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ERROR ANALYSIS OF A THROWING ACTION

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The purpose of the present study was to characterise the temporal regulation of a simple but natural movement, forearm throwing. Our finding is the time leg of wrist flexion throwing is less consistent than that ofdeviation throwing. Two experiments demonstrate two potential error factors involved in a simple throwing action. The result data demonstrated that there is a limit with which people can perform self-timing activities. The limit for best people could do in releasing two fingers is 6ms, 12ms for deviations throwing only, flexion throwing with finger releasing is about 18 ms, but was about 25ms in deviation throwing with finger releasing.

KEY WORDS: throwing task, time delay, error.

INTRODUCTION: The skill of throwing is probably the second most elemental sports, behind running. Throwing can be defined as the act of propelling an object through the air by the action of the human body (Adrian & Cooper, 1995). It includes a rapid acceleration of the trunk arm segments just before release. Throwing involves the proximal to distal sequencing of arm segments with an increasing velocity of the distal segments. Sequentially accelerating and decelerating body segments around the joints used in throwing has an obvious effect on the displacement and velocity of the object in the hand prior to release. To execute accurate and rapid throws a high degree of accuracy is required for muscle activation timings across different joints. Relative timing can be a powerful constraint in complex, multi-degree of freedom movements (Stephen A, 1990).

Release timing of releasing is also important in throwing activities. The primary objectives in throwing are distance and accuracy. Optimal movement magnitude and direction of force exerted by the thumb and index finger tip during releasing finger movements has previously been analysed (Rosenbaum, 1991), however, the temporal coordination limits of the movement has not. This timing is crucial for dexterous manipulation both in terms of fully releasing the object and with regard to potential unbalanced forces acting on it with asynchronous release of the digits. Although different optimal release window has been found (Calvin, 1983) it is agreed that the size of release window is heavily influenced by the level of coordination required to produce the hand trajectory.

The aims of this study were: to quantify a reliable and accurate measure of coordination error between elbow and wrist joint timings for both Flexion-Extension (FE) overarm throwing and Radial-Ulnar Deviation (RUD) overarm throwing task; to determine the individual difference of proximal to distal delay.

METHODS: Twelve right-handed subjects (age 19-28 years) with no history of hand impairment or prior injury were recruited for the study. The study includes two separate experiments.

In the first experiment, a custom-made wooden stand, which consisted of a wooden base and an adjustable top layer with two pieces of cut and planed foam fixed on top of one end of the wooden base and an adjustable layer was constructed (Figure 1). Two identical force transducers were attached to the top of the foam surfaces. The distance of the sensors was adjusted for each subject so it was equal to the length between the tips of index finger to wrist lunate bone. The subjects performed two wrist control tasks whilst performing elbow extension: Flexion-Extension and Radial/Ulnar Deviation at the wrist joint while maintaining a constant finger posture. During the FE task, the subject performed extension prior to flexion in one cycle with the aim of moving segments as fast and as accurately as possible. They were instructed to hit the two sensors simultaneously with the index finger and the wrist. The RUD

task was similar to the FE task except that the motion was in the radial-ulnar direction. Five FE and RUD sets with either 10 or 20 trials were performed by each subject.
The second experiment required the subjects to produce pinching and releasing movements on a custom-made wooden block which had force transducers mounted to it to detect the contact of the thumb and index finger (Figure 2). The pinching and releasing movements were performed under two speed conditions; Normal and Controlled. In both conditions the subjects were instructed that the movement should be performed so that both digits contact and then leave contact with the sensors simultaneously. In the Normal speed condition, the subjects were instructed to close and open the two digits as quickly as possible. No specific strategies for moving the digits were provided. In the Controlled speed condition subjects were instructed to perform the task at a relatively slow speed and concentrate on the movement path of both digits. The subjects were also provided with strategies such as the initial placement of the fingertips relative to the force transducer. Each subject performed 50 pinch and release movements under each condition, which were interspersed with rest periods to prevent fatigue.
Force data were captured at 5000Hz and were subsequently low-pass filtered in both directions using a fourth order Butterworth filter with a cut-off frequency of 50Hz. Force onsets were obtained digitally using three standard deviations above the resting signal as a threshold of detection.

