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Sensitivity to Error Tolerant Solutions in a Redundant Virtual Throwing Task

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Abstract

It is suggested that when learning a redundant goal-oriented motor task, people explore and choose error tolerant solutions of the task to reduce result variability. This assumption was tested with a virtual throwing task where the error tolerant solutions were designed such that subjects needed to recurrently adapt to a new tolerant solution in order to achieve high performance. We tested 13 participants who practiced the task over six days. All of them adapted to changes in error tolerant solutions although the absolute number of adaptations as well as the rate of adaptation varied strongly between subjects. Results are discussed with reference to motor noise and the integration of practice trials according to error probability.

1. Introduction

Human movements are noisy. Nevertheless, we can accomplish highly constant reproductions of movement goals, like hammering on a nail or shooting a basketball free throw. Especially in sports, the precision of movements is a sign of virtuosity that can only be achieved with consequent long-term practice. However, the result of practice is not only a reduction of motor noise. In redundant tasks, i.e. tasks that offer an infinite set of solutions to achieve the same result, performance can be enhanced by choosing solutions that allow greater deviations in execution without affecting result variability. We call these solutions error tolerant solutions. Previous findings indicate that people who practice a goal-oriented throwing task are able to find such error tolerant solutions [1, 2]. However, in these results, several mechanisms of performance improvement are concatenated and there is no study showing sensitivity to error tolerant solutions in isolation. The detection of error tolerant solutions is challenging because performers have to integrate results of several trials to be able to estimate the success rate.

The goal of the present study was to experimentally separate the sensitivity to error tolerance from other components of performance improvement (e.g. noise reduction). To do so, we used a virtual goal-oriented throwing task where we could manipulate the area of error tolerant solutions and its location. We tested whether and how fast people adapted to changes in task tolerance during a relatively long practice period.

2. Methods

2.1 Experimental task

Participants practiced a redundant virtual goal-oriented throwing task called Skittles. The idea of the task comes from a British pub game where a ball is suspended from a string attached to the tip of a vertical post. The player has to throw the ball around the post in order to knock down a target skittle on the other side. In the experimental version, participants saw the work space of the task in two dimensions from a bird's eye view on the projection surface from which they stood approximately 2 m away. They manipulated a lever with one degree of freedom (elbow) in the horizontal plane to gain velocity and released an electrical contact on the lever with their index finger to release the virtual ball on the screen in front of them (Fig. 1).

Performance, as the minimal distance between the trajectory of the ball and the center of the target, was determined by the execution variables angle and velocity at the moment of ball release.

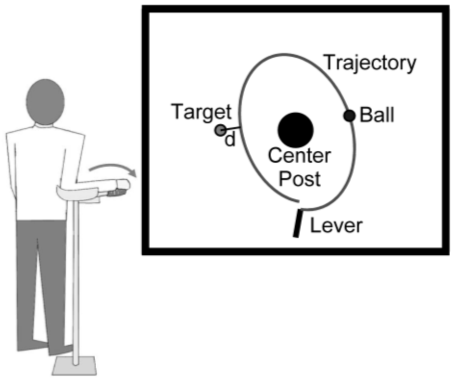

Fig. 1. Experimental Task: Skittles

Via software we modified the result in certain execution areas such that the task was especially error tolerant in these areas (white bubble in Fig. 2). We did this by shifting the actually performed release velocity in the direction of the optimal velocity at the current release angle. Subjects were not aware of this manipulation.

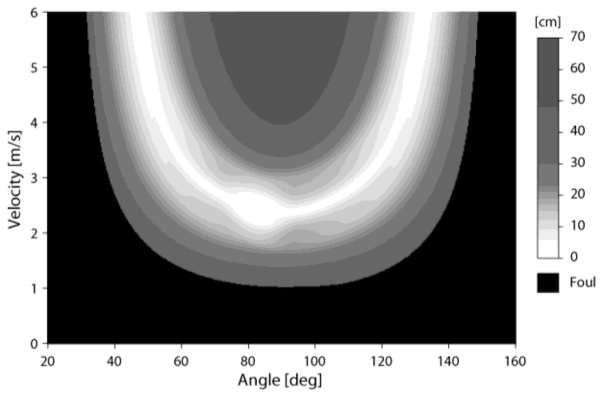

Fig. 2. Execution and result space with error tolerant area (white bubble)

2.2 Participants and procedure

We tested 13 participants (9 females, 4 males) with mean age of 23 (SD = 2.3). All subjects practiced Skittles for six days with 400 up to 600 trials each day. Within each session, the location of the error tolerant area was shifted to another location as soon as subjects had adapted to it. Therewith, several adaptations per session were possible. The criterion for adaptation is described below (2.3).

