THE MECHANISM OF INTERVAL TIMING: LEARNING AND GENERALIZATION EFFECT OF INACCURATE FEEDBACK

Chihiro Saito and Tadayuki Tayama
Department of Psychology, Hokkaido University, Hokkaido, Japan
chihiros@let.hokudai.ac.jp

Abstract

Interval timing, the ability to perceive intervals ranged from seconds to minutes, is affected by performance feedback. Accurate feedback reduces absolute errors from targeted performance and the variability. Inaccurate feedback adjusts produced time length accordingly. The present study investigated whether performance feedback effect can be generalized across different durations. A three-phrase experiment composed of a time production task with a start-stop procedure was conducted. In the first and second phases, participants produced 10-sec intervals, and then they performed 30-sec intervals in the third phase. Only in the second phase, they were randomly assigned to one of 4 feedback groups (accurate, 80 and 125 %-inaccurate-feedback, and no-feedback). In the second and third phases, reduction of absolute errors and group variability was found among accurate and inaccurate feedback groups. The performance in inaccurate feedback groups was shifted proportionately to the feedback in these phases. Although the effect on the group variability was found, the individual variability was not changed across phases. These results support that performance feedback has generalization effect on interval timing.

Interval timing, the ability to perceive time intervals which could range from seconds to minutes, is a fundamental mechanism for mammals and birds, including human beings. In human daily life, the mechanism guides our decision making. When we wait for something or someone, we know whether the waiting time is long or short without having to look at our watches. To make such a decision, it is necessary to have a mechanism that keeps track of time, and that is interval timing. In laboratory settings, time related behaviors of animals, such as food hunting, have been well studied by a peak-interval procedure based on a fixed-interval procedure. In the fixed-interval procedure, animals' first response after a specific time duration is reinforced by food rewards. The peak-interval procedure is the almost same as the fixed-interval procedure, except that several trials in the peak-interval procedure do not provide reinforcement. In such trials, the probability of generating response is the highest within the duration and the variability is approximately proportional to the length of the duration. This phenomenon is called scalar property (Rakitin, Gibbon, Penney, Malapani, & Meck, 1998). Several researchers apply scalar property theory to human interval timing and study the mechanism (e.g. Meck & Rosseau, 2003), but the mechanism is not fully understood.

To clarify human interval timing mechanism, several factors which have an effect on interval timing have been examined. One of them is performance feedback. Performance feedback is information about an individual response that shows the difference between a targeted performance and its actual performance. It is used to adjust the accuracy of the actual performance by reducing the probability of errors from targeted performance and the variability of actual performances. Such effect of performance feedback is reported in the interval timing research by using different paradigms and durations (Frassen & Vandierendonck, 2002). Brown, Newcomb, and Kahrl (1995), for example, used a time production task to examine the effect of performance feedback. In the time production task which requires participants to produce a specific time period by telling the beginning and the end of intervals, performance were shifted toward the targeted intervals by accurate feedback.

Although some studies indicate that the effect of performance feedback does not continuously exist after it is terminated, other studies have proven the existence of its learning effect (Ryan & Robey, 2002). To prove the existence of the learning effect, Ryan and Fritz (2007) used a time production task containing a start-stop procedure. This method is developed based on the peak-interval method which is used for animal time perception research as mentioned earlier. An original production task requires participants to respond at the beginning and the end of time intervals. The start-stop procedure differs from the original task in response to the end of time intervals. Participants produce bracket of the end time by two responses, holding down and releasing a space bar. When participants think that the current time is equal to the targeted time, they starts holding down a space bar (start response). Then, they release the space bar when they are absolutely sure the targeted time exceeds (stop response). The time length between the beginning of a trial and the start response is called start time, whereas the time length between beginning of a trial and the stop response is called stop time. In addition to the start-stop procedure, Ryan and Fritz (2007) used inaccurate feedback and indicated that inaccurate feedback which provides 80 percent of participants' actual performance lead to overestimation, whereas 125 percent of the inaccurate feedback decreased their response magnitude. In addition, both accurate and inaccurate feedback reduced the variability within each group. Furthermore, the shift of the performance persisted even after inaccurate feedback was withdrawn. They also observed the reduction of the spread time, length between start time and stop time, during and after presenting both inaccurate and accurate feedback. From these results, they concluded that performance feedback for timing tasks induced the learning effect.

As discussed in the previous paragraph, performance feedback adjusts performance even after it is terminated. The adjustment (or learning) of the performance is not restricted to the tasks to which feedback is given, but also generally applied to other similar tasks without performance feedback. The general applicability of the adjustment is called the generalization effect. The generalization effect is supported by a study of millisecond interval range (Bartolo & Mercant, 2009). In their experiment using a time production task, the variability of participants' performance in the untrained time intervals decreased after they practiced the time production task of different time intervals with accurate feedback. It is not known whether there is a generalization effect in interval timing. Thus, in the present study, in addition to replicating Ryan and Fritz's study by using a longer duration (10 sec. and 30 sec.), the generalization effect on different durations is investigated. It is hypothesized that (1) performance of interval timing is adjusted depending on the types of performance feedback when it is given and (2) the adjustment of response is generalized across other different durations without performance feedback.