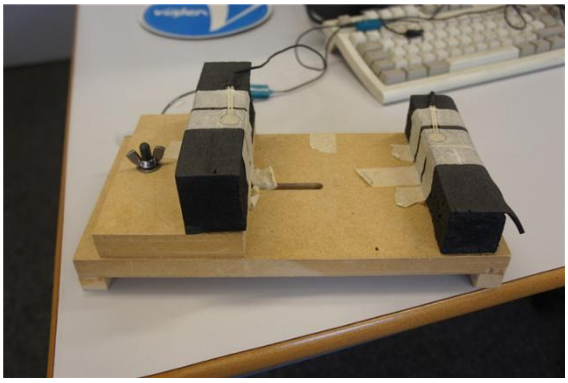

Figure 1: Experiment 1 device

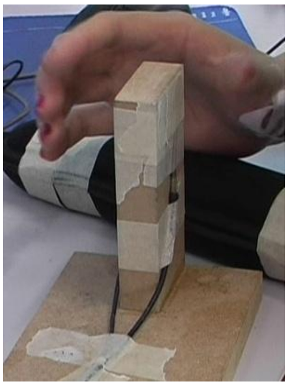

Figure2: Experiment 2 device

RESULTS: For experiment 1, FE throwing has an error ranging from 13.2ms to 50ms, with a mean of 32ms (Figure 3). RUD throwing has an error ranging from 12.1ms to 50.6ms, with mean 26.2ms. Paired t-test showed no significant differences between mean FE time delay and mean RUD time delay ($p > 0.05$). Correlation analysis was performed on the FE and RUD data for the FE and RUD trials which returned $r = 0.339$.
For experiment 2, the mean delay in the offset of force (releasing) during the Normal and Controlled condition was 7.9 ms (range 3.7-12.2 ms) and 6.3 ms (range 3.5-9.1 ms) respectively. The mean delay in the onset of force (pinching) between the thumb and the index finger during the Normal and Controlled conditions were both 12.0 ms (Normal range 5.2-21.8 ms, Controlled range 5.7-25.0 ms). The onset delay during pinching had a considerably wider range than the offset delay during releasing, shown in Table 1. The mean offset delay was significant shorter than the mean onset delay for all subjects (t test, $P < 0.05$).

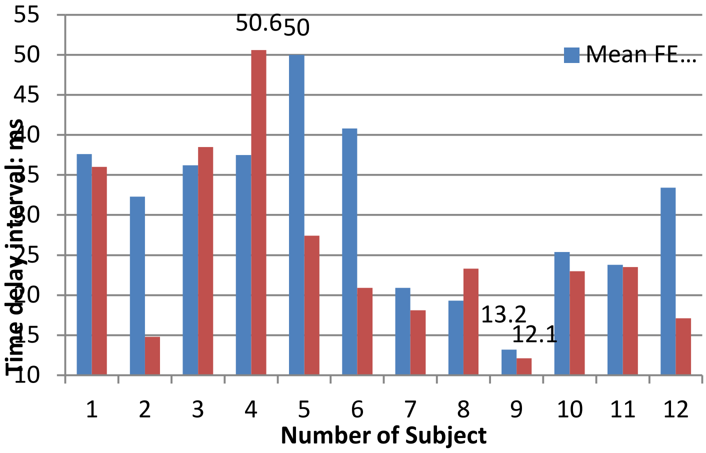

Figure 3: Mean time delay of FE/RUD throwing

Table 1
Time delay of releasing (ms)

Subject	Normal Release		Controlled Release	
	Mean	Std	Mean	Std
1	4.1	3.5	4.4	3.5
2	3.7	2.9	3.5	2.8
3	8.7	8.2	7.6	4.9
4	6.7	7.7	5.9	4.4
5	9.7	11.6	4.8	4.7
6	5.6	4.8	3.9	3.3
7	12.2	10.0	8.7	4.5
8	8.3	7.1	9.1	15.8
9	12.0	16.0	6.7	6.4
10	8.8	6.3	7.3	4.6
11	9.1	7.1	7.0	6.3
12	6.1	4.2	6.9	4.3

DISCUSSION: Our of twelve subjects, the greatest coordination error was about 50 ms, from subject 5 in a FE throwing and subject 4 in a RUD throwing whilst the lowest error was 12ms found in subject 9 in RUD throwing. Six subjects showed their RUD delay was shorter than their FE delay and another six subjects showed no difference between FE/RUD delays. Flexion-Extension throwing might results in a greater value of timing error (with mean 30, as low as 13ms) but have a consistent joint programming.

