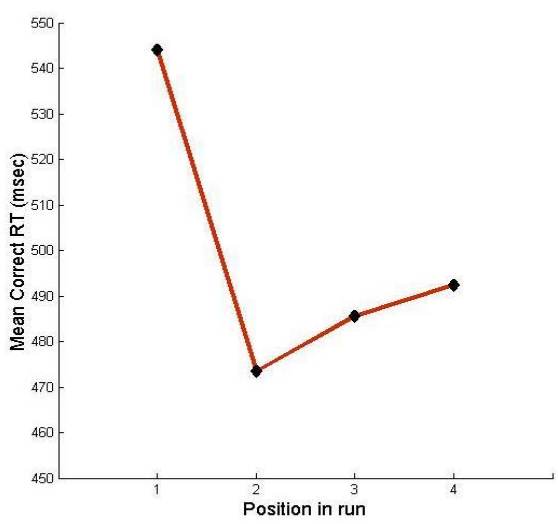
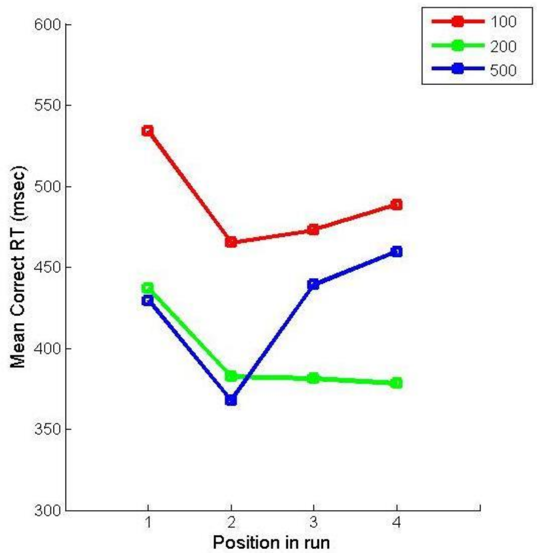
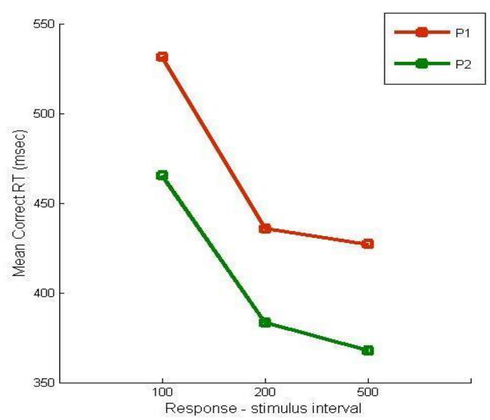


Figure: Mean Correct RT as a function of Position in run showing the effect of preparation
On the RT at different position of runs.

The drop in mean RT from first to second trial of a run (the RT switch cost) was a reliable 71 msec [p = 0.0522 ~0.05, where alpha = 0.005 being the significance level to be decided by the analyzer].As the figure above illustrates there is a slight increase in RT over trials following P2 was not reliable [p = 0.674 >> 0.05].



Altmann and Gray's claim that, with RSI too short to refresh memory trace of last task-set "instruction", it progressively weakens over the course of a run, leading to a steady increase in both RTs and errors. We observed in contrast that reduction in RT from first trial to the second trial of a run following a change in task, with almost no reduction thereafter. With predictable switching, one trial was enough for full recovery from a task switch. If there is any change in RT following P2, then they are small but unreliable.