Method

Participants

Thirty six college students from Hokkaido University participated in this study. The mean age of the participants was 25.75 (*SD* = 5.08). There were 21 male and 15 female participants. They received an informed consent that states their rights as participants in a scientific study.

Time Production Task Containing a Start-Stop Procedure

A number of interval duration ("10 sec." or "30 sec.") located in the center of the circle appeared on a computer screen. Participants clicked a mouse button to start a trial, and then the color of the circle was changed to blue, representing that beginning of the trial. When

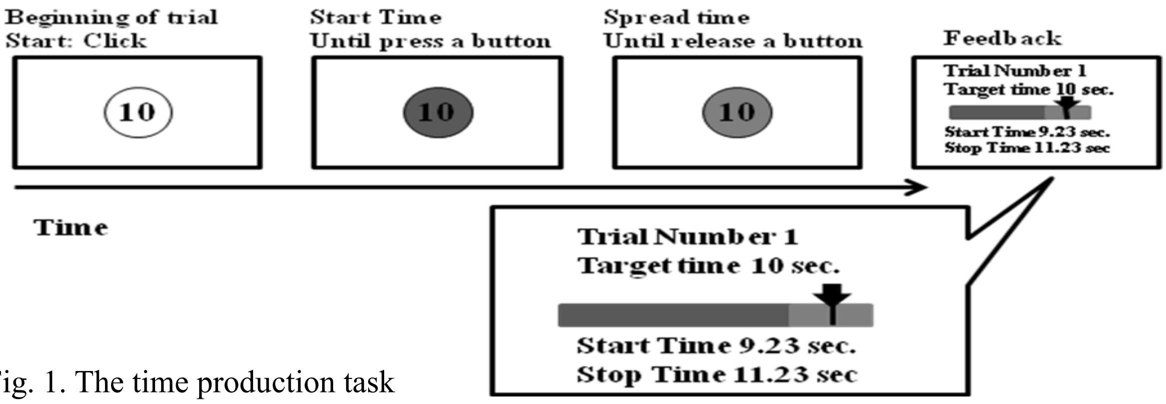

Fig. 1. The time production task

they thought that the required time almost elapsed, they held and kept holding down the mouse button until they were absolutely sure that the duration was passed. During holding down the mouse button, the color of circle was yellow. Time length when the circle is blue indicates start time, while time length from blue circle to yellow circle is stop time. During trials, they were instructed not to count internally.

Performance Feedback

Numerical and graphic performance feedbacks were presented on the screen after each trial in phase 2. Blue rectangular indicates the start time while yellow rectangular represents the time length from the start time to the stop time. The targeted duration was shown by a black vertical line. Numeric values of the performance feedback were located below the graphic feedback. As numerical and graphic accurate feedback, each participant's actual produced time was shown on the computer screen. In the 80 percent (or 125 percent) inaccurate feedback group, participant's produced time was multiplied by 0.8 (or 1.25) and the calculated value was appeared on the screen. Participants in the 80-percent-inaccurate-feedback group received shorter feedback than their actual produced time while participants in the 125-percent-inaccurate-feedback group got longer one. In the no-feedback group, participants were not given any performance feedback. All groups were not given performance feedback in the first phase and the final phase.

Procedure

Participants were seated facing a 17 inch computer monitor inside a soundproof booth. They could start a trial by clicking the mouse button whenever they were ready. In the first phase of the experiment, all participants produced 10-sec intervals without performance feedback. Second, they produced 10-sec. intervals but were randomly assigned to one of 4 feedback groups (accurate, 80-percent, 125-percent and no-feedback). In the third phase, all participants performed 30-sec intervals. In all phases, participants performed 15 trials. After receiving an instruction about how the task is carried out, they practiced the time production task of 6-sec intervals until they fully understood the task.

Statistical Analysis

Two produced times, start and stop times, were obtained from each trial. Middle time and spread time were calculated from these two variables (middle time = (start time + stop time)/ 2, spread time = stop time – start time). Middle time indicates the point of subjective equality for targeted time while spread time is assumed as trial to each participant's trial variability, which is called individual variability. An absolute error was non-directional difference between targeted time and middle time (absolute error = |targeted time – middle time|). Group variability was calculated by the standard deviation between participants within each group divided by mean produced time (group variability = standard deviation/ mean produced time).

