Suboptimal Strategy in Performing Coincident Timing Task under Risk

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Abstract: The best performance often goes hand in hand with risk in many sports. Players are engaged in considering how much risk they take. Some studies reported that movement strategy is modified by risk-sensitivity. Here, we investigated how people responded under risk to which high gain got closer to zero gain. We designed new coincident timing task in which participants were rewarded with the highest score if they pressed a button just at a target time (2300 ms) but they did not get a score if they responded after the target time. In this task, the participants should take the variability of their response into account and take a risk-neutral strategy to get the highest total score that was theoretically calculated. However, we found out that the participants took a risky response compared with an estimated optimal response. This risk-seeking strategy degraded a task performance. These results suggest that not only small variability in response but also taking an optimal strategy is important to get higher performance under risk.

1 INTRODUCTION

The best performance often goes hand in hand with risk in many sports. For example, probability of scoring a point would be highest if a tennis player succeed to hit a ball on line, but he or she loses a point if the ball is out of the line by 1 mm. In such situations, beginners should not aim for edge of the line because they cannot control the ball accurately enough. To take an appropriate strategy, players should take risk as well as variability in their motor output into account. Thus, players are engaged in making a decision about where in a court they should aim under risk.

Classical economic lotteries task have been used to study about decision-making under risk. An example would be a choice between (0.5, \$100; 0.5, \$0) and (1, \$50); a 50%:50% chance at \$100 or nothing versus a certain (100%) gain of \$50. If people are asked to choose either of two lotteries, most people would averse the 0 outcome and choose the second sure lottery. The expected utility theory (von Neumann and Morgenstern, 1944) claimed that people make a decision to maximize expected utility, predicting that most people prefer the second lottery even though on average the two lotteries have the same mean payoff.

However, in the field of behavioural economics, deviation from the expected utility theory has been repeatedly demonstrated, which indicated that human decision-making under risk is not always rational (Kahneman and Tversky, 1979). Referring this concept in behavioural economics, recent research has been focusing on human selection behaviour in motor task under risk.

For example, Wu et al., (2009) showed that participants tended to be risk-averse in deciding between classical economic lotteries, but they tended to be risk-seeking in deciding between same lotteries presented in stochastically equivalent motor form. O'Brien and Ahmed (2013) showed that risk-sensitive behaviour transferred across different movements. They found that participants showed same direction of risk-sensitivity between two movements, that is, they tended to be risk-seeking in performing both arm reaching movement and whole-body movement. It has been suggested that participants underestimated their own motor variability, and then tended to be risk-seeking. (Wu et al., 2009); (O'Brien and Ahmed, 2013); (Nagengast et al., 2011). In contrast, Nagengast et al.,

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(2010) indicated that participants are more risk-averse in the face of increased uncertainty induced by experimentally added large Brownian noise, but they are risk-neutral when an added Brownian noise is small. This result indicated that the direction of risk-sensitivity could be changed according to situation. These studies suggested that movement decision-making is not always optimal under risk, which is inconsistent with previous works claiming models of optimal movement planning (Trommesäusher et al., 2003a; 2003b; 2005).

In this study, we developed new coincident timing task in which high gain and risk goes hand in hand. The first purpose of this study is to investigate relationship between risk-sensitivity and a task performance. The second purpose is to investigate inter-individual differences based on trial-by-trial analysis. First, we compared a observed response in the task with a theoretically calculated risk-neutral response. We demonstrated that the participant's behaviour was not optimal under risk and then discussed the relationship between risk-sensitivity as well as response variability and a task performance. Second, we demonstrated that there is an inter-individual difference in responses following to miss trials.

2 METHODS

2.1 Experimental Task

Twelve right-handed, healthy adults (6 male, 6 female; mean age 28.8 ± 8.7 yr) participated in the experiment. All participants were unaware of the purpose of the experiment. This study was approved by the Ethics Committee of the Graduate School of Arts and Sciences, the University of Tokyo.