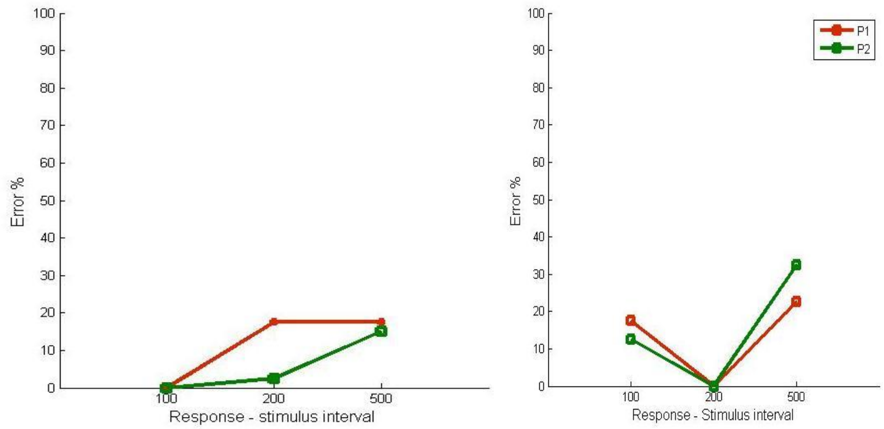


Figure: Upper figure shows Mean Correct RT as a function of preparation interval (response – stimulus interval) for the first (P1) and second (P2) trials/position of a run. Lower two figure shows errors In the task for different Subjects showing that there is no reliability on the errors occuring.

The reduction in RT switch cost (P1 – P2) with increasing RSI (as shown in figure above) was reliable [p = 0.0027 < 0.05]. The statistical significance can also be seen in bee swarm plot and box plot shown below:

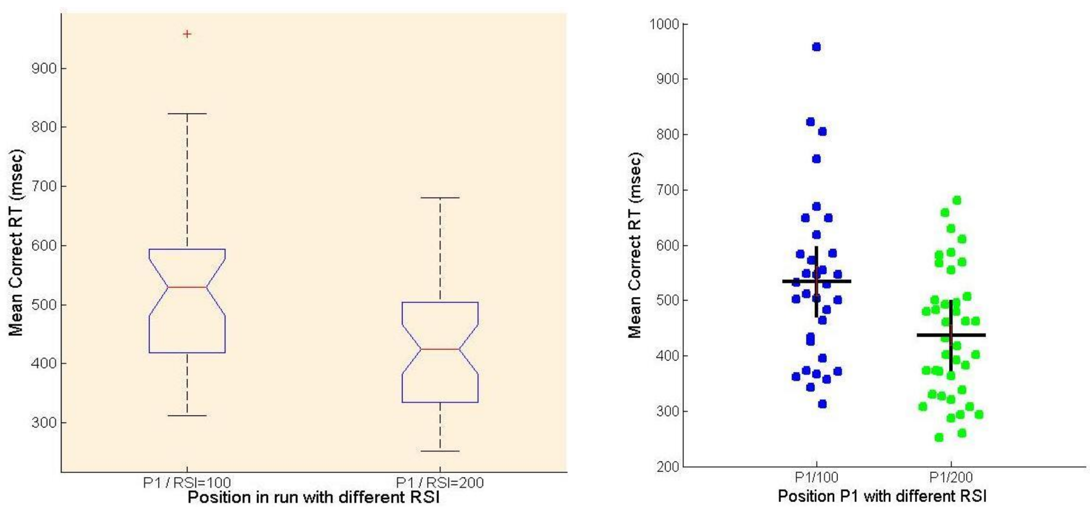


Figure: This illustration explains how the data is distributed around the mean. Left figure shows the box plot generated along with ANOVA1whereas Right figure shows the bee swarm plot of the Mean RT against P with different RSI.

The above showed only the effect of only two RSI (100, 200 msec) at position P1 on the Mean correct RT. We could also discuss the effect of all three RSI together as shown below.