Results

The Feedback Effect on Absolute Errors

A two-way ANOVA with phase (1-3) and group (accurate, 80- and 125-percent-inaccurate-feedback, and no-feedback) was conducted to determine an effect of performance feedback on absolute errors. There were the significant main effects of both group and phase (group effect: F (3, 93) = 6.56, $p < .05$, $\eta^2 = .10$, phase effect: F (2, 93) = 29.60, $p < .05$, $\eta^2 = .31$). In addition, the group × phase interaction effect was significant, F (6, 93) = 3.08, $p < .05$, $\eta^2 = .10$ (see Figure 2). These results indicated that the absolute errors were reduced during the presence of performance feedback, regardless of whether it was accurate or not. In addition, the effect persisted after terminating performance feedback in other time duration, which indicates the generalization effect of performance feedback.

The Feedback Effect on Middle Time

The two-way ANOVA was also conducted on the ratio of middle time to task duration (10-sec and 30- sec intervals). The significant main effect of group as well as the significant interaction effect (group × phase) were found (group effect: F (3, 93) = 18.57, $p < .05$, $\eta^2 = .33$, group × phase interaction effect: F (6, 93) = 3.21, $p < .05$, $\eta^2 = .11$). The ratio of middle time significantly differed among groups across phases.

In order to examine the shift of response magnitude, a one-way ANOVA was conducted on middle time in performance feedback groups except the no-feedback group in phase 3. There was a significant group effect (F (2, 23) = 3.90, $p < .05$, $\eta^2 = .25$). The *post-hoc* analysis revealed that middle time in 80% performance feedback group was significantly longer than middle time in 125 % performance feedback group in phase 3, indicating the generalization effect of inaccurate performance feedback (see Figure 3).

The Feedback Effect on Group and Individual Variability

Figure 4 shows group variability in 3 phases. Significant main effects of group and phase were observed (group effect: F (3, 168) = 25.02, $p < .05$, $\eta^2 = .20$, phase effect: F (2, 168) = 39.97, $p < .05$, $\eta^2 = .21$). In addition, there was a group × phase interaction effect (F (6, 168) = 8.22, $p < .05$, $\eta^2 = .14$). These results suggested that the performance feedback reduced group variability in phase 2, and the reduction was persisted in phase 3, thus supporting the generalization effect. In contrast, individual variability, as indicated by spread time, was not changed across phases (group effect: F (3, 31) = 1.96, $p = .14$, phase effect: F (2, 62) = 1.64, $p = .21$, group × phase: F (6, 62) = 0.84, $p = .48$). These results indicated that the performance feedback does not alter individual variability but shift each participant's responses around a targeted time.

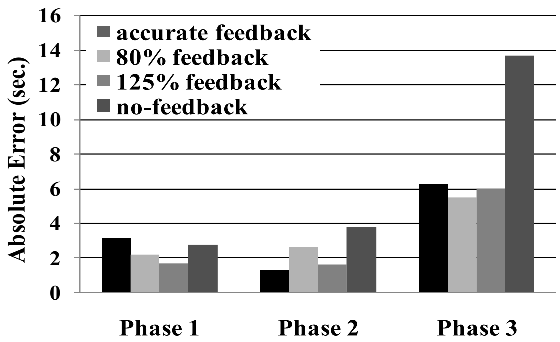

Fig.2. Feedback effect on absolute errors

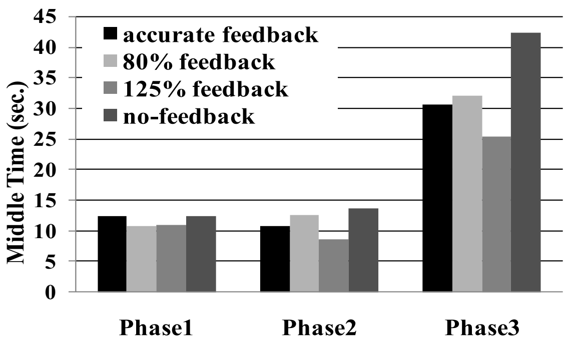

Fig. 3. Feedback effect on middle time

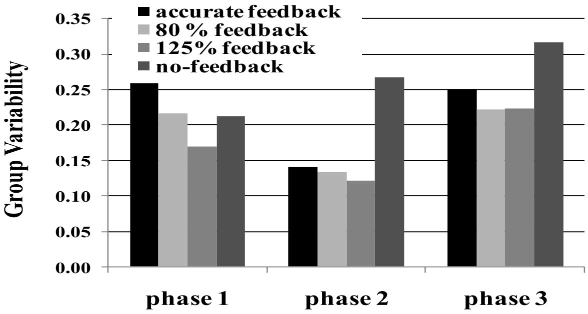

Fig. 4. Feedback effect on group variability

Discussion

The purpose of the present study was to examine the effect of performance feedback on duration and to examine the generalization effect on different duration. In the first point, the result in phase 2 showed reduction of absolute errors and group variability, and a shift in middle times according to performance feedback. Regarding the second point, the same result was also found in phase 3, thus supporting the generalization effect.