The initial location of the error tolerant area was balanced between subjects. Half of the subjects started with an area located around a central angle of 82.5° (Fig. 2), while the other half had an initial tolerant area around 97.5°. As soon as participants had adapted to the initial tolerant area, the area was shifted to a 15° larger central angle (if actual area was below 90°) or to a 15° smaller angle (if actual area was above 90°). The key point of this procedure is that there were still solutions to hit the target at the location of the old tolerant area although these solutions had a lower success rate. Only over the integration of several trials the performer was able to notice that his success rate had degraded and that he needed to change his execution. The change in execution was practically limited to the angle because within the angle range of the tolerance shifts (80° – 100°) the velocity remains around 2.4 m/s.

Within one practice session, several adaptations were possible. Data collection of each session ceased when subjects had completed their last adaptation after at least 400 trials or when 600 trials had been performed.

2.3 Adaptation criterion

Whether participants had adapted to an error tolerant area was determined on-line by testing if the average release angle of the last 30 trials differed statistically from the central release angle of the error tolerant area. We used the t-test for this procedure. To get a deviation independent adaptation criterion, p-values were chosen as a function of the standard deviation of the angle. This adaptation criterion was validated by simulations with different angle deviations and adaptation rates. Once the null hypothesis was accepted, adaptation was regarded as completed and the tolerant area was again shifted by 15°.

The number of trials needed to reach the adaptation criterion defined the adaptation rate.

2.4 Statistical testing

Note that a tolerance shift was not conducted before a subject had adapted to the actual tolerant area. Hence, we had no reference value of absolute possible adaptations. To nevertheless verify that our adaptation criterion was adequate, we tested whether subjects systematically changed their release angles according to the direction of the shift or whether the adaptations might have occurred in a random fashion. Regardless of the direction, each tolerance shift was 15°. Hence, we tested whether subjects systematically followed this 15° shift from their actual position. For this purpose, we determined, for each shift and each subject, the distance of an average angle of three trials to the central angle of the new tolerant area as a function of trials after the shift. We chose fixed trial numbers of 30, 60, 90, 120, and 150 trials after the shift.

3. Results

In total, we found 116 adaptations to the tolerance shifts. Each subject adapted on average 8.9 times, but there was high variation between subjects (SD = 5.7; range = 2 - 19 adaptations). Note that a practice session was terminated after a maximum of 600 trials and subjects had no chance to continue their adaptation in the next session. Hence, we cannot exclude that the subjects with little adaptations would have reached the adaptation criterion more often if they had had more time to practice.

The trials needed for adaptation, i.e. the adaptation rate, was on average 124.8 trials. Similar to the adaptation itself, rates varied strongly between subjects (SD = 100.5; range 30 - 535 trials).

Regardless whether subjects had finally fulfilled the adaptation criterion, they systematically followed the tolerance shifts (Fig. 3). All t-values were above 4.78 and all p-values below .0001 (represented by ***). Note that when subjects had reached the tolerance area after a certain amount of trials, they were excluded from the average of the following fixed-trial moments because in that case a new tolerance shift had already been conducted. For this reason, the number of values in the individual cells is decreasing with increasing trial number.

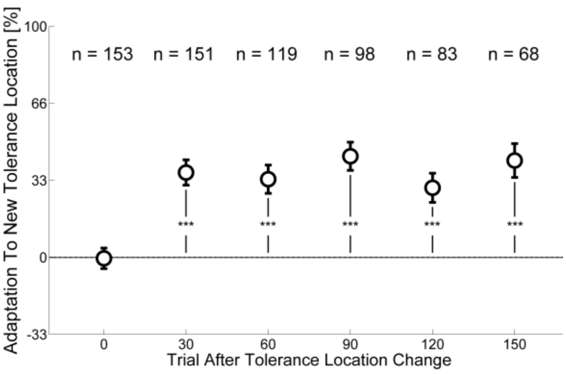

Fig. 3. Percentage of adaptation as a function of trials

4. Discussion

We could show that all participants adapted to changes in task tolerance. Some adapted more often than others and adaptation rate differed also between subjects. In general, however, participants systematically followed the shift of the tolerant area already within the first 30 trials after the shift.

Thus, we can conclude that people are sensitive to error tolerant solutions of a redundant goal-oriented motor task. We will further analyze the cause of the different adaptation rates between subjects. As an explanation, we suggest that people with lower motor noise can detect changes in error tolerance faster than people with higher motor noise. When error tolerance is changing, errors occur with higher frequency. This is more unlikely for people with lower motor noise. In consequence, people with lower motor noise and hence lower result variability would be expected to be more sensitive to certain absolute errors than people with higher motor noise.

We are currently analyzing the connection of motor noise and sensitivity to error tolerance by separating noise from systematic exploration in execution variables with a Kalman filter approach.

References

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