We showed a time sequence of the experiment in Figure 1A. After presenting the warning tone, an imperative stimulus (visual cue) was presented on the screen. Foreperiod interval between the warning tone and imperative stimulus was randomly varied from 800 ms to 1200 ms in steps of 100 ms. The participants were required to press the bottom at 2300 ms after visual cue. This target interval was fixed. A score of a trial was described as a function of response error (time difference between an actual response interval and the target interval). We termed it "score function".

There were two conditions tested with different score functions. One was No Risk condition that had a symmetric score function (Figure 1B). When the participants responded within the target interval, they receive a score for a trial as a positive linear function of response interval. In addition, when the participants responded after the target time, they received a score as a negative linear function of response interval. The maximum possible score of 100 point was associated with responding to the target time perfectly.

The other was Risk condition that had an asymmetric score function (Figure 1C). In Risk condition, the highest gain (100 point) got closer to zero. Within the target interval, the same score function as that in No Risk condition was applied. However, no score was given if the participants responded after the target time. We termed it "miss trial" in which they were cautioned by an unpleasant alarm and flashed red lamp on the screen.

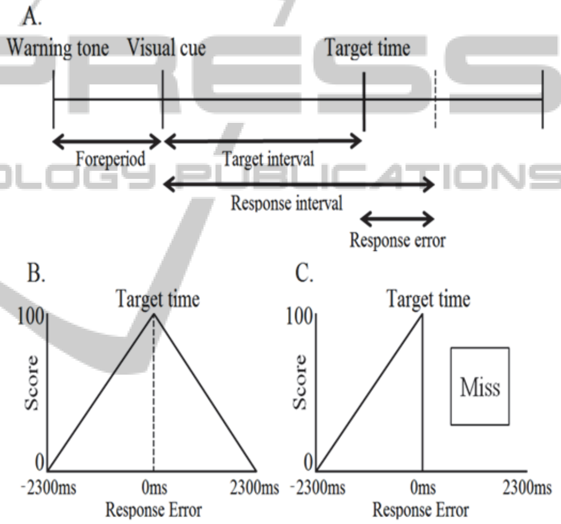

Figure 1: Experimental task. (A) Illustration of time sequence. First waning tone was ringed. After randomized foreperiod duration, visual cue was presented. The participants were required to press the bottom at the target time (2300ms) after the visual cue. A response error (time difference between a response interval and the target interval) was given to the participants in every trial. (B) Symmetric score function in No Risk condition. A score for a trial was given when the participants responded over the target time. (C) Asymmetric score function in Risk condition. A score for a trial was not given (i.e., 0 point), if they responded after the target time. This "miss trial" was cautioned.

We provided the participants with response error, score for a trial and accumulated total score in each trial. We also gave verbal instructions describing the score function before each condition. The participants performed 10 trials training, 100 trials in No Risk condition and lastly 100 trials in Risk condition. The participants were instructed to maximize total score in each condition.

2.2 Definition of Risk-sensitivity

We applied the score function of Risk condition to the obtained distribution of response time in No Risk condition (Figure 2Upper panel). We then calculated the optimal mean response time by simply shifting the distribution until the highest total score was obtained (Figure 2Middle panel). The estimated optimal mean response time was always smaller than the target time given each participant's own variance in response time. This can be regarded as a theoretical risk-neutral optimal response. Finally, we defined risk-sensitivity as the difference between the observed mean response time and the optimal mean response time (Figure 2Lower panel).

