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A relativity account of the "return trip effect": Why does the return trip feel shorter?

Ryosuke Ozawa

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Shigeru Kitazawa

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Abstract

[Purpose] When we move from a station to a destination, and then return to the station, the return trip often feels shorter than the outward trip. This illusory experience of time, termed the "return trip effect," has been explained to arise from the heavier importance of time in the outward trip compared with the time in the return trip, or from greater novelty of landscapes during the outward trip. However, such explanations lack concrete evidence owing to the difficulty of conducting laboratory experiments. In this study, through a series of experiments, I explored why the return trip feels shorter. In Experiment 1, I examined whether it is possible to detect the "return trip effect" in the laboratory and whether the illusion results from "heavier" importance of time, or faster clock speed, in the outward trip. In Experiment 2, I examined whether the decrease of novelty of landscape is essential. In Experiment 3, I tested whether the trip must be a "return" in inducing the illusion. In Experiment 4, I addressed an additional question of whether the time perception is related with sense of direction. Based on the results of these experiments, I finally propose a new hypothesis that explains why the return trip feels shorter.

[Methods/Results] <u>Experiment 1</u>. A group of participants were asked to view a movie of an outward trip and then another of a return trip, each of which lasted approximately 30 min and was taken from the viewpoint of a pedestrian. Another group of participants

(control group) viewed two independent trip movies. Both groups of participants were also asked to verbally report every time they felt that it had taken 3 min while viewing the videos. The test group participants postdictively reported that the first trip was longer whereas the control group did not. Interestingly, the change of the subjective length of 3 min did not correlate with the magnitude of the return trip effect. The results show that the return trip effect can be induced in the laboratory and that the effect is not due to a change in the clock cycle. Experiment 2. A group of participants viewed a movie of an outward trip and another of a return trip through a different route. The participants still showed the return trip effect as long as they were aware that the second movie was that of a return trip. The results demonstrate that the change in the novelty of the landscape during the two moves is not a critical factor for inducing the return trip effect. Experiment 3. A group of participants viewed a movie of an outward trip twice. The second trip was felt to be shorter even when the participants viewed the same movie twice. The result clearly shows that the "return trip effect" occurs even when the second trip is not an actual "return." Experiment 4. I also found in Experiment 2 that variance of the return trip effect can be explained by variance of sense of direction. Participants conducted a time production task of 180 s while viewing visual or listening to auditory stimuli. Their sense of direction was evaluated by using a standardized questionnaire. I found that those who have a poor sense of direction overestimated time intervals.

[Conclusion] In Experiment 1, I showed that the effect is not due to a change in the clock cycle. I further showed that the novelty of the landscape is not a critical factor (Experiment 2) and that the second trip is not required to be an actual "return" as long as the two trips were identical (Experiment 3). Based on these results, I propose that the effect is not due to an absolute change in the clock cycle but due to a change of a reference duration that is prepared before each trip, against which the passage of time is evaluated. Assuming this, the return trip effect is caused by an underestimation of the reference duration for the first trip, which is then replaced with the actual longer duration of the first trip. I conclude that this elongation of the reference duration would make the second trip feel relatively shorter than the first trip.

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Chapter 1: General Introduction

1.1 What is the "return trip effect?"

In physics the observer's reference frame is crucial to the observer's perception of the flow of time (Einstein, 1938). This relative time became the de-facto view (Buhusi & Meck, 2009), but how is our mental time? Albert Einstein stated: "When a man sits with a pretty girl for an hour, it seems like a minute. But let him sit on a hot stove for a minute - and it's longer than any hour. That's relativity." (Einstein, 1938). The idea of Einstein was that the state of mind of the observer may be an additional factor in perception of time. As described by him, time flies in general, when we have fun (Sackett, Meyvis, Nelson, Converse, & Sackett, 2010). For example, playing video games causes subjective time loss (Wood, Griffiths, & Parke, 2007). By contrast, time drags when we experience pain. Exposure to fearful facial expressions slows down time (Bar-Haim, Kerem, Lamy, & Zakay, 2010).

We are able to raise another example of temporal illusion that would is unrelated to fun or pain: in our daily life, we often feel that the return trip is shorter than the outward trip. This illusory experience is termed the "**return trip effect**" (van de Ven, van Rijswijk, & Roy, 2011). Although people often experience this effect in their daily life, there are surprisingly few studies that have directly addressed it (Seno, Ito, & Sunaga, 2011; van de Ven et al., 2011). Instead, the effect has been explained by some speculation. For example, Zakay (2012) suggested that the return trip effect results from the heavier importance of time during the outward trip than during the return trip. When time is important, we pay attention to time. It is well known that the more attention we pay to time, the longer time seems to take (Bar-Haim et al., 2010; Bisson, Tobin, & Grondin, 2012; S. Tobin & Grondin, 2012; Zakay, 2012). Thus, the return trip feels shorter because we pay less attention to time due to the relative lack of importance of the return trip. Another explanation for the effect is the stronger novelty of landscapes during the outward trip. A novel stimulus increases our arousal level, which eventually accelerates a pacemaker in our internal clock (Bar-Haim et al., 2010; Droit-Volet & Meck, 2007). The outward trip may thus be processed with an accelerated clock, whereas the return trip may be processed with a decelerated clock, leading to the return trip effect.

The critical problem of these explanations of the “return trip effect” is that they are based on findings of time perception of relatively short intervals in the ranges from milliseconds to seconds (Grondin, 2010). This is much shorter than the time it takes for our actual daily trip, say tens of minutes, for which we feel the illusion. Patients with pathology in the medial temporal lobes show accurate time estimation when the target interval is below 20 sec, whereas they show strong underestimation when the target interval is above 20 sec (MacDonald, 2014; Mimura, Kinsbourne, & O'Connor, 2000; Richards, 1973; Williams, Medwedeff, & Haban, 1989). This fact clearly shows that the timing mechanism for the range of minutes differs to that for the range of seconds. Thus, it is not clear whether the heavier importance of time really changes time estimations or whether the novelty of the landscape really accelerates the internal clock speed when evaluating longer intervals. These hypotheses must be tested by using much longer intervals that induce the return trip effect. In this study, I aimed at providing a solid explanation supported by hard evidence to the well-experienced but little-explored temporal illusion of the “return trip effect.”

1.2 What is needed to understand the return trip effect?

Considering the intervals required for moves in our daily life, we should first investigate the return trip effect using much longer intervals of tens of minutes. We may raise van de Ven et al. (2011) as the only one study that challenged the return trip effect using an interval as long as 7 minutes. However, they failed to elucidate whether the return trip effect is caused by the return trip or just by adaptation to the length of trip duration. So, strictly speaking, there are no preceding studies that have tested whether the illusion takes place in the laboratory. I therefore address, in the first place, the question of whether the return trip effect can be induced in the laboratory in the time range of tens of minutes.

Another problem of previous studies is the method used for measuring the return trip effect. In most previous studies participants were asked to evaluate the absolute length of each trip, such as 2 min or 4.5 min. A recent study (Wearden, 2008) proposed asking about another aspect of time, which he termed the "passage of time." Participants were asked to report whether time passed quickly or slowly or if time felt short or long. Do passage of time judgments differ from absolute duration judgments? By intuition, when you feel that time flies (the passage of time), your estimation of the time interval would be shorter than when you feel time drags. In Wearden (2008), participants watched a film. One group was just told to watch the film while the other group counted the number of speeches given by a character. All participants were asked to report on the passage of time and on the absolute time length only after task completion. The two groups showed different judgments on the passage of time. The group of participants who were just told to watch the film evaluated that time had passed more quickly than the other group of participants. By contrast, the report of absolute time length was almost identical in both groups. These results suggest that passage of time judgments, which seem more closely related to the return trip effect, can differ from estimations of the absolute time intervals assumed to rest on the internal clock.

After establishing the methodology to investigate the return trip effect, some possible explanations should be explored. As mentioned above, the heavier importance of the outward trip or the stronger novelty during the outward trip is considered as a candidate (Zakay, 2012). Are there any other explanations? I can raise other two characteristics of the return trip. First, in many cases the lengths of duration of the outward and return trip are almost the same. Adaptation to the same length of duration may cause the return trip effect. Previous studies suggest that adaptation to duration occurs in our brain (Hayashi et al., 2015; Heron et al., 2012), as is often the case with our neural circuits such as the visual system (Martinez-Conde, Macknik, & Hubel, 2004). Although these studies used very short intervals in millisecond range, if the adaptation to duration occurs in minute to hour range, all the second trip would feel shorter than the first trip irrespective of the content of trips. The second characteristics of the return trip is the order of landscapes. When compared with the outward trip, landscapes are arranged in the reverse order during the return trip. If the return trip effect is specific to the “return trip,” the return trip effect would be observed only when the order of landscapes is reversed. Lastly, I raise another possible factor which may modulate the return trip effect: an interaction between temporal and spatial processes. Our trips are accompanied by spatial moving: walking, driving a car, or taking a train. In such situations, a sense of direction or spatial navigation functions. Interestingly, differences in time perception have been observed according to a sense of direction (Haga, 2003). The interaction between temporal and spatial domains may produce differences in the return trip effect.

In summary, I should first clarify whether the return trip effect can be detected in the laboratory and then whether the illusion is related to the passage of time or the evaluation of absolute duration. Next, I should investigate the return trip effect from the perspectives of the importance of time, the novelty of landscapes (or clock speed), adaptation to time, the order of landscapes, and the interaction between temporal and spatial processes.

1.3 Composition of this thesis

In this study, I explored why the return trip feels shorter through a series of experiments. In Experiment 1 (Chapter 2), I examined whether it is possible to detect the "return trip effect" in the laboratory and whether the illusion results from the heavier importance of time, the faster clock speed during the outward trip, or adaptation to the length of trip duration. I compared a test group viewing round-trip movies and a control group watching two independent trip movies. I also developed a new method in which participants make ongoing and postdictive time judgments in one experiment to distinguish a clock cycle and subjective time judgment.

In Experiment 2 (Chapter 3), I examined whether a decrease in the novelty of landscapes is essential. Participants viewed an outward trip movie and a return trip movie via a different route to make the return trip as novel as the outward trip. I also examined the contribution of a sense of direction to the return trip effect using a standardized questionnaire for evaluation the sense of direction (the Sense of Direction Questionnaire-Short Form, SDQ-S).

In Experiment 3 (Chapter 4), I tested whether the return trip must be a "return" in inducing the illusion. Participants watched an outward trip twice.

In Experiment 4 (Chapter 5), I addressed the additional question of whether time perception is related to sense of direction. Participants conducted a time production task while viewing visual or listening to auditory stimuli.

Based on the results of these experiments, I finally propose a new hypothesis in Chapter 6 that elongation of a reference duration makes the second trip feel relatively shorter than the first trip.

Chapter 2: Experiment 1 – The return trip is felt shorter only postdictively: A psychophysiological study of the return trip effect

2.1 Introduction

Our perception of time is a guiding force in our behaviors because it is an essential component of cognition and motor performance, representing one of the basic mechanisms of cerebral function (Coelho et al., 2004). To deal with time, multiple systems over more than ten orders of magnitude have been developed because we process and use temporal information across a wide range of intervals (Buhusi & Meck, 2005). Time perception researchers often separate time into millisecond timing, interval timing including the range of seconds-to-minutes-to-hours, and circadian timing (Buhusi & Meck, 2005). In this paper I call timing in the range of minutes-to-hours “real-life” timing in order to highlight its relevance to our daily life. Interval timing is less accurate than other timing ranges (Buhusi & Meck, 2005; Meck, 1996). Because of this inaccuracy, we experience many odd phenomena related to time perception. For example, when we go from a station to a destination, and return to the same station, the return trip often seems shorter than the outward trip, though the distance traveled and the actual duration of the trips are almost identical. This phenomenon is called the “return trip effect” (van de Ven et al., 2011).