When attempting a simultaneous release of the thumb and index finger from the force sensors the best subjects were able to achieve a mean offset of between 3-4 ms. Seven out of the 12 subjects were able to improve their synchronisation offset by performing the movement at a controlled pace and concentrating on the path of both digits, all subjects were able to achieve a synchronisation offset than 10 ms during releasing. Unlike onset, the average offset time lag of whole population is around 8ms for normal condition, but it could improve to 6ms when subjects concentrate and slow down the angular velocity of finger digits.

After we combining two errors together the result bar chart (Figure 4) is quite the same as wrist throwing error chart. The correlation test also showed there are strong correlation between wrist time delay and total time delay (r=0.97 for FE throwing, r=0.99 for RUD throwing).

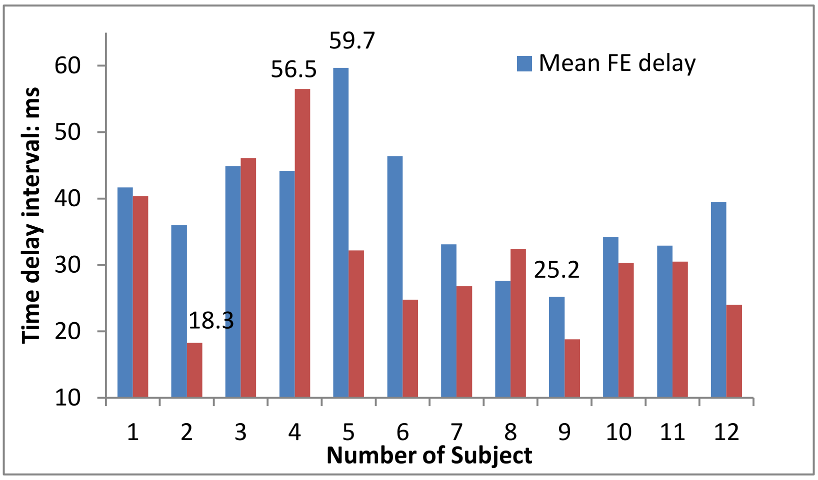

Figure 4: Mean time delay combined errors of experiments 1 & 2

On way to explain this is subjects have practised FE throwing action in their previous life, like playing badminton, baseball, or even just lifting a mouse from one place on the table to a nearby place when the mouse reach the edge of our comfort. All these daily practice of wrist flexion-extension might help a little of what they've done in the FE test. And RUD throwing is not that familiar to the entire group only any of them likes play darts or rope skipping. What might happened is they use the feel of tactile feedback from their tip of index finger as a stop signal to slow forearm motion. The experiment itself is open loop test which introduce no feedback to the central nerve system, not any common visual feedback at all. When we looking at the recorded video of subjects in the test we found flexion-extension has wider range of motion (70° - 75°), the Radial-Ulnar deviation only has a range of 20° - 35°. So the deviation throwing are more like a rigid object not two independent segment which rotates with different angular velocity.

CONCLUSION: In the present study the coordination timing limits of simple throwing task with pinching and releasing under different requirements were investigated. The results showed there is a limit to which people can perform self-timed activities and that the limit depends on the nature of the movement. The coordination timing limit for performing a simultaneous release appears to be around 3-4 ms for best performers in the group. It is possible to shorten the timing asynchronisation when we choose to slow down the velocity of movement and focus on the task.

To execute accurate and rapidly throws, a high accuracy of timing is required in activations of muscles across different joints, forearm especially. Our study showed the minimum delay for a voluntary throwing type task was 18ms. Wrist flexion throwing is less consistent than deviation throwing. Inclusion of these limits in future work on modeling of manipulation of objects and throwing will allow for more biofidelic control timings and strategies to be investigated. For certain sports involving forearm throwing like baseball, darts, javelin, handball and some racket sports (badminton, squash & tabletennis) we have a better understanding of the reason of incoordinated movement and the corresponding training stratagy to assist coaches.

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