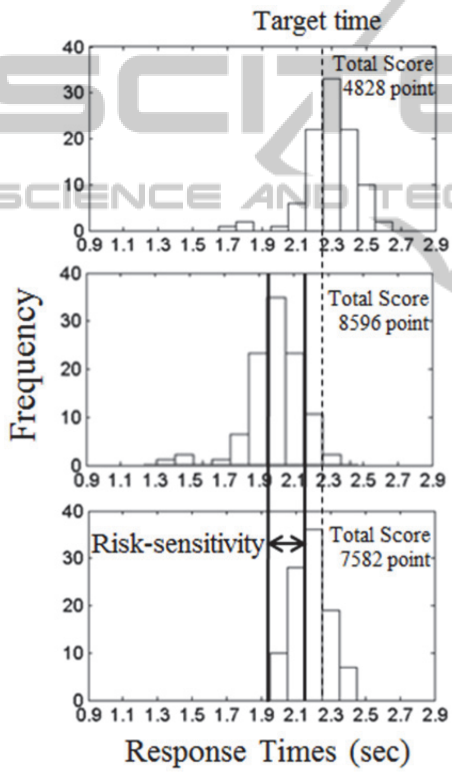

Figure 2: Procedure of estimating risk-sensitivity. (Upper panel) We applied the score function of Risk condition to the obtained distribution of response time in No Risk condition. (Middle panel) We shifted the distribution until the highest total score was obtained. Left solid line means the estimated optimal mean response time. (Lower panel) We showed the distribution of response time in Risk condition. Right solid line means the observed mean response time. Risk-sensitivity was defined as the difference between the observed and the optimal responses.

Positive risk-sensitivity value indicates that the participants pressed the button later than the optimal timing (risk-seeking response), and negative risk-sensitivity value indicates that the participants pressed the button sooner than the optimal timing (risk-averse response).

2.3 Inter-individual Differences

In addition to the risk-sensitivity based on all the trials, it would be interesting to see inter-individual differences based on trial-by-trial analysis. We focused on presages of miss trials and recovery from miss trials in Risk condition. Trial-by-trial analysis would explain inter-individual difference in performing the task. We compared histograms of response time in trials which are previous to miss trials and that in trials which are preceded by success trials. We also compared histograms of response time from the trials following to miss and success. In this paper, examples of two participants are discussed.

3 RESULTS

All the participants took an inappropriate risk for their own variance in response time. Observed response time and estimated optimal response time are plotted against standard deviation (SD) of response time in No Risk condition for all twelve participants (Figure 3). The observed response time was higher than the estimated optimal response time for all the participants, and thus positive risk-sensitivity was observed.

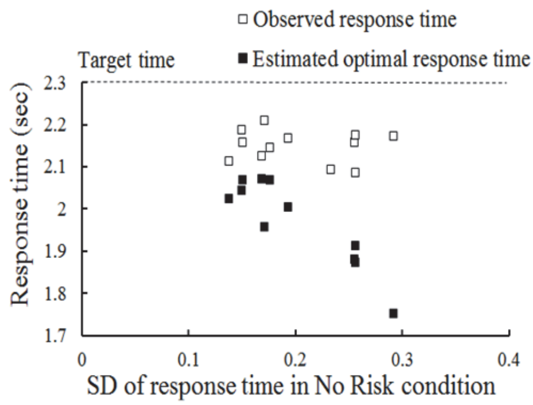

Figure 3: Risk seeking strategy taken by the participants. Theoretically, optimal response time (filled squares) must be smaller than the target time as a function of one's variability in response time (x axis shows SD of response time in No Risk condition as an index of the variability). However, observed response time (open squares) was higher than the estimated response time for all the participants, which indicates that they took higher risk for their own variability.