Zakay (Zakay, 2012) discussed this effect from the viewpoint of time relevance, which indicates how important it is in a specific situation to be aware of the passage of time. The higher the time relevance, the more attentional resources will be allocated to time and therefore the longer the estimate of duration. When we have to go somewhere at a certain time for an important event, time relevance is high. On the contrary, when returning to the starting point, time is not so important and time relevance is low. However, two studies directly examining the return trip effect provide other potential explanations. These studies did not include a purpose for the outward trip; therefore, time relevance seemed to be equal between outward and return trips. Ven et al. (van de Ven et al., 2011) confirmed that the return trip effect is frequently experienced in daily life. Seno et al. (Seno et al., 2011) conducted a virtual travel experiment with verbal instructions and examined two factors: one perceptual (optic flow inducing self-motion perception or random dot control condition) and one cognitive (with or without a round trip story). Their results indicate that the return trip effect is induced only when self-motion perception is accompanied by the round-trip story, in other words, by combined perceptual and cognitive factors.

The foregoing studies provide important suggestions about the return trip effect, but there are also some problems. One is that a comparison between the round-trip condition and non-round-trip condition in an environment close to daily experience is needed. Ven et al. (van de Ven et al., 2011) used actual trips, or virtual trips by movies, but they compared only round-trip conditions, without a control condition. Seno et al. (Seno et al., 2011) examined the round-trip and non-round-trip conditions, but their experimental environment seems to be far from actuality, and the duration of the task (40 s) was much shorter than real-life trips. Recently, the need for ecologically valid tasks has been discussed (Bisson et al., 2012; S. Tobin, Bisson, & Grondin, 2010; S. Tobin & Grondin, 2012). To address these issues, I investigated not only the round-trip condition but also the non-round-trip condition by presenting walking movies for relatively long intervals. The duration of a trip in this study was over 20 min, which is closer to typical trip-durations than previous studies. The experimental setup using walking movies is more ecological than that in Seno et al. (Seno et al., 2011) and the same as that in Ven et al. (van de Ven et al., 2011). In one of my unpublished studies, when participants walked on a treadmill during the same experiment setup, they sometimes tried to turn right or left on the treadmill as if they had walked in a real environment. The method of watching a movie presented by a projector in a dimly room seems to have a sufficient sense of immersion, though I acknowledge that watching a movie is different from a real walk. From the viewpoint of duration interval and environment, this study is comparatively ecologically valid.

A second issue is the need for prospective timing for a long real-life interval. Time perception studies are divided into prospective and retrospective timing (Coelho et al., 2004; Wearden, 2008; Wearden & Pentonvoak, 1995). Prospective timing is involved in the situation where participants are alerted in advance that timing is an essential part of the task presented, for instance, you are asked to perform arithmetic exercises for a given duration and asked in advance to estimate the duration upon the completion of the interval. This timing depends on attentional processes, as explained by the attentional gate model (Bar-Haim et al., 2010; Bisson et al., 2012; S. Tobin et al., 2010; Simon Tobin & Grondin, 2009; S. Tobin & Grondin, 2012; Zakay, 2012): the attention paid to the duration closes a switch between an intrinsic pacemaker and a pulse accumulator, and time judgment is based on the pulses counted in the accumulator. As a result, the more attention is paid to the duration, the longer time is felt to be. Retrospective timing is the situation where participants are asked an unexpected question about duration, for example, you try to recall how long a film was, or how long it took to talk with friends. Retrospective timing is based on memory processes (Bar-Haim et al., 2010; Bisson et al., 2012; S. Tobin et al., 2010; Simon Tobin & Grondin, 2009; Zakay, 2012), and a larger memory for an event leads to a longer remembered duration. When estimating time, it has been assumed that the amount of segmentation determines the size of a memory as a contextual change model indicates (Block, 1982; Poynter, 1983): the contextual changes perceived generate temporal referents in memory and we reconstruct the duration of the event based on them. That is, more mental contextual segmentations lead to longer estimation. Ven et al. (van de Ven et al., 2011) used the retrospective paradigm. On the contrary, Seno et al. (Seno et al., 2011) used the prospective paradigm, but as mentioned above the duration of the task was very short. Therefore, it is unclear whether the return trip effect is observed in prospective timing for longer, real-life intervals. I adopted two methods of time estimation. One was repeated production of a 3 min interval (RP3), which reflects time perception in real time, or prospective timing. The other method was an 11-point scale reflecting postdictive time perception, or retrospective timing, as it was also used in a previous study (van de Ven et al., 2011). Using RP3 and an 11-point scale enabled me to evaluate both prospective and retrospective timings within the same experiment. However, it should be noted that I use the terms "time perception in real time" and "postdictive time perception."

It is important that the return trip effect has been observed when using the verbal estimation method (Seno et al., 2011; van de Ven et al., 2011) and the comparison method (van de Ven et al., 2011). The estimation method may be a more complex time judgment, because it implies the quantification of duration in time units while the comparison method only requires a comparison between durations (S. Tobin & Grondin, 2012). Regardless of this difference the return trip effect has occurred. In this study, RP3 as the production method and an 11-point scale as the comparison method were used. The production method is compatible with the verbal estimation method (Coelho et al., 2004). Based on the observations in previous studies, I hypothesized that the return trip effect would be observed not only in the postdictive rating task but also in RP3.

Studies of time perception have focused on physiological factors such as heart rate (HR), body temperature, or age, as well as perceptual or cognitive factors, in search of fundamental timing mechanisms (Coelho et al., 2004; Meissner & Wittmann, 2011; Wearden & Pentonvoak, 1995). Classically the relationship between time perception and body temperature has been well known. The general rationale is that, as increase in temperature facilitates chemical reactions, any physiologically based pulser or oscillator will operate at a faster rate, with decrease in temperature having the opposite effect (Wearden & Pentonvoak, 1995). Compared to body temperature, HR may have more complex effects. Jamin et al. (Jamin et al., 2004) found a linear relationship between time estimation and HR, with underestimation of duration with decreased HR. This seems to be explained by the same rationale as that for body temperature because a decrease in HR may lead to a slower rate of the physiologically based pulser, which can cause underestimation of duration. Lediett & Tong (Lediett & Tong, 1972) indicated that increases in HR improved the accuracy of time perception in some participants, but lessened it in other participants, depending on their personality. Though the direction of the effect of HR is unclear, HR can modulate time perception. Moreover, HR can be analyzed in more detail. HR is regulated by the sympathetic and parasympathetic nervous systems; therefore, HR variability (HRV) represented by the standard deviation (SD) includes the influence of both systems (Smith & Reynolds, 2006). Analyses such as spectral analysis or the Lorenz plot can separately evaluate these modes of regulation (Camm et al., 1996; Pagani et al., 1989; Toichi, Sugiura, Murai, & Sengoku, 1997; Yamamoto & Hughson, 1991). Measurement of HR enables me to use these analyses, which is the advantage over measurement of body temperature.

While these physiological factors that are assumed to underlie timing mechanisms are mainly investigated over relatively short intervals, perception for long intervals is attributed to cognitive processes such as memory or attention. However, it is not denied that physiological factors may also affect time perception for long intervals. HR and HRV seem to be related to cognitive processes as well as autonomic regulation. HR has been found to react to the emotional valences of film clip stimuli while HRV has been found to be related to acoustic startle reflex sensitive to negative stimuli (Bos, Jentgens, Beckers, & Kindt, 2013). It is possible that these physiological responses could not only underlie the oscillator of the internal clock but also modify time perception for long intervals through more complex cognitive processes such as emotion (Bar-Haim et al., 2010; Droit-Volet & Meck, 2007).

The aims of this study were 1) to compare the round-trip and non-round-trip conditions with a real-life duration and comparatively ecological environment, 2) to identify the circumstances where the return trip effect occurs (i.e., time perception measured in real time or postdictively), and 3) to examine whether autonomic nervous system activity contributes to the return trip effect. I hypothesized that the return trip effect would be observed in both RP3 and the 11-point scale, and that differences in autonomic nervous system activities between the two groups may underlie the return trip effect.

2.2 Materials and Methods

2.2.1 *Participants*

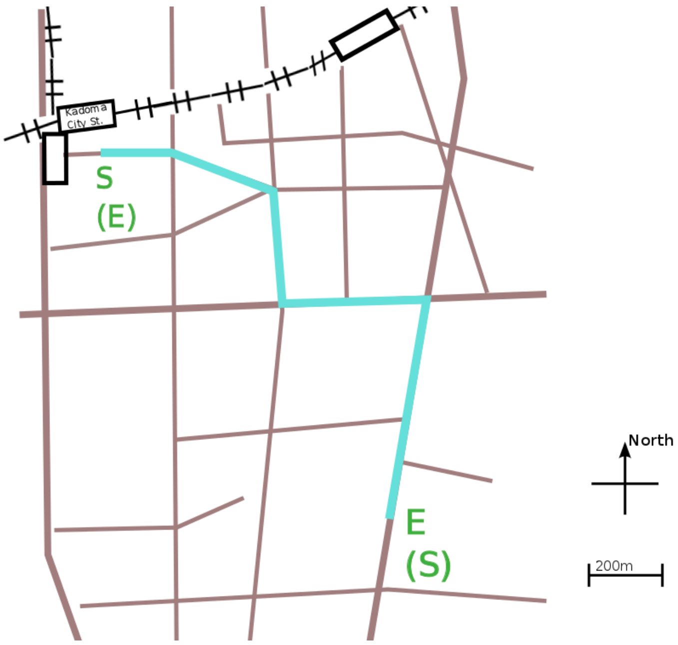
Twenty healthy males (aged 20−30 years) participated in the study. All participants reported normal or corrected-to-normal vision. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Local Ethics Committee of the Graduate School of Human and Environmental Studies, Kyoto University. Participants gave written informed consent according to institutional guidelines.

2.2.2 *Procedure and tasks*

The experiment consisted of two test sessions: the first trip session and the second trip session. In both sessions, participants were asked to watch a movie recorded while walking. Before each session, they were handed a map of a route they would watch in the movie and instructed to glance at the map during the task as if they actually walked the route for the first time. There were three different movies: movie-1, -2, and -3 (Fig. 2-1). Movie-1 showed a route from “S” to “E” in Fig. 2-1A. Movie-2 showed a route from “(S)” to “(E)” in Fig. 2-1A, which meant that the route was the same as that of movie-1, but the direction of travel was reversed. Movie-3 showed a route from “S” to “E” in Fig. 2-1B, which was completely different from those of movie-1 and movie-2. The durations and distances of the three movies were equal (26.3 min, 1.7 km). A round-trip group, comprising 10 participants, watched movie-1 or movie-2 in each session. A control group, comprising the other 10 participants, watched movie-2 or movie-3 in each session. The order of movies was counterbalanced across participants in both groups. I confirmed that all twenty participants were unfamiliar with the routes they had watched.

While watching the movie, participants were required to verbally report when they felt it had taken 3 min, and to continue these reports until the end of the movie (repeated production of a 3 min interval task hereafter called RP3 task). After watching the two movies, they were asked which movie they felt was longer on an 11-point scale from −5 (the first was a lot longer) to +5 (the second was a lot longer). They were not informed of this question in advance. Participants were instructed to remove their wristwatch or any rhythmical devices and not to use verbal nor nonverbal counting strategies such as “1, 2, 3 ...” during the tasks. Before the experimental sessions, there was a practice session in which participants watched a movie, saw a map, and carried out the RP3 task using a route that was different from those used in the test sessions. There was a rest interval of 10 min between sessions.

A



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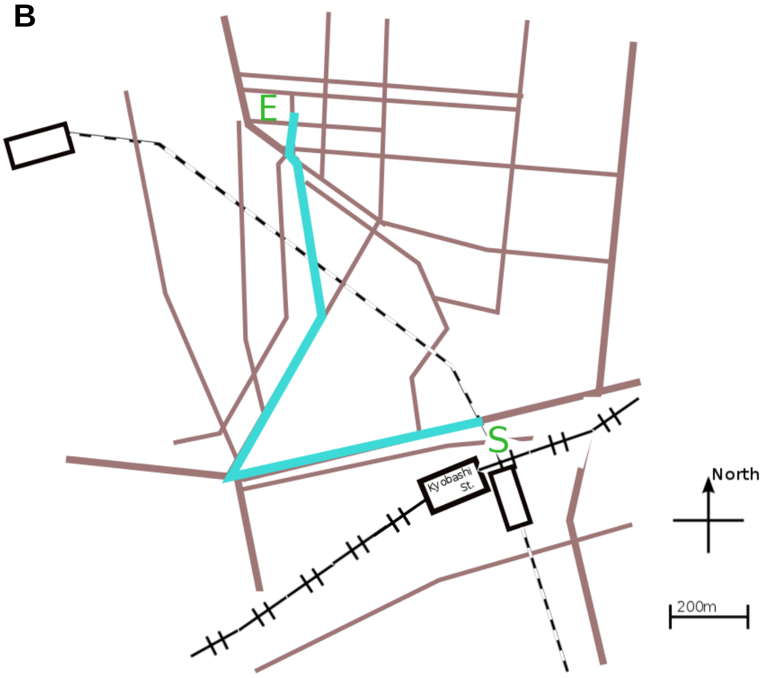


Fig. 2-1. Maps of routes displayed in movies.

