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VARIABILITY IN TIMING AND RANGE OF THE "TIME WINDOW" OF RELEASE IN DARTS THROWING: A COMPARISON BETWEEN EXPERTS AND NOVICES

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This study aimed to investigate differences in the variability of timing and range of accurate release timing between dart throwers of different skill levels. Each of 8 expert players and 8 novices made 60 dart throws. The movements of the dart and index finger were captured using seven 480-Hz cameras and the data analyzed in 1-ms intervals. The estimated vertical error on the board was calculated as a time series. Two variables to assess accuracy in the vertical plane and two variables to assess release timing were quantified on the basis of time-series error. The timing errors were smaller for the experts than for the novices. The "time window" at which release would result in hitting the target was longer for some experts than for the novices. However, other experts exhibited less variability in release timing instead of a longer timing window.

KEY WORDS: accuracy, proficient, skill level, motion capture

INTRODUCTION: Throwing accurately plays an important role in the outcome of the game in many sports. Throwing darts is a typical example because scoring is determined by accuracy. The location at which a thrown dart will hit the board depends on a combination of the dart's position, velocity, and direction of motion at the moment of release. In order to hit the target, throwers must move their hands along a trajectory that provides an appropriate combination of these parameters and also release the dart at the appropriate time.

Reducing the variability in both the movement path of the hand trajectory and the timing of release is believed to be the most effective way to throw more accurately. In addition, aligning or "flattening" of the trajectory of the hand toward the intended target line also increases the potential accuracy by decreasing the consequences of imperfect timing of release. The primary source of vertical error in overhand throws is reported to be inappropriate timing of release rather than variability in the hand trajectory (Hore, Watts, & Tweed, 1996). However, the reducing variability of timing accuracy is limited by the "noise" present in the nervous system (e.g., signal propagation due to synaptic fluctuations). It has recently been reported that skilled subjects can compensate for the intrinsic timing limitation by optimizing the throwing trajectory. Cohen and Sternad (2012) found that skilled subjects performing virtual throwing had a longer range of release timing that resulted in hitting the target. This range of accurate release timing was defined in the current study as the "time window."

However, Smeets et al. (2002) reported a contradictory result, finding that their skillful dart players did not use such compensatory trajectories. One cause of this contradiction may be the differences in situation and/or task specificity between "skittles" throwing in the virtual environment and dart throwing in the real environment. The Smeets' study also included a smaller and perhaps insufficient number of subjects.

This study aimed to confirm that expert dart throwers have not only less timing variability but also a longer time window than novices. Because the horizontal hand trajectory in dart throwing is in almost perfect alignment with the intended target line, this study, like the previous studies, focused on accuracy in only the vertical plane.

METHODS: The study enrolled 16 right-handed males, 8 of whom were expert players and the other 8 novices. The experts were competitive soft-darts players with 2–6 years of dart-playing experience, whereas the novices had thrown darts only a few times in their lives.

Each subject made 60 dart throws at a dartboard positioned according to the general rules of soft darts. The height of the center of the dartboard (the bull's eye) was 1.73 m above the floor, and the horizontal distance from the throwing line to the board was 2.44 m. The target was the bull's eye 4.4 cm in diameter. The subjects were free to choose their throwing postures.

Seven 480-Hz infrared cameras (Qualisys, Inc., Gothenburg, Sweden) were used to capture the movements of 3 markers. A spherical marker (r = 3.5mm) was attached to the index finger and another spherical marker was attached to the rear of the dart. The third was reflective tape wound around the middle of the dart. The captured data were filtered using a Singular Spectral Analysis in which the window length was a quarter of the data size and the principal components were 2–6 (SSA; Alonso, Castillo, & Pintado, 2005).The filtered data were interpolated as 1-ms intervals using a spline interpolation.

The time of release was defined as the moment when the difference between the vertical velocities of the dart and the index finger exceeded the threshold decided for each subject (50–500 mm/s).

To quantify the variables consistent with accuracy, the researchers calculated the vertical errors on the board for both the actual release and the fictional release, including the time after the actual release. The calculated time-series errors were thus based on the index finger movement with position (*x*, *z*) relative to center of the bull's eye, velocity *v*, and direction of motion *θ (rad)*. The researchers also assumed that after release, the dart follows the parabolic trajectory of a point of mass. At time *t*, the equation for the vertical error (E_z) in mm was written as follows:

$$E_z(t) = \mathrm{z} + \tan\theta \cdot \mathrm{x} - \frac{9800\,\mathrm{x}^2}{2(\mathrm{v}\cos\theta)^2}$$

Fig.1: Three examples of time-series vertical errors on the board and timing variables. The curves represent the calculated vertical location on the board on the basis of the position, velocity, and direction of the index finger (see Text for detail). The filled dot represents the actual release moment (t = 0) and the square the optimal release moment at the millisecond producing the least vertical error. When the curve crossed the "0" error line twice, the point nearer to the actual release was selected as the optimal release moment. A: The time window is longer when the zenith of the error curve is in the bull's eye zone. The actual release coincides with the optimal release in this example, yielding a timing error of 0. B: When the zenith of the curve is under the bull's eye zone, the curve does not enter the bull's eye zone (non-hit trajectory). C: When the zenith of the curve is above the bull's eye zone, the curve crosses the zone twice. In such cases, the time window was quantified as the sum of two values.

The following 4 variables were calculated on the basis of these time-series errors. Two of these variables were positional errors relating to the performance outcome and the other 2 were related to the timing (Cohen and Sternad, 2012, Fig. 1).