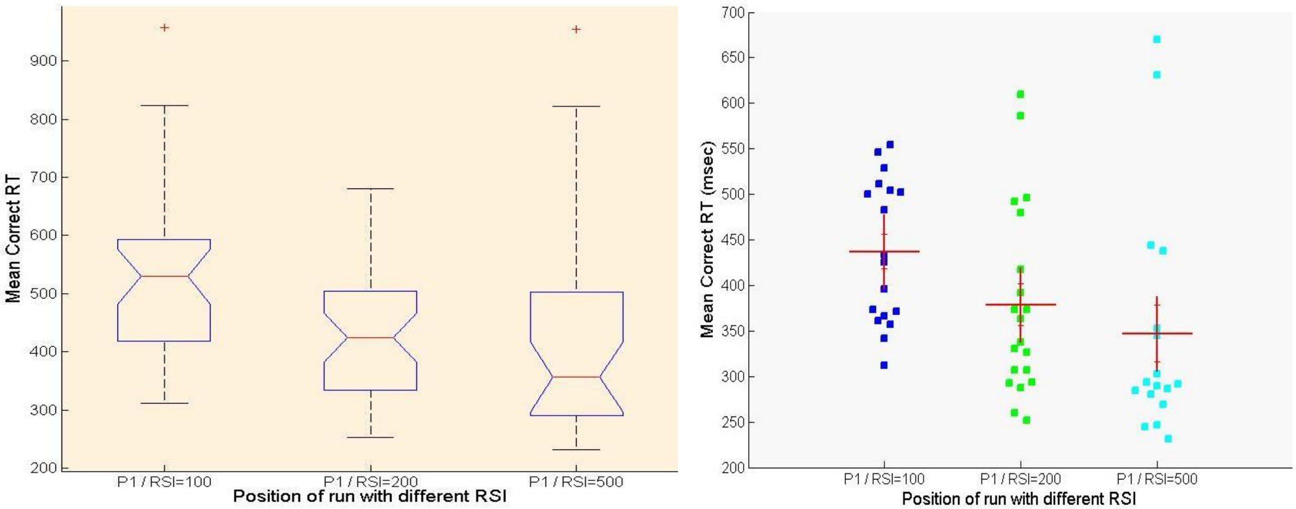


Figure: Left figure shows the box plot whereas right shows the bee swarm plot of effect of RSI on RT switch cost.

The reduction in the Mean correct RT at position P1 due to RSI (100, 200, and 500 msec) is quite reliable [p-value = 0.0082 < 0.05] but reduction in mean RT at P1 from RSI = 200 msec to RSI = 500 msec is not reliable (significant enough) [p-value = 0.8376 >> 0.05]. Although the reduction of RT between RSI = 100 and RSI = 500 msec is reliable [p-value = 0.0158 < 0.05].

The above analysis shows that the reduction in RT switch cost occurs significantly when RSI is increased from 100 to 200 to 500 msec but the reduction in RT switch cost when RSI is increased from 200 to 500 msec may or may not occur, i.e., the RT switch cost at RSI = 500 ms maybe either same as that corresponding to RSI = 200 ms or may increase a little.

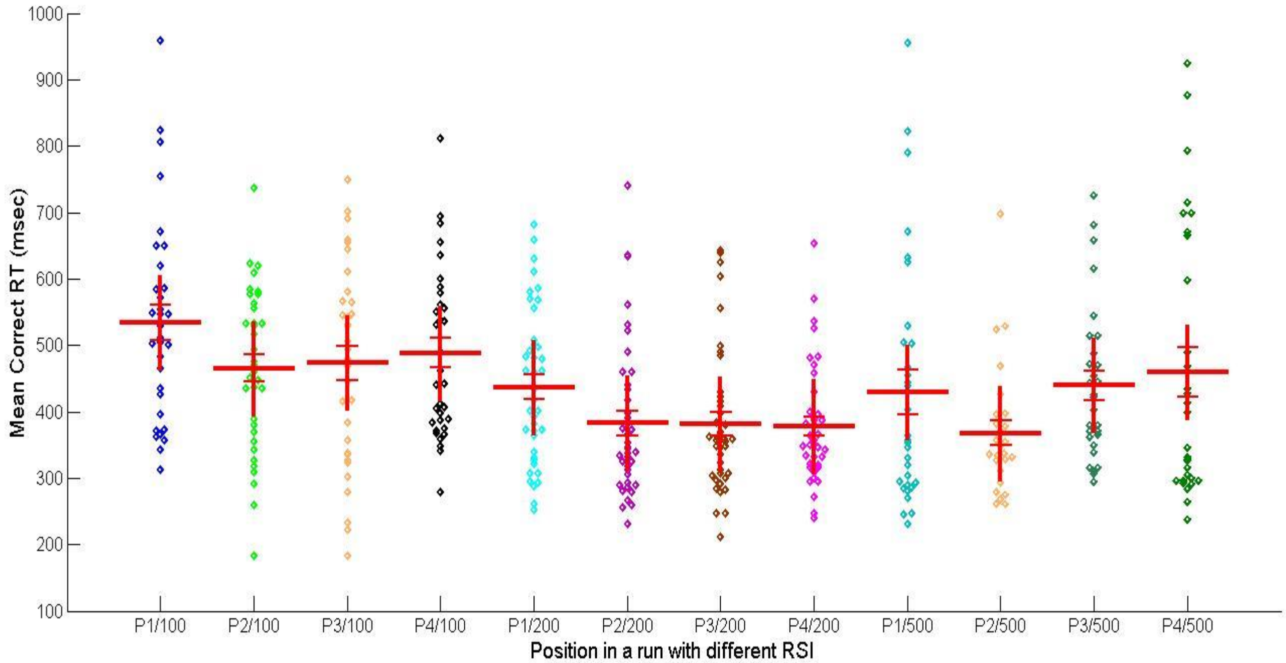


Figure: Illustration of statistical significance and data distribution of Mean Correct RT at different position in run and RSI combinations.