'S' on the maps denotes the starting point, and 'E' the endpoint for each route. Cyan line represents the routes of movies. (A) A route in movie-1 and -2, with 'S' and 'E' for movie-1 and 'S' and 'E' with parentheses for movie-2. (B) A route in movie-3.

2.2.3 *Apparatus*

I had recorded four movies (movie-1, -2, -3, and the movie used in the practice session) using a camera (EX-F1, HD/30 fps, CASIO, Tokyo) held in front of the chest while walking. I carefully prepared three experimental movies to precisely match their durations. Firstly, I practiced walking in order to walk with constant speed. Secondly, I preliminarily searched routes to examine the timings when traffic lights change so that I could adjust the frequency of being stopped by red traffic lights. Finally, I shot each movie four to six times. Based on these efforts, I prepared movies with well-controlled durations. The movies used in the first and second test sessions were approximately 26.3 min long, and the movie used in the practice session was approximately 9.0 min long. Movies were played back by a PC and presented on a screen by a projector (NP62, NEC, Tokyo) at a size of 0.9 m × 1.5 m. Participants were individually tested in a dimly lit room and comfortably sat on a chair. The distance between the screen and the projector was approximately 2.70 m, and that between the screen and the chair was approximately 3.65 m. At the start of the movie, a stopwatch was started, and I filmed the session so that the times of participants' verbal reports could subsequently be confirmed. To obtain heart beats, a bipolar electrocardiogram (ECG) was continuously measured by a precordial lead. The recorded ECG was stored on a computer via 16-bit analog-digital converter

(PowerLab 16SP, ADInstrument, Sydney) at a sampling frequency of 1 kHz.

2.2.4 *Data and analyses*

Two indices were used to evaluate time perception. RP3 represented the objective durations between the start of the movie and the first report, or between a report and the following report produced by participants in the RP3 task. The larger the RP3, the shorter the participant evaluated the past time was because overproduction in the production method equals to underestimation in the verbal estimation method. This index evaluated time perception in real time because it was produced during the experiment. The other index was the 11-point scale. This index of time perception more closely corresponds with our daily experiences. Also the judgment on the 11-point scale was not processed during the tasks because it was unexpectedly asked in the end. Therefore this judgment was constructed after the tasks.

Autonomic nervous system activity was assessed from the ECG data. Detection of each cardiac impulse was triggered by the R wave, and visual inspection was used to search the possibility of extra or missing beats. Then R-R intervals were calculated from these impulses, and were converted into instantaneous HRs. To investigate overall changes in HR, the mean instantaneous HR and the SD of instantaneous heart rates (SD-HR) were calculated. SD-HR is considered to be an index reflecting the activity of the whole autonomic nervous system, because the SD of HR reflects all cyclic components responsible for variability, and the variance is mathematically equal to the total power in spectral analysis (Smith & Reynolds, 2006). To investigate autonomic nervous system activity in detail, the Lorenz plot was adapted. This is a two-dimensional non-linear plot. When the sequence of the consecutive R-R intervals is expressed by I_1, I_2,…, I_n, the Lorenz plot is constructed by plotting I_{k+1} against I_k. Two components of the R-R fluctuation are calculated from the plots: the length of the transverse axis (T), which is vertical to the line $I_k = I_{k+1}$, and that of the longitudinal axis (L), which is parallel with the line $I_k = I_{k+1}$. These components are calculated by quadrupling the SDs of the plotted points along its axis. Two autonomic indices were obtained from these components: cardiac vagal index (CVI) is defined as $\log_{10}(L \times T)$ and cardiac sympathetic index (CSI) as L/T. CVI and CSI reflect parasympathetic and sympathetic functions, respectively. This analysis is more sensitive than spectral analysis (Toichi et al., 1997).

RP3s were averaged within participants in each session. ECG data were separated into segments corresponding to RP3s. Then HR, SD-HR, CVI, and CSI were calculated in each segment and averaged across segments within participants in each session.

2.2.5 *Statistics*

To assess the independent and combined effects of RP3, HR, SD-HR, CVI, and CSI, a two-way mixed-model analysis of variance (AVOVA) was conducted with the round-trip and control groups as a between-subjects factor (Group) and the first and second trips as a within-subjects factor (Trip Session). If a significant interaction was found, within-subjects differences were analyzed for each group using two-tailed pair-wise *t* tests. To assess the 11-point scale, a two-tailed Welch's *t* test was used because of the difference of variance mentioned in Results (see also Fig. 2-2B). Also, a two-tailed one-sample *t* test was used for each group to judge whether the estimation was significantly biased. Effect size was estimated by using partial eta-squared (η_p^2) and Cohen's *d*. Pearson correlations between autonomic nervous activities (the change of HR, SD-HR, CVI, and CSI) and time estimates (changes in RP3, and the values of 11-point scale) were investigated in each group. The change in each index was defined by subtracting the value in the second trip session from that in the first trip session. For all statistical calculations, $p < .05$ was accepted as significant. In case of multiple comparisons at follow-up analyses, Holm correction was used to control for false positives.

2.3 Results

2.3.1 *Time estimation*

The mean RP3s are plotted in Fig. 2-2A. An ANOVA on RP3 revealed that there was a significant effect of Trip Session ($F(1, 18) = 5.57$, $p = .03$; $\eta_p^2 = .24$). There was no effect of Group ($F(1, 18) = .13$, $p = .72$; $\eta_p^2 = .007$) and no significant Trip Session × Group interaction ($F(1, 18) = .84$, $p = .37$; $\eta_p^2 = .04$).

The mean 11-point scale scores are plotted in Fig. 2-2B. There were an apparent difference in SE between two groups. In the round-trip group the evaluated scores were all negative whereas in the control group the scores included both negative and positive values. Due to this difference we performed a Welch's *t* test showing that there was a significant difference between the two groups ($t(12) = -2.92$, $p = .013$; $d = -1.31$). A one-sample *t* test showed that the mean score for the round-trip group was smaller than 0 ($t(9) = -6.53$, $p = 1.1 \times 10^{-4}$; $d = -2.06$). In addition, all ten participants produced negative values. The scores on the 11-point scale for the control group did not differ from 0 ($t(9) = .60$, $p = .57$, $d = .19$).

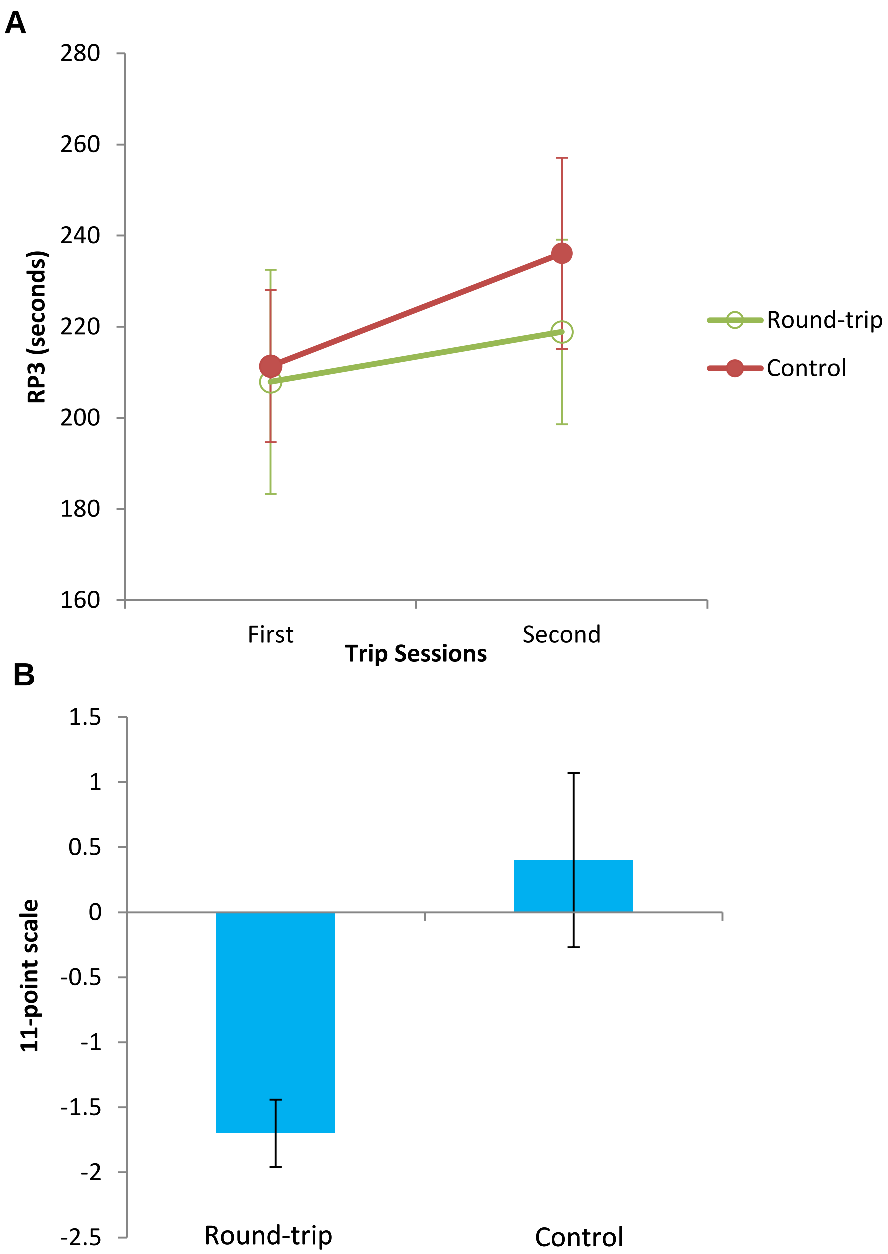


Fig. 2-2. Time estimations.

(A) Mean RP3 in each condition, calculated across participants, and (B) mean 11-point scale in each group, calculated across participants. Values are means ± 1SE. RP3, repeated production of a 3 min interval.

2.3.2 *Autonomic nervous function*

Variables related to autonomic nervous system activities are plotted in Fig. 2-3. In the round-trip group one participant showed very slow HR (around 55 beats/min) with low variability because he was a skilled sport player, and another showed very fast HR (around 100 beats/min) with high variability, which led to wide distributions of HR and SD-HR within the group (Fig. 2-3A and 2-3B). An ANOVA on HR (Fig. 2-3A) revealed that there was no effect of Trip Session ($F(1, 18) = .10$, $p = .75$; $\eta_p^2 = .006$) or Group ($F(1, 18) = .14$, $p = .71$; $\eta_p^2 = .008$), and no interaction ($F(1, 18) = .70$, $p = .42$; $\eta_p^2 = .04$). On SD-HR (Fig. 2-3B), there was no effect of Trip Session ($F(1, 18) = 1.77$, $p = .20$; $\eta_p^2 = .09$) or Group ($F(1, 18) = .77$, $p = .39$; $\eta_p^2 = .04$), but there was a significant Trip Session × Group interaction ($F(1, 18) = 5.16$, $p = .036$; $\eta_p^2 = .22$). Two-tailed pair-wise *t* tests revealed that SD-HR in the second trip session was larger than that in the first trip session for the control group ($t(9) = -3.40$, $p = .016$; $d = -.48$), and that there was no difference between trip sessions for the round-trip group ($t(9) = .55$, $p = .59$; $d = .08$). On CVI (Fig. 2-3C), there was no effect of Trip Session ($F(1, 18) = .51$, $p = .48$; $\eta_p^2 = .03$) or Group ($F(1, 18) = 2.30$, $p = .15$; $\eta_p^2 = .11$), and no interaction ($F(1, 18) = 2.74$, $p = .12$; $\eta_p^2 = .13$). On CSI (Fig. 2-3D), there was a significant effect of Trip Session ($F(1, 18) = 9.47$, $p = .006$; $\eta_p^2 = .35$), but no effect of Group ($F(1, 18) = .59$, $p = .45$; $\eta_p^2 = .03$). The Trip Session × Group interaction approached significance ($F(1, 18) = 3.87$, $p = .065$; $\eta_p^2 = .18$). This interaction was not significant, but *t* tests showed that CSI in the second trip was larger than that in the first trip session for the control group ($t(9) = -4.130$, $p = .005$; $d = -.64$), and that there was no difference between trip sessions for the round-trip group ($t(9) = -.70$, $p = .50$; $d = -.10$).