1) Absolute error (AE) and variable error (VE) on the board, which were calculated from the movement of the index finger at the moment of release, were used as the performance outcome.
2) The timing error was quantified as the absolute difference between the actual release and the optimal release time. The optimal release was defined as the moment (within a millisecond) at which the time-series error calculated by the finger movement was minimal.
3) The time window was quantified as the amount of time for which the time-series error curve was in a region in which release would result in an absolute error < 22 mm (the bull's eye zone, Fig. 1).

Four t-tests were used to assess the differences in these parameters between the expert and novice groups ($p < 0.05$).

RESULTS & DISCUSSION: As expected, the expert group performed more accurately than the novice group. The absolute and variable errors on the board were significantly smaller for the expert group (Table 1).

The results support the hypothesis that reducing variability in release timing is an effective way to improve the accuracy of throwing. The timing error relative to the optimal release was significantly smaller in the expert group than in the novice group (Table 1). This result indicates that experts released the dart nearer to the point at which the error within their trajectory was minimal. These results partially support the previous report by Hore et al. (1996), who found that the vertical error in fast arm-only ball throws resulted from inappropriate timing of release rather than from variability of hand trajectory.

Cohen and Sternad (2012) described that there are intrinsic limitations to control the release timing accurately because of the “noise” in the nervous system. They reported that subjects performing virtual throwing developed a hand trajectory that included a long time window for accuracy. In the current study, the time window was significantly longer for experts than for novices (Table 1). This result indicates that the experts’ hand trajectories compensated for the intrinsic variability of release timing.

The researchers investigated the experts’ results in detail because the standard deviation of the time window for the expert group was relatively large. Strikingly, some experts exhibited time windows similar to those of the novice group; however, their timing errors were surprisingly small and their performance outcomes were clearly superior to those of the novice group. Fig. 2 demonstrates examples of the 2 strategies used by the expert group. Each sample time-series error was synchronized with the curve zenith for easy comparison. Subject T demonstrated a long time window in the bull’s eye zone (Fig. 2A). The subject seemed to utilize this window to compensate for the timing variability. However, this strategy increased the risk for producing a “non-hit trajectory” (Fig. 1B). In contrast, subject Y exhibited a short time window (Fig. 2B) but surprisingly small timing error, producing a performance outcome almost identical to that of subject T.

The belief that the most important way to improve throwing accuracy is to reduce movement variability leads many motor learners to use repetitive drills to improve accuracy. The results of this study indicate that changing strategy may be as effective as reducing variability. Coaches and beginning dart throwers should be aware of this method for improving throwing accuracy.

Table 1 Variables (mean ± SD)

	Experts (N = 8)	**Novices (N = 8)**	***p***
Vertical error on the board			
Absolute error (mm)	18.7 ± 7.4	56.6 ± 13.3	0.000*
Variable error (mm)	24.5 ± 6.0	62.8 ± 14.1	0.000*
Timing error (msec)	2.2 ± 0.9	4.1 ± 1.1	0.004*
Time window (msec)	7.7 ± 2.5	5.4 ± 0.6	0.046*

Note. N is the number of subjects. Differences significant at the level of $p < 0.05$ are indicated by asterisks.

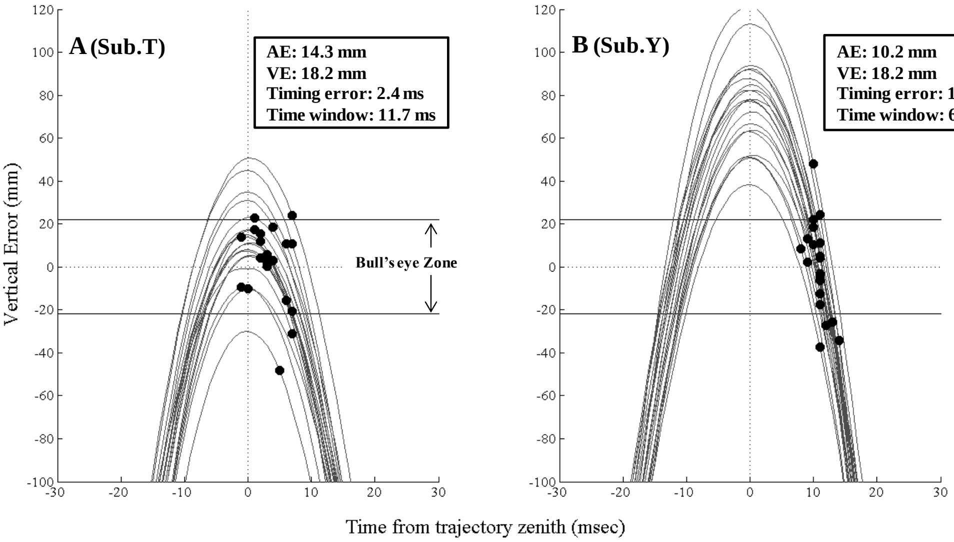

Fig. 2: Two strategies used by the expert group. For easy observation, the time-series error was synchronized with the curve zenith (t = 0), and the first 20 trials were plotted. The filled dot represents the actual moment of release. **A:** Many curves have their zeniths in the bull's eye zone, resulting in a long time window. **B:** All curves have their zeniths above the bull's eye zone, resulting in a narrow time window. The timing error was quite small.

CONCLUSION: This study investigated differences in release timing between darts throwers of different skill levels. The timing errors, defined as the differences from the calculated optimal timing, were shorter for experts than for novices, while the time windows were longer for most experts than for novices. However, some experts did not have a longer time windows and instead exhibited very little timing variability. These results indicate that changing the movement strategy may improve throwing accuracy as effectively as reducing movement variability.

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