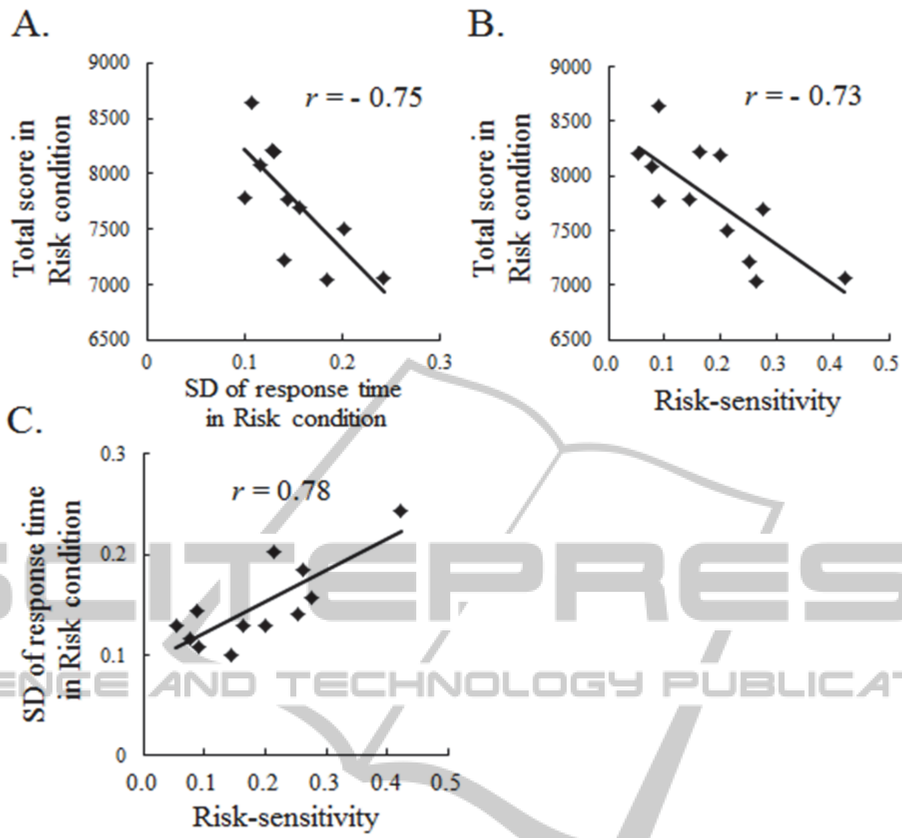

Figure 4: The results of correlation analysis. Negative correlation between SD of response time in Risk condition and total score in Risk condition (A), negative correlation between risk-sensitivity and total score in Risk condition (B), positive correlation between risk-sensitivity and SD of response time in Risk condition (C).

We then analyzed the effect of the variance in response time and the risk-sensitivity on the total score by calculating Pearson's correlation coefficient between them. The total score was affected not only by response variance but also by suboptimal risky strategy. The risk-sensitivity, as well as SD of response time, had a strong negative correlation between the total score (Figures 4 A&B; r = -0.75, p < .01; r = -0.73, p < .01, respectively). Moreover, there was strong positive correlation between SD of response time and risk-sensitivity (Fig. 4C; r = 0.78, p < .01). The result suggests that the larger response variance is (i.e., less accurate in response time), the higher value of positive risk-sensitivity the participants had. The participants responded closer to the target time even though they had large response variance, thus, the value of risk-sensitivity was high.

We also investigated inter-individual differences based on trial-by-trial analysis. Examples of two participants were shown in Figure 5. The histogram of response time on the whole trials in Risk condition are shown in Figures 5A and 5B. The response times are normally distributed in both histograms. The histograms from the trials before miss (filled bars) and success (open bars) are shown in Figures 5C and 5D. The shape of the histograms from the trials before miss was similar to that from the trials before success. It was not also different between participants. This would suggest that miss responses randomly occurred: miss responses were independent on the response in the previous trials. However, the histogram of response time from the trials following to miss (filled bars) had obviously different shape with that from the trials following to success (open bars) in participant 2 (Figure 5F). Earlier responses to the target time were shown after miss trials more than after success trials. This would indicate that participant 2 made a large compensation after miss trials. He might strongly avoid consecutive miss. On the contrary, such tendency was not shown in participant 1 (Figure 5E). In Figure 5E, some responses after miss trials were plotted over the target time in contrast to Figure 5F, which indicated that consecutive misses were shown in participant 1.