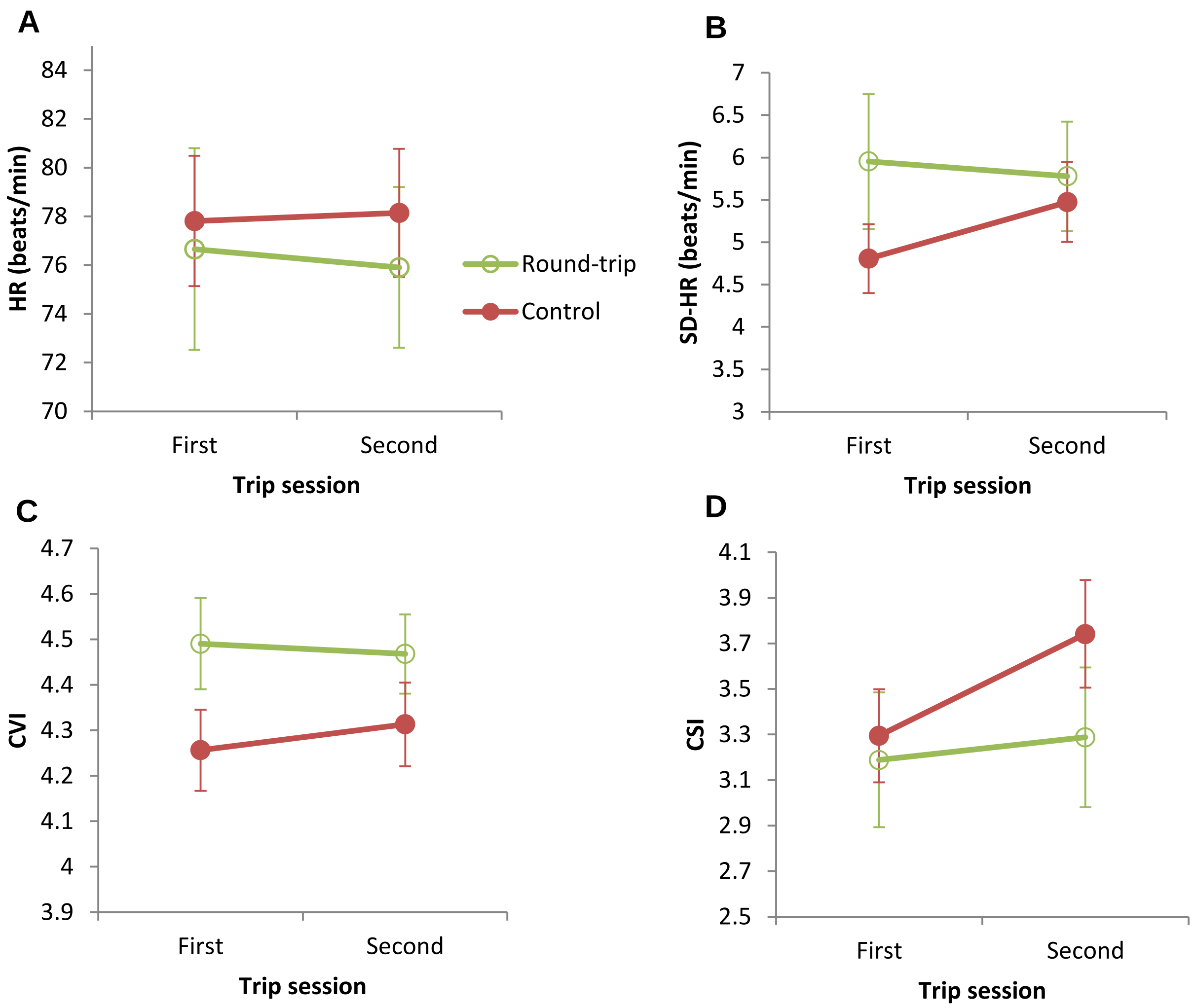


Fig. 2-3. Physiological indices.

(A) Mean HR in each condition, (B) mean SD-HR in each condition, (C) mean CVI in each condition and (D) mean CSI in each condition, calculated across participants. Values are means ± 1SE. HR, heart rate; SD-HR, standard deviation of heart rate; CVI, cardiac vagal index; CSI, cardiac sympathetic index.

2.3.3 *Correlations*

Correlations between autonomic nervous system activities and time estimates are presented in Tab. 2-1. A significant correlation between the 11-point scale and the change in CVI was found in the control group (r = .74, p = .014) (Fig. 2-4A). The correlation between the 11-point scale and the change in SD-HR approached significance in the control group (r = .62, p = .054) (Fig. 2-4B). No other significant correlation was found in the control group, and no correlations were found in the round-trip group.

Tab. 2-1. Correlation coefficients between autonomic nervous system and time perception for the round-trip group and the control group.

	Round-trip				Control			
	RP3		11-point scale		RP3		11-point scale	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
HR	-.49	.149	-.45	.197	-.32	.370	-.41	.240
SD-HR	-.26	.474	-.36	.314	.08	.828	.62	.054
CVI	.23	.532	-.07	.853	.33	.347	.74	.014*
CSI	-.29	.416	-.37	.287	-.16	.656	.35	.316

* p <. 05.

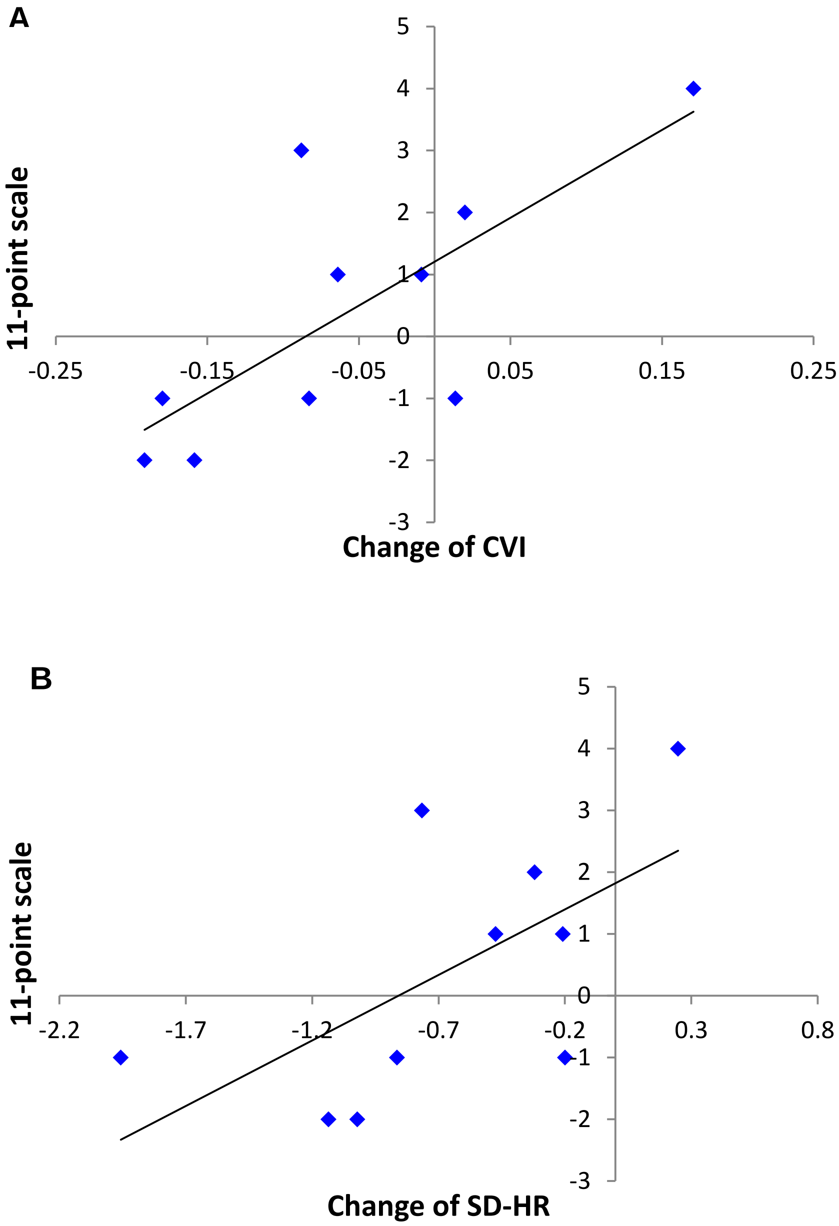


Fig. 2-4. Relations between autonomic nervous system and postdictive time perception.

(A) Correlation of the change of CVI with 11-point scale for the control group, and (B) correlation of the change of SD-HR with 11-point scale for the control group. The change was defined as subtracting the value in the second trip session from that in the first trip session. CVI, cardiac vagal index; SD-HR, standard deviation of heart rate.

2.4 Discussion

It should be noted that I cannot be confident of the null results of ANOVA interaction effects mentioned below due to low statistical power. Assuming sample size = 10 per group and medium effect size f = .25 equivalent to $\eta_p{}^2$ = .06, the statistical power to detect the interaction = .56 (calculated with G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007)).

2.4.1 *Discrepancy between the two time estimates*

I assessed time perception in two ways, prospective judgment involving on-going temporal production (RP3) and retrospective judgment comprising a comparison of two intervals on an 11-point scale. These two indices apparently showed different results, suggesting that the return trip effect might be caused only postdictively. According to the 11-point scale results, only the round-trip group estimated that the second trip took less time than the first trip. In contrast, the RP3 results indicate that both groups felt that time had been shorter in the second trip session. Considering that the 11-point scale is a similar method for evaluating time perception to that used in previous research (van de Ven et al., 2011) and is also close to the situation in which we experience the return trip effect in daily life, it is certain that the return trip effect is observed at least postdictively. In addition, this difference between the two time estimates suggests that postdictive time perception, measured by the 11-point scale, might not be based on time perception in real time, as estimated by RP3. During tasks, time may be felt to be shorter in the second trip session for both groups, but this would not lead to the same experience of time after completion of the tasks.

The discrepancy between the two estimates can be explained by timing strategies. Time perception includes prospective and retrospective timing (Coelho et al., 2004; Wearden, 2008; Wearden & Pentonvoak, 1995). RP3 would be prospective timing because participants were aware of this task during the experiment, and the production method is a major method in prospective timing. The 11-point scale may reflect retrospective timing because it was conducted unexpectedly and postdictively, though participants knew that timing was a major task because of RP3. One of the purposes of this study was to reveal whether the return trip effect is observed when using prospective timing for a long real-life interval. The absence of the effect in RP3 indicates that the return trip effect is not induced in prospective timing. The difference between my results and Seno et al. (Seno et al., 2011) also using prospective timing could be attributed to duration intervals because their stimuli were 40 seconds. In addition to the two timing paradigms, Wearden (Wearden, 2008) proposed another one, passage of time. Different from prospective and retrospective timings, which focus on how long a time period lasted, passage of time concerns how quickly time seemed to pass. By intuition, if time seems to pass quickly during an event, the event might be judged as short. However, Wearden (Wearden, 2008) reported that film clip stimuli which seemed to pass more quickly were evaluated equally in retrospective time estimation. Passage of time may be easily influenced whereas retrospective timing appears to be difficult to manipulate. The return trip effect, which was only observed in the subjective scale judgment, may not be a matter of the duration judgment, but of passage of time. The question in the 11-point scale was “which movie they felt was longer” and the answer was for example “the first was a lot longer.” This subjective scale may have been confused with passage of time. To investigate whether the 11-point scale was confused with passage of time, I should compare the postdictive verbal estimation and the 11-point scale with the settings of the present experiment.

