Repetition enhances movement preparation

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It is well established that behavior is shaped not only by current sensory signals but also by our recent experiences and actions. It was shown, for instance, that repetition of movements to a particular location made the subsequent movements to that location less variable, but at the cost of directional bias of reaches to other targets, a process called use-dependent learning (UDL)[1,2]. It remains unclear, however, whether the benefits of repetition simply reflect the influence of prior expectations about where the target may appear, or whether repetition might have a more fundamental effect on facilitating movement preparation. We performed two experiments to more clearly characterize how the history of one's movements affects the ability to prepare future movements. In a first experiment, we had participants repeat a particular movement hundreds of times. This consistent repetition led to a selective reduction in the reaction time to generate that same movement, even in a different context. In a second experiment, we found that this selective enhancement in reaction time was not caused by increased probability of guesses toward the repeated target, but instead is attributable to more rapid preparation of that movement.

In Experiment 1, sixteen right-handed subjects moved a pen across a digitizing tablet, without vision of their hand, to maneuver an on-screen cursor. Participants performed three blocks of 7cm movements. The first block consisted of 50 trials of quick reaches toward the center of an arc-shaped target. This block assessed any default movement direction bias present at baseline. In the second block, subjects were instructed to reach to a circular target as quickly as possible after hearing the fourth tone in a sequence of four tones (spaced 500 ms apart, Fig. 1B). In each trial, one of six potential targets (at 15°, 45°, 75°, 105°, 135° and 165°) appeared synchronously with the fourth tone. This predictable sequence of the auditory tones served to minimize the ambiguity about the time of target presentation, which tends to increase reaction times (RTs). Targets appeared in a pseudorandom order, with each target appearing 24 times. In the third block, subjects were instructed to make 476 repetitions toward a particular location on the arc (directed to 45°; Fig. 1C). To ensure that participants repeated a consistent movement direction, they were provided score-based feedback based on their distance from the desired direction. On a subset of trials (1/6), we introduced probe trials in which a single target was presented and subjects were required to initiate a movement towards it. The structure of these trials was identical to those in the second block (Fig. 1C). We found a reduction of RT for movements made in the repeated (Rep) direction, but not for those made in non-repeated (No-Rep) directions ($p = 0.0056$, Fig. 1D). Additionally, we found a significant directional bias toward the repeated target ($p = 0.034$), indicative of a use-dependent biasing effect (Fig. 1E).

The results of Experiment 1 showed that prior repetition of a movement accelerates how quickly that movement can be initiated in the future. One potential interpretation is that participants anticipated the high likelihood of this movement being required and therefore prepared that movement in advance. Alternatively, participants may have been able to prepare this movement more rapidly than other movements. It is also possible that participants were simply willing to initiate movement more quickly towards the repeated target. We performed a second experiment which allowed us to dissociate between these explanations by reducing available preparation time through a forced reaction time paradigm[3] (Forced RT; Fig. 2A). Ten participants performed five blocks of reaching movements (Fig. 2B). The first block was similar to Block 1 in Exp.1. The second block (30 trials) allowed participants to practice the timing of their initiation (the target was visible from the onset of the first tone). Participants were trained to initiate their movement synchronously with the onset of the fourth tone. In subsequent blocks (2x108), the amount of preparation time (PT) was varied from trial to trial by presenting the target at varying times ($PT \sim U(50{,}250ms)$) prior to the fourth tone. This manipulation allowed us to build a speed-accuracy trade-off by assessing the accuracy of participants' movements as a function of the imposed RT. A subset of twelve trials were "catch" trials in which no target ever appeared but participants were still required to move. These catch trials discouraged participants from simply waiting until the target appeared before initiating a movement, and also enabled us to assess whether participants were preparing any particular movement by default before observing the true target location. The last block included 24 sub-blocks of 30 repetitions toward 0° followed by 7 non-shuffled Forced RT ($n_{ForcedRT} \geq 5$) and catch trials ($n_{catch} \leq 2$). We found that reaching movements to a repeated target became accurately prepared earlier than at baseline. Importantly, this enhancement in movement preparation was not present in the non-repeated targets (Fig. 2C&D) and was not due to participants preparing the repeated target in advance (Fig. 2E).

Our observations illustrate how repetition not only promotes more accurate (less variable) and faster (reduced movement time) movements, but also facilitates more rapid movement planning. We speculate that these phenomena may be distinct consequences of a common underlying use-dependent learning mechanism.