In phase 2, the performance effect could be seen from minimizing absolute errors and group variability and shifting middle times proportionally to performance feedback. However, there was no performance feedback effect on individual variability. The absence of the performance feedback effect on individual variability was inconsistent with Ryan and Fritz' finding (2007) that performance feedback, regardless of whether it is accurate or inaccurate, reduces individual variability. Although individual variability was unchanged across 3 phases in the present study, group variability was significantly smaller in phase 2 and 3 than in phase 1. Similar results were found in Ryan and Robey (2002) though they used coefficient of variances (CVs) as individual variability, instead of spread time.

The generalization effect was observed in phase 3 by analyzing the absolute errors, middle times, and group variability. Same as phase 2, the absolute errors and the group variability were smaller in both of the accurate and inaccurate feedback groups relative to the no-feedback group. In addition, shifts of response magnitude were observed among two of the inaccurate feedback groups. Participants who received 80 percent inaccurate feedback produced longer than those receiving 125 percent inaccurate feedback. Ryan and Fritz (2007) also reports that the tendency of overproduction in 80 percent inaccurate feedback group and underproduction tendency in 125 percent inaccurate feedback group persists even after the termination of performance feedback though they used the same durations. The present study showed that the adjustment of overproduction and underproduction was generalized across other durations even though performance feedback was not provided.

There are several ways to explain how performance feedback affects the mechanism of human interval timing. The models of human interval timing, such as the temporal information processing model (TIP), could explain the phenomenon. Gibbon and Church developed the TIP model to clarify interval timing (see Figure 5). The TIP model posits three information processes: an internal clock, memory, and decision. The internal clock consists of a pacemaker, switch, and accumulator. In memory process, pulses which the pacemaker regularly emits through the switch are stored in the accumulator. As to decision process, the numbers of pulses in the accumulator (a) is compared with the numbers of pulses in memory storage, called the reference memory (m). When the value of ($|a-m|/m$) is smaller than a threshold, a response is made (Meck & Rosseau, 2003). Although the TIP model is still debated, especially about the existence of the pacemaker (see Staddon & Higa, 1999), these researchers also agree that memory and decision process are involved in human interval

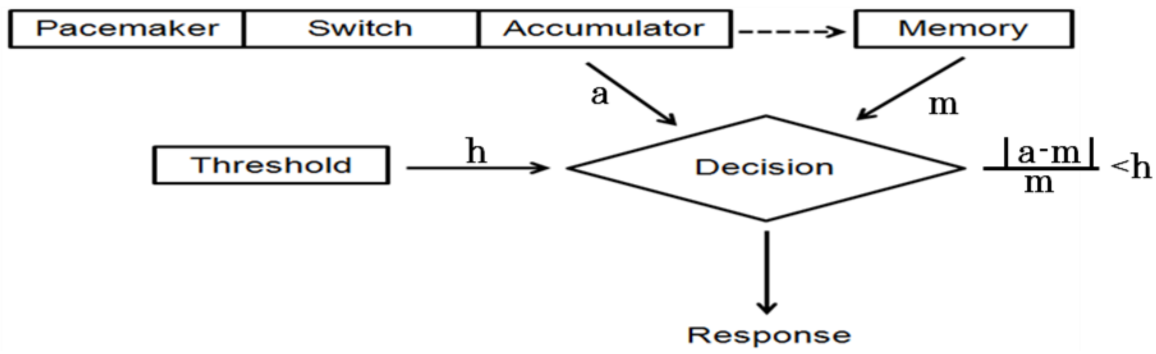

Fig. 5. The temporal information processing model (Meck & Rosseau, 2003)

timing. Thus, performance feedback might affect these processes. The threshold might decrease and be stabilized through trials with performance feedback, thus increasing the accuracy of interval timing. However, that is inconsistent with the results of the present study because individual variability in phase 2 and 3 did not change. Performance feedback might adjust temporal information stored in the reference memory so that provided time was adjusted according to performance feedback. This hypothesis explains the performance effect in phase 2. However, the generalization effect in phase 3 cannot be interpreted by the hypothesis because it implies more than the adjustment of pulses for specific time durations, 10 sec. in the present study. If the generalization effect occurs in the reference memory, temporal information of 10 sec. in the reference memory can be used for estimating other duration (e.g. 30 sec.). Actually, in cognitive level, several participants in feedback groups of the present study told that they refer their performance in 10 sec. trials for 30 sec trials. Such process might occur in the reference memory. In the future study, it is important to investigate whether the reference memory is actually affected by performance feedback, especially inaccurate performance feedback, and how it is affected by performance feedback.

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