The absence of interaction in RP3 may reflect the specific timing method rather than the timing strategy. Previous studies have observed the return trip effect when using the verbal estimation and subjective scale methods (Seno et al., 2011; van de Ven et al., 2011), which suggests that the return trip effect can be assessed by both the method requiring quantification and that requiring just comparison (S. Tobin & Grondin, 2012). As the production method used in RP3 seems homologous to the verbal estimation method (Coelho et al., 2004), I had expected the return trip effect in RP3, but did not observe it. One of the possible difference between the production and the verbal estimation methods is a review of past time. In the production method, participants can predict how long they should pay attention to time because the target duration, 3 min in this study, is presented beforehand. On the contrary, in the verbal estimation method participants do not know how long they will measure time; presented durations may be 10 sec, 10 min, or 1 hour. In this unpredictable situation without counting strategies it may be more or less necessary to postdictively review past time after the task. The return trip effect observed in previous studies (Seno et al., 2011; van de Ven et al., 2011) using the verbal estimation may be attributed to the review of past time. The postdictive 11-point scale in the present study also includes the review of past time, which may support the importance of the review of past time.

It is worth noting that the increase in RP3 in both the round-trip and the control condition in the second session might be attributable to repeated reports. According to interviews after completion of the tasks, participants initially seemed to find the RP3 task to be difficult, but as they continued they became accustomed to the task and found it easier. In general, the durations of simple or dull tasks tend to be underestimated, whereas complex or detailed tasks tend to be overestimated (Burt & Kemp, 1994; Roy, Christenfeld, & Jones, 2013; Roy, Mitten, & Christenfeld, 2008). Another possible explanation for the increase in RP3 is that there is a lag before the participant becomes absorbed by the movie. When playing a video game, players often underestimate the playtime, but when playing the game only briefly, they overestimate the playtime because of an "adaptation period" that is required to be fully immersed in the game (Bisson et al., 2012; Rau, Peng, & Yang, 2006; S. Tobin et al., 2010). Bisson et al. (Bisson et al., 2012) discussed that the adaptation period might be less pleasant and thus induce overestimation of time. It is also possible to interpret the adaptation period from an attentional perspective: after this adaptation period, participants can be absorbed in the game, which distracts attention from its duration (Simon Tobin & Grondin, 2009). According to a model for apparent duration suggested by Glicksohn (Glicksohn, 2001), apparent duration is a multiplicative function of the size of and the number of the subjective time unit. Externally oriented attention decreases the size of the time unit. In the present experiment, after an adaptation period in which participants might have been absorbed enough into the movie, more attention might have been deployed to the movie (an external stimulus) thereby decreasing the size of the time unit, and thus apparent duration might have been shortened. If the duration of the practice session is extended to fully elicit the possible habituation to the RP3 task or the possible absorption into a movie in advance, the change in RP3 observed in this study might vanish. Also, if absorption causes overproduction (underestimation) in RP3, RP3 while playing a video game could be increased after a certain adaptation period. These approaches could provide informative evidence about the change of RP3.

As mentioned above, the absence of the interaction in RP3 may reflect low statistical power. The difference between the two groups in the 11-point scale measure was very large, so the return trip effect seems to be prominently observed in postdictive time estimation. However, I can’t be confident of the null results of RP3.

2.4.2 *Moderately different influences on autonomic nervous system*

The two experimental conditions did not cause drastic, but only moderately different, changes in overall autonomic nervous system activity. The whole autonomic nervous system, as measured by SD-HR, was more active in the second trip session only for the control group. Similarly CSI, reflecting sympathetic activity, increased only for the control group. These results suggest that overall autonomic nervous system activity differently responded for the two groups, mainly as a result of sympathetic activity. Increased HRV is associated with lower mental load (Hill & Perkins, 1985; Toichi et al., 1999). However, the increase in sympathetic activity is considered to reflect an increase in mental stress or concentration (Kubota et al., 2001). It is difficult to infer the change in mental state in the control group. However, on the basis of the major contribution of sympathetic activity discussed above, it is possible that the control group might have felt greater mental stress in the second session. Watching one trip movie over 25 min was a lengthy task. During the second session participants in the control group might have felt that they would have to watch another long dull movie. In contrast participants in the round-trip group might have been relaxed because they would know it from past experiences of return trips that the return trip would seem short. Here I emphasize only that the combinations of movie-1 & -2 and movie-1 & -3 had moderately different influences on autonomic nervous system activity.

2.4.3 *Influence of* autonomic nervous system *activity on time perception*

Time perception, estimated postdictively, seems to be related to the parasympathetic activity. When the change in CVI between the two sessions was larger, participants in the control group felt that the session with larger CVI was shorter. The correlation between the change in SD-HR and the 11-point scale showed the same trend. On the basis of the fact that the parasympathetic nervous system activity represented by CVI contributes to autonomic nervous system activity represented by SD-HR, and the values of *r* (.74 and .62 for CVI and SD-HR, respectively), it can be inferred that among autonomic nervous system activities the parasympathetic activity mainly contributed to postdictive time perception. A recent study investigating the relationship between body signals and time perception suggests that the parasympathetic activity may affect time perception. In the reproduction method a decrease in HR caused by an increase of the parasympathetic activity during encoding of time improved the accuracy of duration reproduction (Meissner & Wittmann, 2011). In my study I cannot refer to the accuracy of postdictive time judgment, but the significant correlation between the 11-point scale and CVI may correspond to an improvement of the accuracy of time estimation. Participants may have tended to overestimate the duration, and the parasympathetic activity may have improved the accuracy of time estimation. As a result, the parasympathetic activity shortened time estimation and participants felt that the session with larger CVI was shorter. Contrary to the control group, the change in CVI was not related to comparative judgments on the 11-point scale for the round-trip group. This indicates that the relationship between postdictive time perception and the parasympathetic activity may not be so robust.

At the end of this section we should represent one concern that the significant and nearly significant correlations out of 16 might well be false positives. In the present study CVI showed the significant correlation with time perception, which in part follows previous research (Meissner & Wittmann, 2011) finding the relationship between time perception and the parasympathetic activity. Moreover, it seems reasonable that CVI and SD-HR showed higher *r* values because the parasympathetic nervous system composes autonomic nervous system. So the correlations I found may be genuine. Nevertheless more research is need in this issue.

2.4.4 *What causes the return trip effect?*

Why does the round trip bias time perception? Ven et al. (van de Ven et al., 2011) reported that the return trip effect was observed not only when the return trip was via the route same as the initial trip, equivalent to our round-trip group, but also via a route different from the initial trip. Seno et al. (Seno et al., 2011) found that the return trip effect was induced only when self-motion perception was accompanied by a round-trip story. Though these two studies used shorter durations than the present study (7 min in Ven et al. (van de Ven et al., 2011), 40 s in Seno et al. (Seno et al., 2011)), their results both suggest that the fact or the awareness of “return trip” would be necessary for the return trip effect. My control group did not have this awareness, which supports this idea. If this awareness is systematically manipulated, conditions necessary for the return trip effect might be found.

To interpret the return trip effect in a clearer way, the experimental design should be improved. The round-trip group watched movie-1 and -2 as a round trip while the control group saw movie-2 and -3 as a non-round trip. Due to this design the two groups were looking at different scenery or objects. I preliminarily searched the numbers of corners, distances, sizes of the roads, and traffic volume in order to match the environments of the routes. However, the scenery of the movies the two groups watched was not completely the same. For future research, one of the ways to solve this problem would be to use two sets of round-trip movies, such as pairs of movie-1 and -2, and movie-3 and -4. This design will enable me to make four round-trips and eight non-round-trips by counterbalancing the order and combination. Using this design, I will be able to compare the round-trip condition and the non-round-trip condition with the same scenery.

Also, the ecological validity could be elevated. I used as stimuli real-life intervals and the projection of walking movies, which seem to provide a sufficient sense of immersion. However, this environment is different from a real walk in some ways, for example, a narrow field of vision or the absence of physical activity. There are few studies relating time perception to physical activity, but physical activity may modulate time perception. It has been reported that physical activity lessened the accuracy and the variability of time perception (Vercruyssen, Hancock, & Mihaly, 1989). In contrast, Tobin & Grondin (S. Tobin & Grondin, 2012) found smaller variability of time perception with physical activity than visualizing that activity. The impact of walking as a physical activity should be investigated by using treadmill or a field study.

2.5 Conclusion

I investigated the return trip effect in a comparatively ecologically valid situation over a real-life interval. By comparing the round-trip condition and the non-round-trip condition, it was confirmed that the return trip effect is not caused by heavier important of time in the outward trip nor adaptation to the length of duration. Moreover, my two methods of time estimation suggest that the return trip effect is not explained by the in clock cycle but rather by more subjective time judgments. We also examined whether autonomic nervous system activity measured by ECG is related to time perception. Parasympathetic function is one of the resources for temporal information, but is not robust one.

For future research, it would be interesting to test the contribution of the awareness of “return trip” because this semantic labeling may be a major factor in inducing the cognitive bias of the return trip effect. Moreover, neuroimaging studies could provide insight into how time is perceived in ecological situations.

Chapter 3: Experiment 2 – Awareness of the “return trip” can induce the return trip effect

3.1 Introduction

In Experiment 1, I confirmed that the return trip effect is not explained by the heavier importance of time, the faster internal clock cycle during the outward trip, or adaptation to the length of trip duration. Moreover, through a comparison with previous research (Seno et al., 2011; van de Ven et al., 2011), it was noted that the awareness of the “return trip” may be responsible for this effect. In this chapter, I investigate whether the return trip effect is observed when the return trip is accompanied by novel landscapes and when we require awareness of the “return trip.” The experimental tasks and settings were almost identical to those of Experiment 1, except the routes of the movies. In Experiment 1, the round-trip group watched the round-trip movies with the same route. In Experiment 2, two movies were used. These movies shared the starting and ending points, but the routes were different. One group was informed that they would return to the starting point, whereas the other group was not so informed. Due to this instruction the awareness of “return trip” was manipulated.

In Experiment 1 the relationship between the autonomic nervous system and time perception was discovered. This finding provides the important insight that physiological parameters, such as autonomic nervous system, may underlie the timing mechanism even in long intervals based on memory processes. However, when considering the environment where we experience the return trip effect, other possible factors should be investigated. Our trips are accompanied by spatial moving: walking, driving a car, or taking a train. In such situations, a sense of direction may play an important role. A sense of direction questionnaire short form (SDQ-S) has often been used to evaluate the sense of direction (Takeuchi, 1992). Moreover, differences in time perception have been observed according to sense of direction (Haga, 2003). In this chapter, the contribution of sense of direction to the return trip effect was also examined using SDQ-S.

The aims of Experiment 2 were 1) to examine the effect of the novelty of landscapes, 2) the timing of being aware of the "return trip," and 3) the relationship between the return trip effect and sense of direction.

3.2 Materials and Methods

3.2.1 *Participants*

There were 36 male participants (aged 18−29 years). All participants reported normal or corrected-to-normal vision. They gave written informed consent according to the institutional guidelines, and the study was conducted in accordance with the Declaration of Helsinki.