Inferences and General Discussion

The Experiment demonstrated that, when tasks alternate after runs of predictable length, one trial can be sufficient enough to “recover” from the switch effect. There is no further improvement in performance with further repetitions of the task. Also, with increasing preparation effect, the switch cost decreases but to a certain level. As soon as some threshold is reached, no (or negligible) decrease in switch cost is seen. For cases in which a cuing paradigm is used, its recommended to analyze data for atleast first three or four positions in run. The predictable switching paradigm has some advantages:

- It encourages fuller preparation,
- It is efficient, as runs of only two trials are sufficient to estimate the switch cost,
- There is equal amount of trials per position in run and there is no need to worry about controlling run-length distributions,

Even in alternating runs paradigm, it is recommended to use run lengths of atleast three to see the asymptotic recovery has indeed occurred.

The hand movement paths were observed to be straight line paths. Why was this path followed? Why not other?

These questions are answered by dynamics, as discussed by other researchers, there are various models which brain may use to minimize the torque at joints, or minimize force in muscles or minimize energy required to reach target, etc. Also, the velocity profiles of hand movements were observed to be bell – shaped. The response time is taken by subjects to actually start the movement. Actually, some part of it goes in deciding where the target is, how to reach the target, what path to take, etc. The slow hand movement involves some kind of inhibitory control due to which the response time for slow hand pointing movements in almost double to that for fast hand movements. Kinematic attributes are explicitly present in movement planning.

References:

1. **Bernstein, Nikolaj A**. "The co-ordination and regulation of movements." (1967).
2. **Bizzi, Emilio, et al.** "Posture control and trajectory formation during arm movement." *The Journal of Neuroscience* 4.11 (1984): 2738-2744.
3. **Bizzi, Emilio, Ferdinando A. Mussa-Ivaldi, and Simon Giszter.** "Computations underlying the execution of movement: a biological perspective." *Science*253.5017 (1991): 287-291..
4. **Padoa-Schioppa, Camillo, Chiang-Shan Ray Li, and Emilio Bizzi.** "Neuronal correlates of kinematics-to-dynamics transformation in the supplementary motor area." *Neuron* 36.4 (2002): 751-765.
5. **Flash, Tamar, and Neville Hogan.** "The coordination of arm movements: an experimentally confirmed mathematical model." *The journal of Neuroscience*5.7 (1985): 1688-1703.
6. **Hasan, Z.** "Optimized movement trajectories and joint stiffness in unperturbed, inertially loaded movements." *Biological cybernetics* 53.6 (1986): 373-382.
7. **Hollerbach, J. M., and C. G. Atkeson.** "Deducing planning variables from experimental arm trajectories: pitfalls and possibilities." *Biological cybernetics*56.5-6 (1987): 279-292.
8. **Kalaska, J., & Crammond, D. (1992).** Cerebral cortical mechanisms of reaching movements. *Science*, *255*(5051), 1517-1523.
9. **Monsell, Stephen, Petroc Sumner, and Helen Waters.** "Task-set reconfiguration with predictable and unpredictable task switches." *Memory & Cognition* 31.3 (2003): 327-342.
10. **Morasso, Pietro.** "Spatial control of arm movements." *Experimental brain research* 42.2 (1981): 223-227.
11. **Uno, Yoji, Mitsuo Kawato, and Rika Suzuki.** "Formation and control of optimal trajectory in human multi joint arm movement." *Biological cybernetics* 61.2 (1989): 89-101.
12. **Norman, D.A., & Shallice, T. (1986).** Attention to action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwartz, & D. Shapiro (Eds.), *Consciousness and Self Regulation* (Vol. 4, pp. 1-18).New York: Plenum

Uno, Y., Kawato, M., and Suzuki, R. ____ Formation and control of optimal trajectory