[1] Diedrichsen et al., (2010); [2] Verstynen & Sabes (2011); [3] Haith et al., (2015)

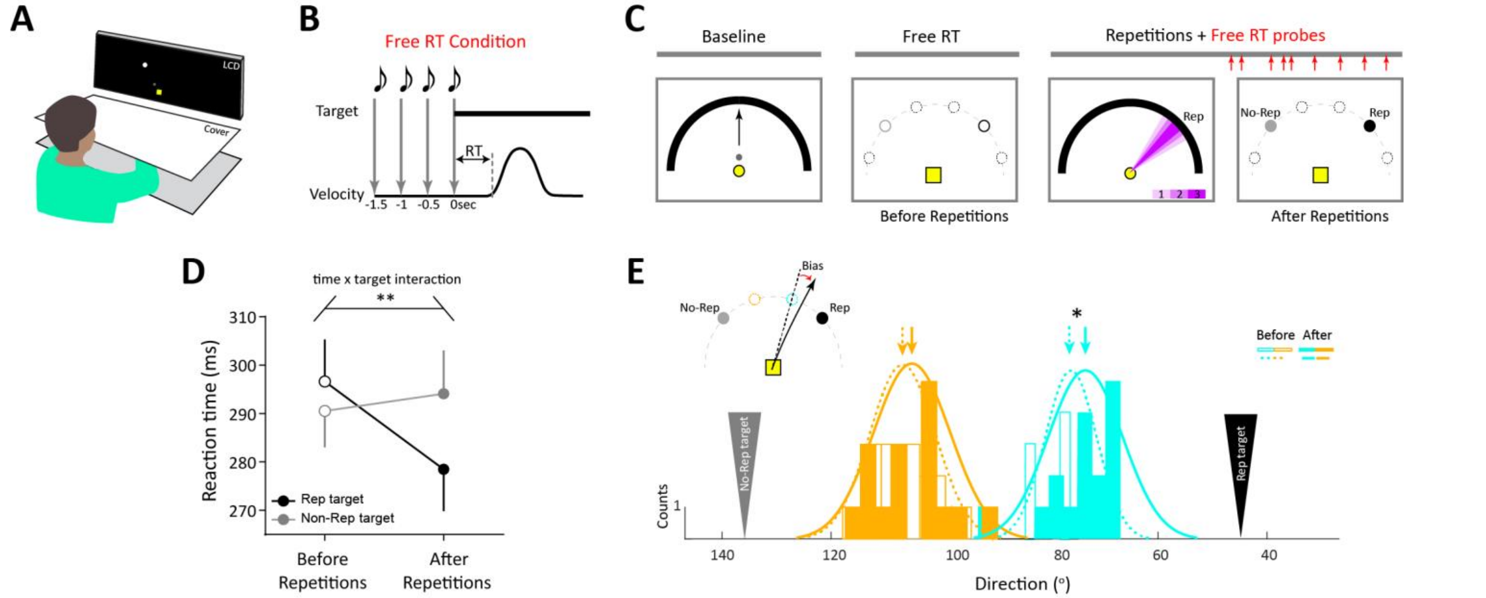

Fig. 1. Repetition reduces Reaction time. Experimental setup. Participants made planar reaching movements to targets presented via LCD display. **B**, Free RT condition. In this condition, a single target appeared at an unknown location at a predictable time (cued by a series of 4 tones), and participants were instructed to move as soon as the target appeared. **C**, Experimental protocol. To ensure that participants repeated a consistent movement direction, they were provided with a score after each movement based on their distance from the desired direction (+3 points for $|distance|<10^{\circ}$, +2 points for $10^{\circ}\leq|distance|<15^{\circ}$, +1 points for $15^{\circ}\leq|distance|<20^{\circ}$, 0 else). **D**, Mean RT across participants before (open circles) and after (filled circles) for the repeated (black) and non-repeated target (grey). Repeated measures ANOVA shows significant $time \times target$ interaction ($F_{1,15} = 9.111, p = 0.0086$). Post-hoc analysis shows that repetition induced a reduction of RT for the repeated (Rep) direction compared to the non-repeated (No-Rep) direction and relative to baseline ($p = 0.0056$). **E**, Top: Example of single movement (black arrow) toward a probe target (75°) shows directional bias toward the repeated target. Bottom: Histogram of movement directions in probe trials across subjects shows small but significant shift ($p = 0.034$) of the mean direction toward the repeated target.