3.2.2 *Procedure and tasks*

The experiment consisted of two test sessions: the outward trip session and the return trip session. In both sessions, participants were asked to watch a movie recorded during walking. There were two different movies: movie-1 and movie-2 (Fig. 3-1). Movie-1 showed a route from “S” to “E” in Fig. 3-1A. Movie-2 showed a route from “S” to “E” in Fig. 3-1B. “S” in movie-1 was identical to “E” in movie-2, and vice versa. Two movies had almost different routes while partly sharing the route. In Fig. 3-1, the light blue lines represent the routes that the movies did not share, whereas the red lines represent the shared route. Distances and times of the two movies were equal (23.8 min, 1.7 km). All participants watched movie-1 or movie-2 in each session, and the order of movies was counterbalanced. One group with 16 participants was given the instruction, “You would go back from the end point to the starting point in the first movie” before the return trip session (the With group). Although the route of the return trip movie was different from that of the outward trip movie, the With group was able to conduct the return trip session, knowing it was the return trip (due to the instruction). By contrast, the other group with the other 16 participants was given no instructions beforehand; thus, this group conducted the return trip session as if it had led to an unfamiliar place (the Without group). However, parts of the route shared by the two movies (red lines in Fig. 3-1) told participants that they had returned to the starting point of the first movie. Thus, they were aware that the second movie had shown the return trip. This manipulation of instructional content was adopted to affect the timing (and strength) of the awareness of "return trip."

Tasks participants were required to perform were the same as for Experiment 1, except for the SDQ-S (Kato & Takeuchi, 2003). After repeated production of a 3 min interval (RP3) task and an 11-point estimation, participants were also required to answer the SDQ-S. They were asked to evaluate 20 items on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree).

Participants were instructed to remove their wristwatch or any rhythmical devices and not to use verbal nor nonverbal counting strategies such as "1, 2, 3…"during the tasks. Before experimental sessions, there was a practice session in which participants watched a movie and carried out the RP3 task. The route was different from those used in test sessions. There was a rest interval of 10 min between sessions.

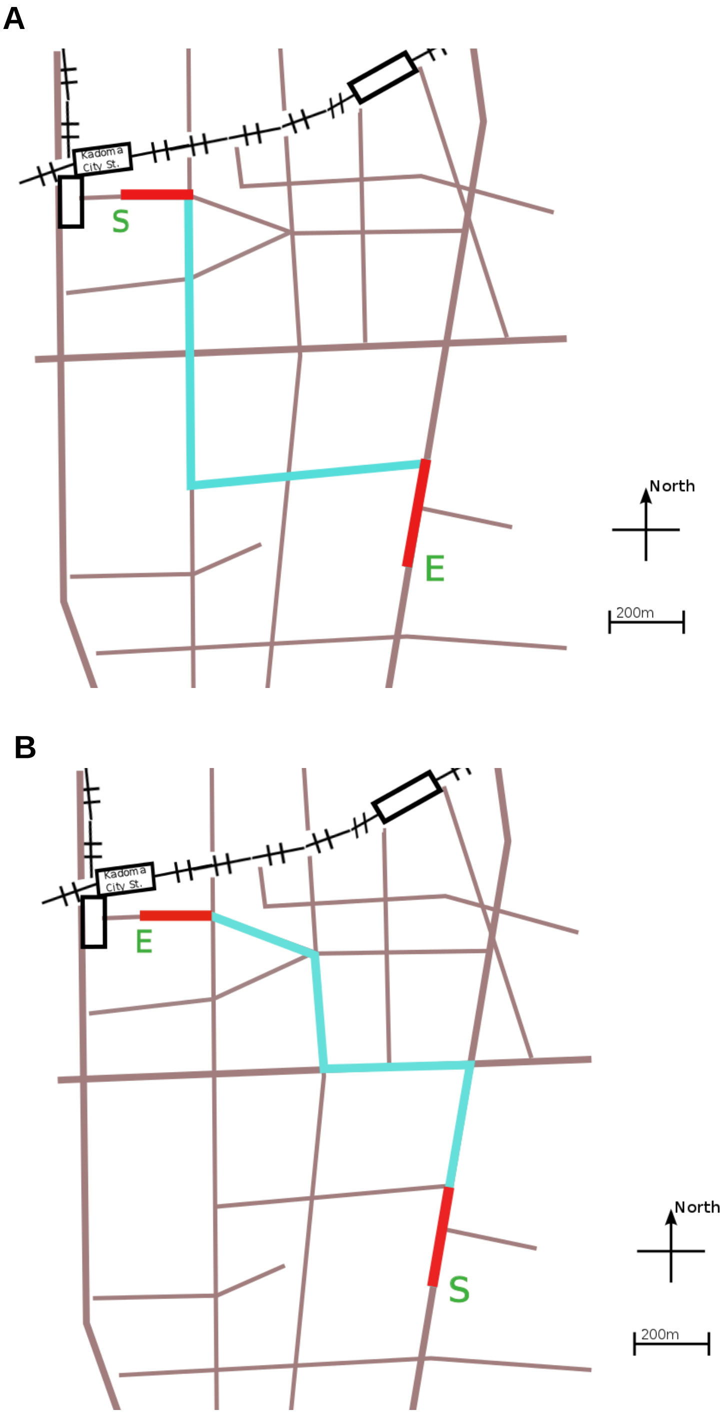


Fig. 3-1. Maps of routes displayed in movies 1 and 2.

"S" on the maps denotes the starting point and "E" the end point for each route. The light blue lines represent the routes of each movie, and the red lines represent the route shared by the two movies. (A) is the route in movie-1 and (B) is the route in movie-2.

3.2.3 *Apparatus*

I had recorded 3 movies (movie-1 and movie-2 and the movie used in the practice session) using a camera (HDR-PJ790V, HD / 60i, Sony, Tokyo), held in front of my chest while walking. The movies used during the outward and return trip sessions were approximately 23.8 min long, and the movie in the practice session was approximately 9.0 min long. Movies were played back using a PC and presented with a projector (NP62, NEC, Tokyo) at a size of 0.9 m × 1.5 m on a screen. Participants were tested individually in a dimly lit room and sat comfortably on a chair. The distance between the screen and the projector was approximately 2.70 m and that between the screen and the chair was approximately 3.65 m. At the start of the movie, a stopwatch was started and it was recorded by the camera to subsequently confirm the times of reports verbally given by participants. To obtain heart beats, bipolar electrocardiogram (ECG) was measured continuously by the precordial lead. Recorded ECG was stored on a computer via a 16-bit analog-digital converter (PowerLab 16SP, ADInstrument, Sydney) at a sampling frequency of 1,000 Hz.

3.2.4 *Data and analyses*

Two indices evaluating time perception were the same as per Experiment 1. RP3 evaluated time perception in real time, whereas the 11-point scale expressed the postdictive one.

SDQ-S was used to measure the sense of direction in the real word (Kato & Takeuchi, 2003; Suzuki, 2012; Takeuchi, 1992). It comprised two scales: Scale 1 for awareness of orientation consisted of 9 items, such as “I become confused about cardinal directions when I am in an unfamiliar place” and “I feel anxious about my walking direction in an unfamiliar area.” And Scale 2 for memory for usual spatial behavior consisted of 8 items, such as “I cannot remember landmarks in an area where I have often been” and “I have a poor memory for landmarks.” In this study, I calculated three scores from the SDQ-S: the total score (Total SDQ score), the score of Scale 1 (Scale 1), and the score of Scale 2(Scale 2). Total SDQ score, Scale 1, and Scale 2 were obtained by summing all 20 items, 9 items, and 8 items, respectively.

HR, SD-HR, CVI, and CSI were calculated with methods used in Study 1. ECG data was separated into sections corresponding to RP3s. HR, SD-HR, CVI, and CSI were calculated in each section and averaged across sections.

3.2.5 *Statistics*

To assess the independent and combined effects of RP3, HR, SD-HR, CVI, and CSI, a two-way mixed-model analysis of variance (AVOVA) was conducted with both the With and Without groups as a between-subjects factor (Group) and time estimates of the outward and return trips as a within-subjects factor (Trip Session). Within-subject differences were analyzed for each group using two-tailed pair-wise *t* tests if a significant interaction was found. To assess the 11-point scale, a two-tailed *t* test was used. Moreover, a two-tailed one-sample *t* test was used for each group to judge whether the estimation was significantly biased. The effect size was estimated using partial eta-squared (η_p^2) and Cohen's *d*. For all statistical calculations, $p < .05$ was accepted as significant. In the case of multiple comparisons at follow-up analyses, Holm correction was used to control for false positives.

3.3 Results

3.3.1 *Time estimation*

The mean RP3s are plotted in Fig. 3-2. An ANOVA on RP3 revealed that there was a significant effect of Trip Session ($F(1, 30) = 7.827$, $p = .009$; $\eta_p^2 = .207$). There was no significant effect of Group and interaction Trip Session × Group.

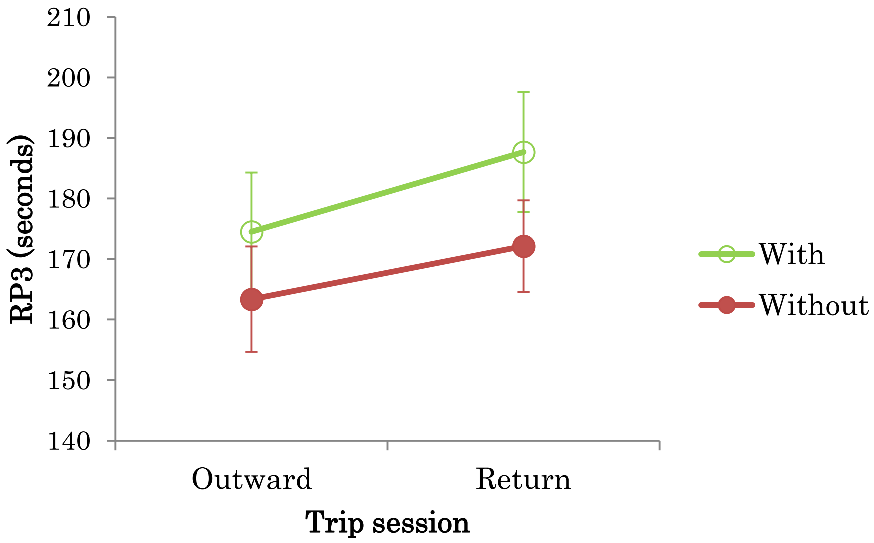


Fig. 3-2. Ongoing time estimation.

Mean RP3 in each condition, calculated across participants. Values are means ± 1SE. RP3, repeated production of a 3 min interval.

The mean 11-point scales are plotted in Fig. 3-3. An independent *t* test showed that there was no difference between the With and Without groups ($t(30) = -.44$, $p = .66$; $d = -.16$). However, a one-sample *t* test showed that the 11-point scale for the With group was smaller than 0 ($t(15) = -2.5$, $p = .025$; $d = -.62$), while the 11-point scale for the

Without group did not differ from 0 (t(15) = -1.7, p = .12; d = -.42).

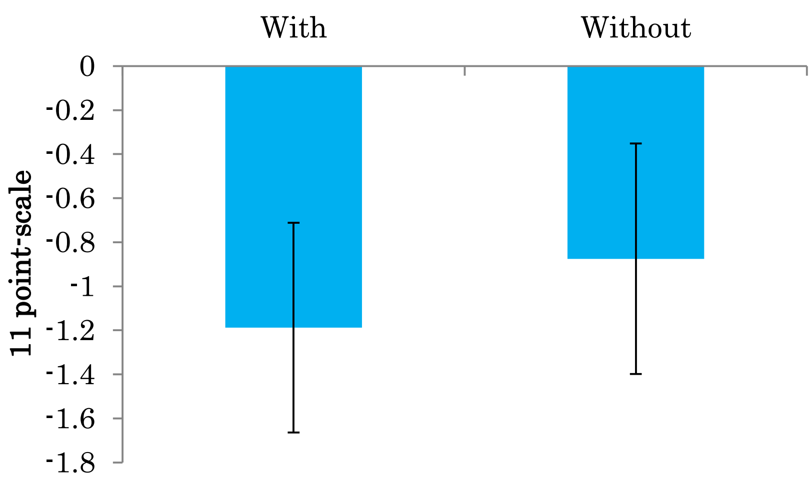


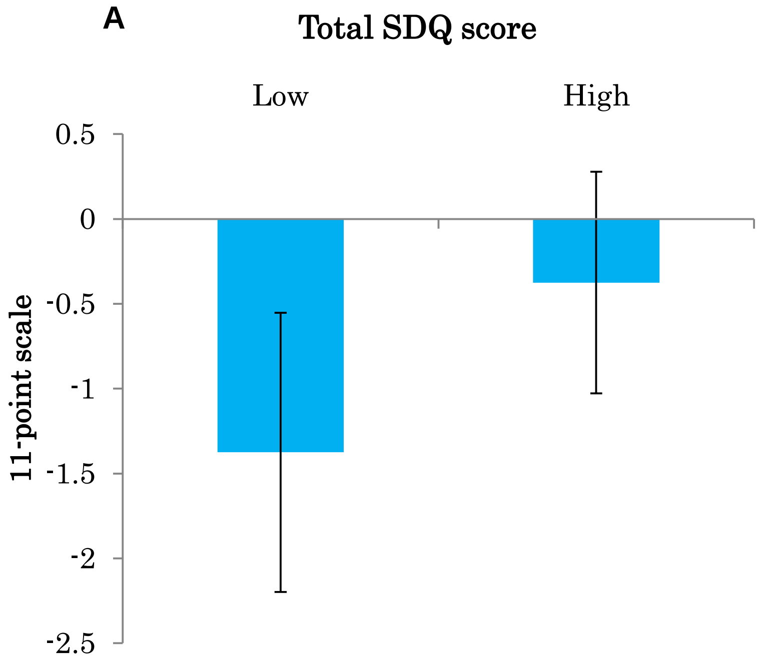
Fig. 3-3. Postdictive time estimation.