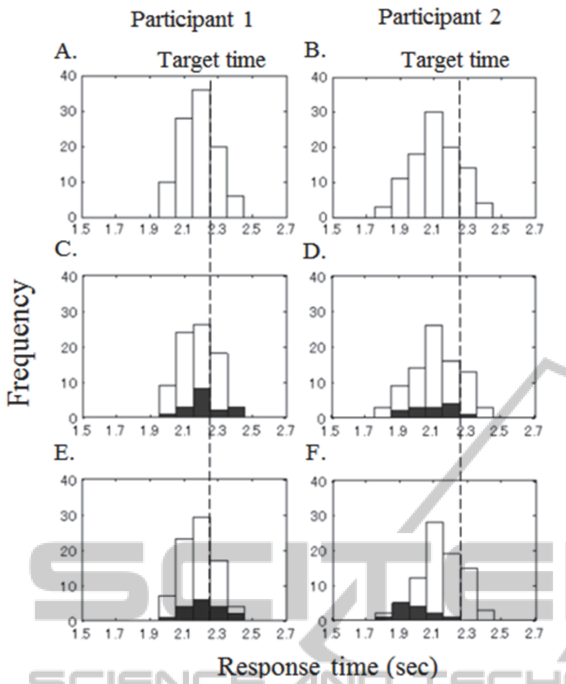

Figure 5: Inter-individual differences in trial by trial compensation. Examples of two participants are shown. (A, B) Histograms of response time on the whole trials in Risk condition. Both histograms are normally distributed. (C, D) Histograms of response time from the trials before miss (filled bars) and success (open bars). Histograms have a similar shape between them and between the participants. (E, F) Histogram of response time from the trials following to miss (filled bars) and success (open bars). In participants 2, earlier responses to the target time are shown after miss trials more than after success trials. In participants 1, consecutive misses were shown.

4 DISCUSSION

This is the first study to assess the relationship between risk-sensitivity and task performance. We showed that the participants tended to be risk-seeking under a risk situation where high gain and zero gain are joining to each other. This risk-seeking strategy, as well as response variability, had a significant effect on degrading the task performance.

In Risk condition, the observed response time was closer to the target time than the theoretically calculated optimal response time, that is, all the participants tended to be risk-seeking. Cumulative prospect theory (Tversky and Kahneman, 1992) would explain that this tendency might be due to underestimation of their own response variance (Wu et al., 2009); (O'Brien and Ahmed, 2013); (Nagengast, et al 2011). The participants might believe themselves to have smaller response variability than they actually have, which would likely influence them to respond closer to the target time.

The asymmetric score function was applied in Risk condition. Wu et al., (2006) found that participants performed suboptimally when pointing in the asymmetric expected gain landscape. On the other hand, Trommershäuser et al., (2003a; 2003b) showed risk-neutral and optimal movement planning in the symmetric expected gain landscape. Our participants might not be able to perform a theoretically optimal strategy under the asymmetric score function. This was confirmed by calculating the difference between the observed total score and the theoretically calculated total score. From the typical example in Figure 2, this participant could improve 924 points that was calculated by subtracting the observed total score (i.e., 7582 points) from the optimal total score (i.e., 8596 points).

Risk-seeking behaviours are sometimes observed in real sports fields. For example, professional NBA basketball players attempt consecutive three point shots after they successfully scored three points even though the probability of taking points is decreased (Neiman and Lowenstein, 2011). They may believe they will succeed again. Therefore, suboptimal decision-making would have the effect on degrading a performance of beginners as well as experts in a variety of sports.

We also investigated inter-individual differences in responses following miss trials. In participants 2 in Figure 5F, earlier responses to the target time were shown after miss trials more often than after success trials. This indicated that he made a large compensation with a different strategy. This tendency was not shown in participants 1 (Figure 5E). The histogram of the response time from the trials following to miss had similar shape to that from the trials following to success. In contrast to Figure 5F, some responses were plotted over the target time, which indicated that consecutive misses were shown. For this participant, the total score will surely increase by responding within the target time with surely strategy to avoid consecutive miss. The behaviour following to miss would be an important factor to explain the individual response pattern. Thus, we need to investigate how these differences are produced in future studies.

As implication for real sports field, our results suggest that it is important to evaluate and improve optimal strategy depending on each player's skill level. Coaches and trainers often instruct how to move a body focusing on a form itself. In addition to such instruction, instruction based on the improvement of risk-handling strategy leads to organize better training.

5 CONCLUSIONS

Under risk situation where high gain and zero gain are joining to each other, optimal strategy can be calculated depending on the player's variability. However, the participants tended to take higher risk, possibly because of their underestimation of variability. This suboptimal decision-making resulted in reducing the total score. Therefore, improving the risk-handling strategy can contribute to improve task performance both for beginners and experts in a variety of sports.

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