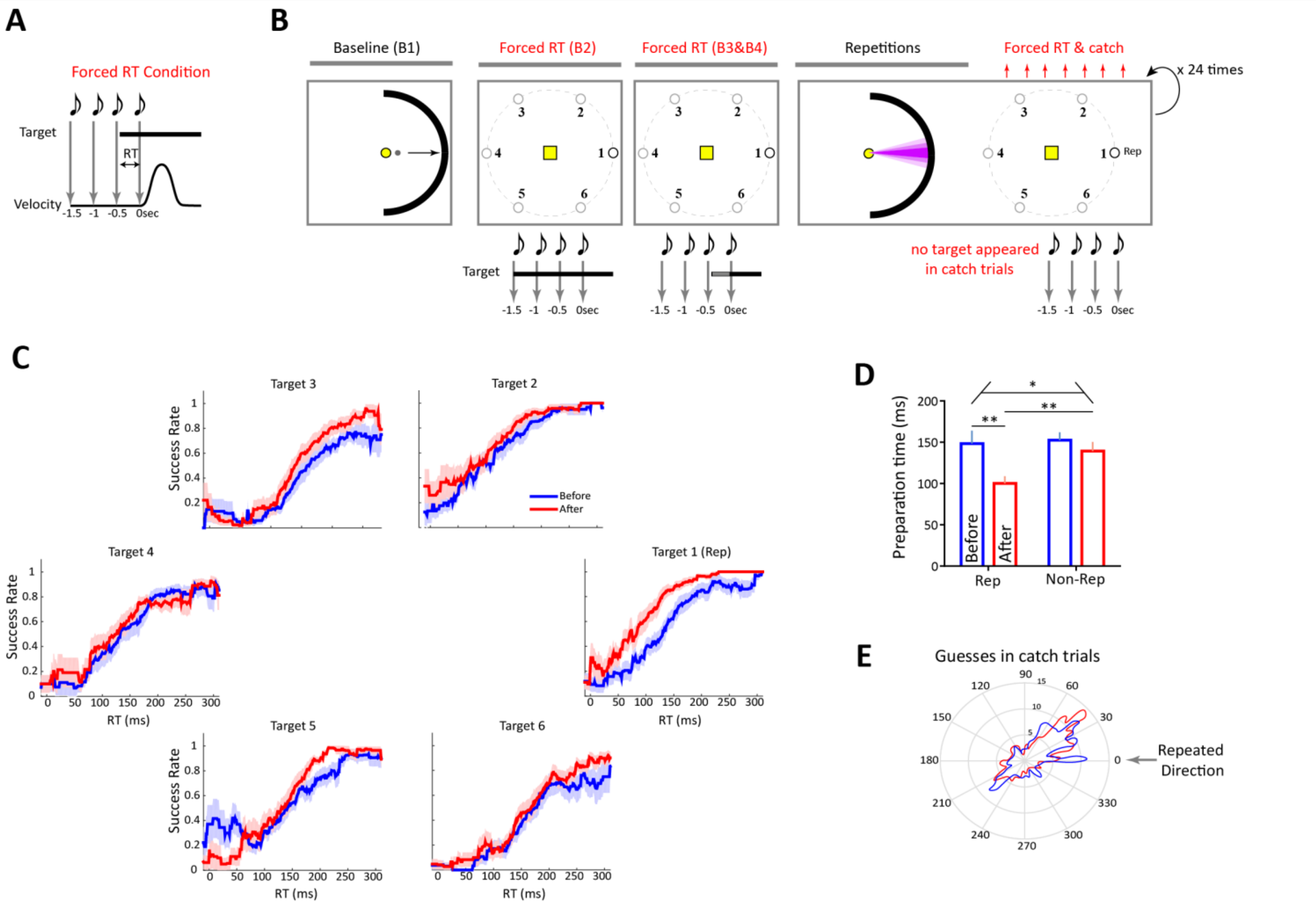

Fig. 2. Repetition accelerates movement preparation. **A,** Forced RT condition. In this condition, participants were instructed to move synchronously with the fourth tone. RT was manipulated by varying the time that the target was presented relative to the time of movement onset. **B**, Experimental protocol. **C**, Blue lines represent speed-accuracy tradeoff (moving average of the probability that a movement is successful for a given RT in the Forced RT condition) prior to the repetitions (B3&4) for each target. Red lines represent the same as C but for movements **after** repetitions. **D**, Mean preparation time (estimated based on parametric fits[3] to data in **C**) across participants before (blue) and after (red) for the repeated and non-repeated targets (averaged across 5 non-repeated targets). Repeated measures ANOVA shows significant $time \times target$ interaction ($F_{1,9} = 6.926, p = 0.0273$). Post-hoc analysis shows specific reduction of RT for the repeated ($p = 0.0013$). **E**, Distribution of the guesses in catch trials for all subjects before (blue) and after (red) repetitions. Data shows no significant change in the guesses directions.