Mean 11-point scales in each group, calculated across participants. Values are means ± 1SE.

3.3.2 *Time estimation and sense of direction*

Similar to Experiment 1, the return trip effect was observed in postdictive time estimation. To investigate this estimation in detail, three scores from SDQ-S were used. The With and Without groups were divided into subgroups, including a low-score (Low) subgroup and a high-score (High) subgroup according to Total SDQ score, Scale 1, and Scale 2, respectively. Figure 3-4 represents subgroups from the Without group. A one-sample t test showed that the Low subgroup divided by Scale 1 was smaller than 0 (t(7) = −2.646 ; p = .033) (Fig. 3-4B). The 11-point scale for other subgroups from the Without group did not differ from 0. Figure 3-5 expresses subgroups from the With group. The results were identical when divided by Total SDQ score, Scale 1, and Scale 2. A one-sample *t* test revealed that the Low subgroup tended to be smaller than 0 ($t(7) = -2.201$; $p = .064$). The 11-point scale for the High subgroup did not differ from 0.

A



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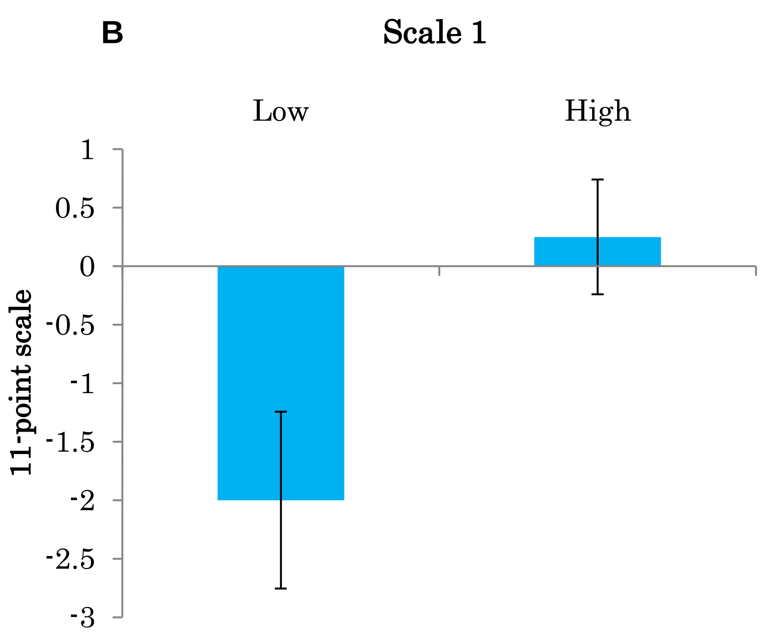


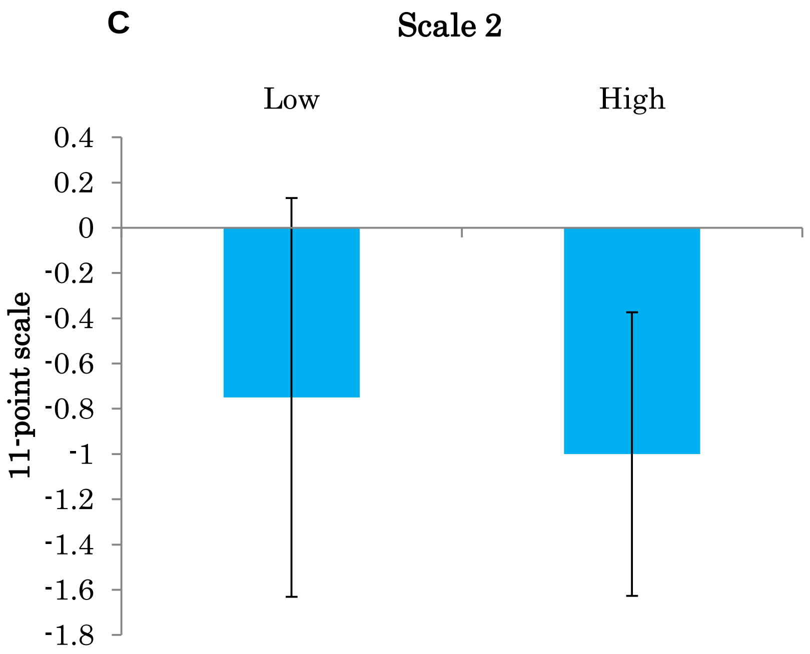


Fig. 3-4. Postdictive time estimation of the Without group.

Mean 11-point scale for the Without group divided by (A) Total SDQ score, (B) Scale 1, and (C) Scale 2 calculated across participants. Values are means ± 1SE. Low, low score subgroup; High, high score subgroup.

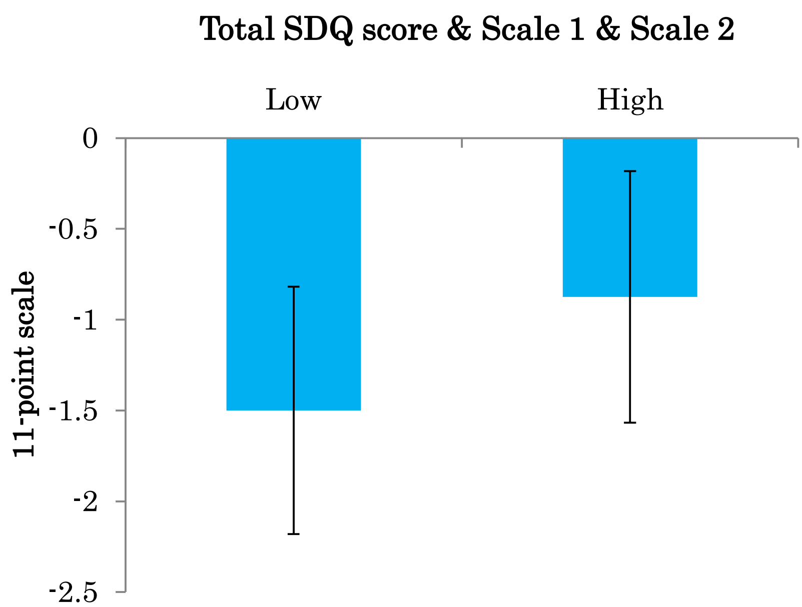
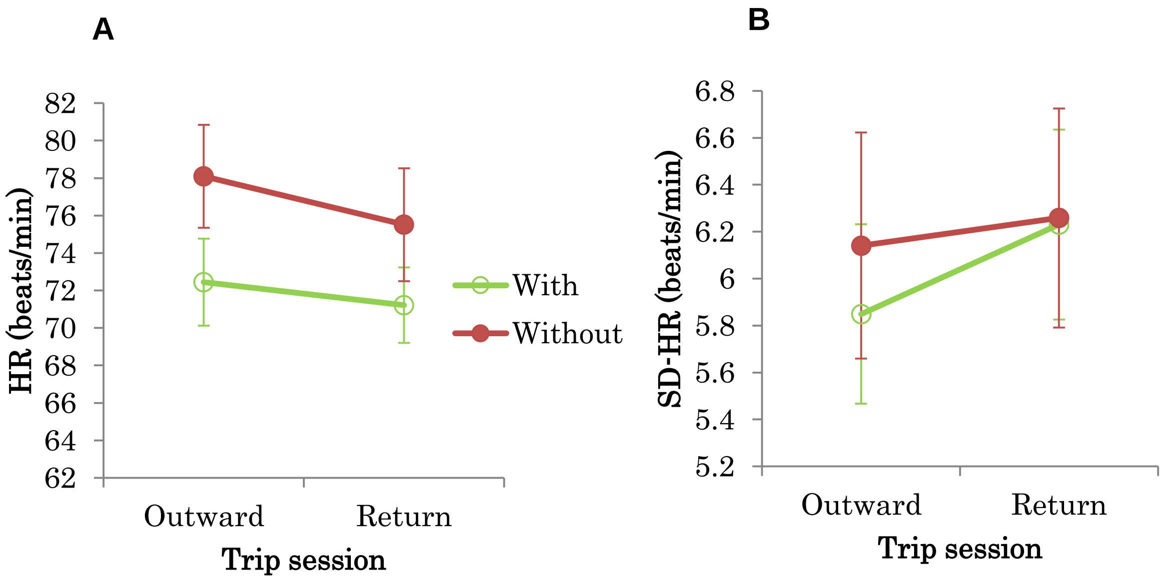


Fig. 3-5. Postdictive time estimation of the With group.

Mean 11-point scale for the With group. The results were identical when divided by Total SDQ score, Scale 1 and Scale 2. Values are means ± 1SE. Low, low score subgroup; High, high score subgroup.

3.3.3 *Autonomic neuvous function*

Variables related to autonomic nervous system are plotted in Fig. 3-6. An ANOVA on HR (Fig. 3-6A) revealed that there was a significant effect of Trip Session (F(1, 30) = 11.554 , p = .002; η_p^2 = .278) but no effect of Group or interaction. On SD-HR (Fig. 3-6B), there was no effect of Trip Session, Group, or interaction. On CVI (Fig. 3-6C), there was a significant effect of Trip Session (F(1, 30) = 5.602 , p = .025; η_p^2 = .157) but no effect of Group or interaction. On CSI (Fig. 3-6D), an effect of Trip Session approached significance (F(1, 30) = 3.264 , p = .081; η_p^2 = .098), but there was no effect of Group or interaction.



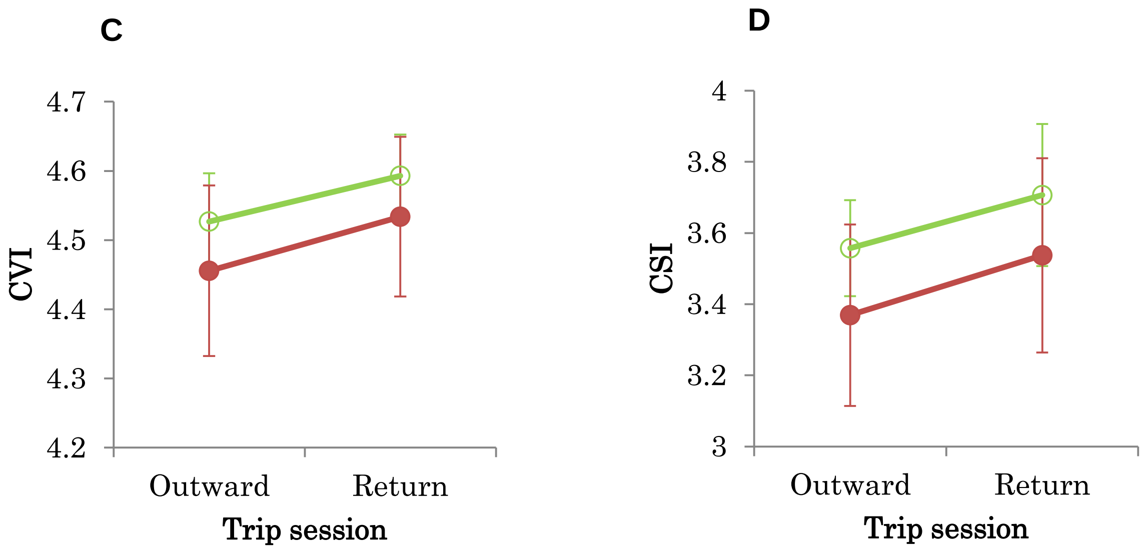


Fig. 3-6. Physiological indices.

(A) Mean HR in each condition; (B) mean SD-HR in each condition; (C) mean CVI in each condition; and (D) mean CSI in each condition, calculated across participants. Values are means ± 1SE. HR, heart rate; SD-HR, standard deviation of heart rate; CVI, cardiac vagal index; CSI, cardiac sympathetic index.

3.4 Discussion

3.4.1 *Manipulation of awareness of "return trip"*

The main purpose of this study was to investigate whether a decrease in the novelty of landscapes is essential and when we need to be aware of the "return trip" to experience the return trip effect. I addressed these issues by round trip via different routes and the instruction of the return trip. The With group, which was aware of the return trip, showed the return trip effect. In contrast, the Without group, which lacked this awareness, could, at the end of the movie, be aware of the return trip, and, thus, seemed to show a weak return trip effect. Physiological analyses also support the view that a weak return trip effect was caused in this group compared with the control group in Experiment 1. In this study, four indices were calculated to evaluate the autonomic nervous system. These four indices showed the same response patterns in both the groups. In Experiment 1, the round-trip group showed different response patterns from the control group, which suggests that the round trip would differently influence the autonomic nervous system when compared with the neutral condition. The autonomic nervous system of the Without group was not different from that of the With group, indicating a weak return trip effect in the Without group.

Fig. 3-7 shows the results of the 11-point scale in Experiments 1 and 2 according to the degree of the awareness of "return trip." The round-trip and the With groups exhibited a clear return trip effect and the Without group showed a weak effect, but the control group displayed no effect. The percentages of participants who evaluated that the first trip was longer (negative values in the 11-point scale) were 100%, 75%, 63%, and 50% for the round-trip, With, Without, and the control groups, respectively. The idea that labeling the second trip as the "return trip" is a crucial factor is compatible with Seno et al. (2011). In their study, participants evaluated that time was shorter when they were told the return trip story in comparison with other conditions. It is conceivable that awareness of the "return trip" would be a necessary factor to induce the return trip effect.

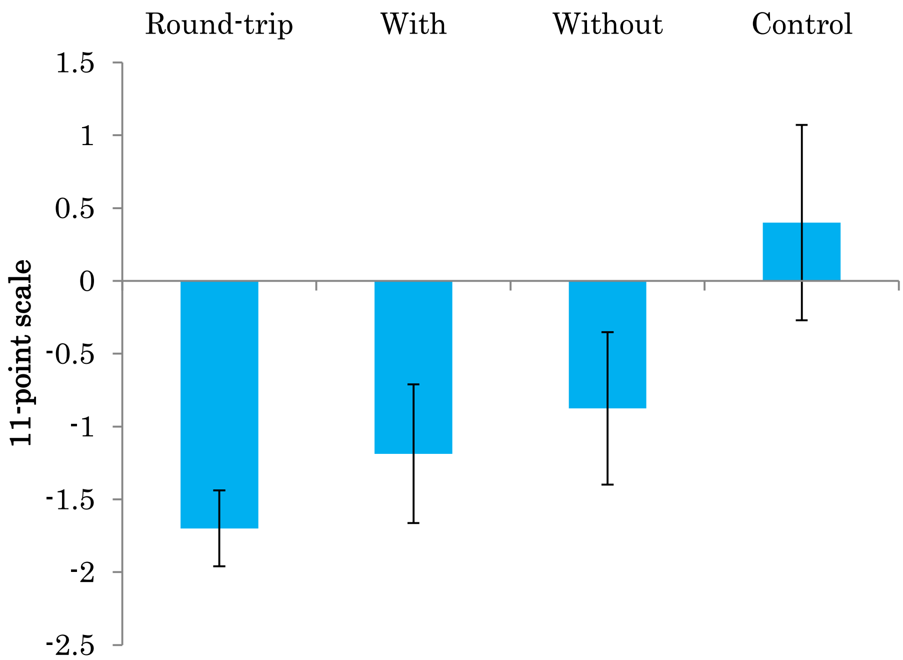


Fig. 3-7. Awareness of the "return trip" causes the return trip effect.

Mean 11-point scale for each condition. Round-trip and Control groups are cited from Experiment 1. Four conditions are aligned according to the degree of awareness of the "return trip." Values are means ± 1SE.

3.4.2 *Sense of direction in the return trip effect*

When focusing on the influence of sense of direction on the return trip effect, participants who had a poor sense of direction tended to more frequently experience it. Although the statistically significant return trip effect was observed only for the Without-Low subgroup, divided by Scale 1, almost all the Low subgroups showed a tendency to be more susceptible to the return trip effect than the High subgroups (Fig. 3-4 & -5). Two possible explanations will be discussed here. One is the difference in the ability to determine whether two routes are identical or not. In general, having an inferior sense of direction leads to losing our way (Galea & Kimura, 1993; Haga, 2003; Takeuchi, 1992; Wen, Ishikawa, & Sato, 2011). In other words, participants with a poor sense of direction may not have a tendency to detect the difference in routes. The experiment in this study used round-trip movies with different routes. Participants categorized in the Low subgroups may not have detected the difference of two routes due to shared parts at start and end points, which may have led to awareness of the "return trip" and induced the return trip effect. In contrast, participants in the High subgroups may have been able to detect this difference, which may have led to a withdrawal of awareness. In route-learning research, the performance of learning can relate to spatial ability but not to landmark memory (Galea & Kimura, 1993). This finding seems to be compatible with the largest difference between the Without-Low and Without-High subgroups, divided by Scale 1, because Scale 1 from SDQ-S is referred to as "awareness of orientation."

The other explanation refers to the relationship between sense of direction and performance of time perception. Though there are few studies investigating this relationship, Haga (2003) reported that the low-score group in SDQ-S overestimated time, which suggests that people with a poor sense of direction may also be inferior in time perception. His study used an estimation method. Here, RP3 was further investigated. To elucidate the possible relation between time perception and sense of direction, three-way ANOVAs on RP3 were conducted with the With and Without groups, as well as the subgroups of Low and High, divided by Total SDQ score, Scale 1, or Scale 2 as between-subjects factors (Group and Sense of direction, respectively) and time estimates of the outward and return trips as a within-subjects factor (Trip Session). When divided by SDQ-S scores, a main effect of Trip Session was significant ($F(1, 28) = 7.815$, $p = .009$; $\eta_p^2 = .218$; $F(1, 28) = 7.523$, $p = .011$; $\eta_p^2 = .212$; $F(1, 28) = 7.671$, $p = .010$; $\eta_p^2 = .215$; when divided by Total SDQ score, Scale 1 and Scale 2, respectively). Moreover, when divided by Scale 1, an effect of Sense of direction approached significance ($F(1, 28) = 4.032$, $p = .054$; $\eta_p^2 = .126$) (Fig. 3-8). The Low subgroup tended to underproduce in the RP3 task. In other words, participants with a low score in Scale 1 tended to overestimate time, which is compatible with Haga (2003). With respect to this issue, it is necessary to directly examine the relationship between sense of direction and performance of time perception. For example, experiments using various tasks, such as listening to music, doing arithmetic, and only measuring time, could be performed. These comparisons can provide evidence on whether time perception is related to sense of direction in general, or in specific tasks requiring spatial ability.

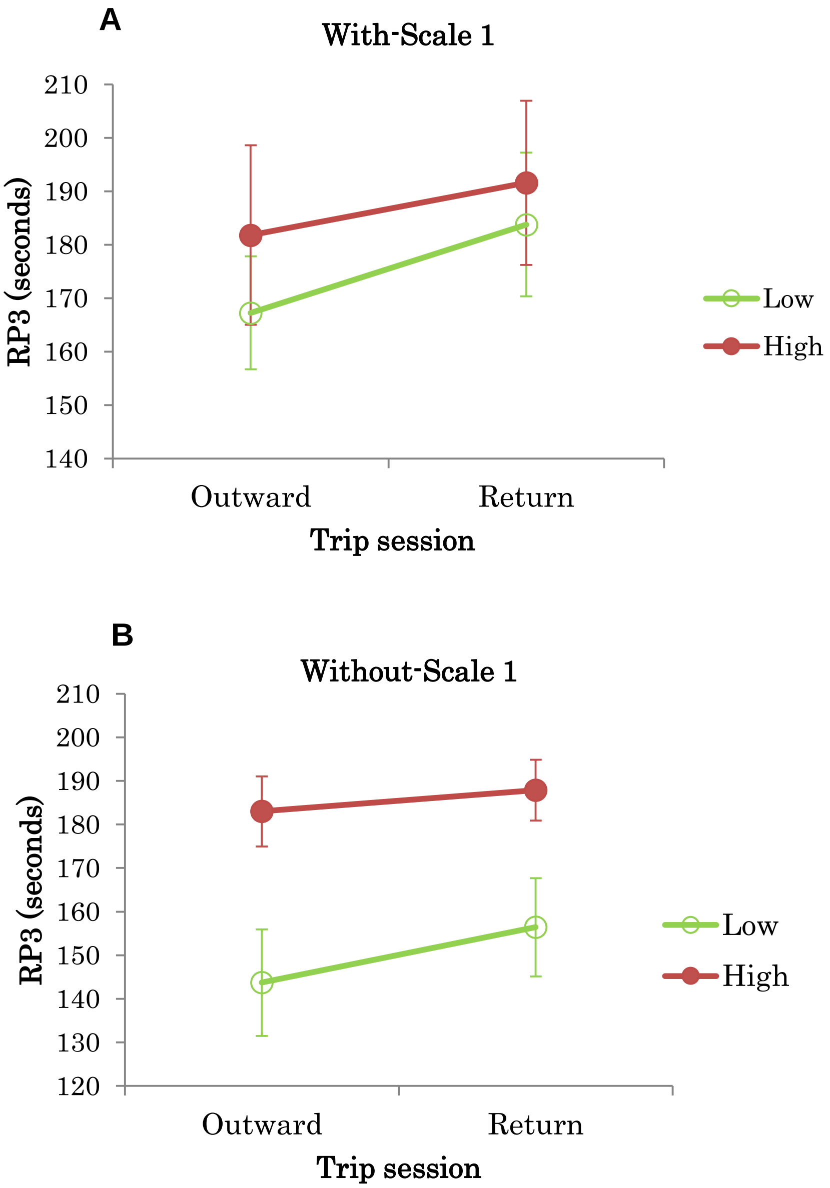


Fig. 3-8. Ongoing time estimation and sense of direction.

(A) Mean RP3 of With group and (B) mean RP3 of Without group divided by Scale 1, calculated across participants. Values are means ± 1SE. RP3, repeated production of a 3 min interval.

3.5 Conclusion

This study was designed to investigate the effect of novelty of landscapes and timing of being aware of the “return trip” on the return trip effect itself. It was revealed that although the route in the return trip was novel, a return trip effect was induced. The earlier and the more strongly participants were aware of the “return trip,” the more clearly they experienced the return trip effect, suggesting that awareness of the “return trip” is a key factor in inducing the return trip effect. I also examined the contribution of sense of direction to the return trip effect using SDQ-S. Variance in the return trip effect was explained by variance in sense of direction. Underproduction of RP3 or, in other words, overestimation of time was observed for participants with a poor sense of direction. Further studies revealing the relationship between time perception and sense of direction will provide evidence to explain the inter-subject difference in the return trip effect.

Chapter 4: Experiment 3 – Repetition of trip shortens the postdictive time perception as the return trip effect

4.1 Introduction

In Experiment 2, I suggest that the return trip effect would not be attributed to adaptation to the route but to awareness of the "return trip." However, is the return trip effect specific to the "return trip?" The characteristics of the return trip are not only having the same route with the outward trip but also having the same two endpoints. Their order is reversed in the return trip as compared with the outward trip. If the order is important, the return trip effect is observed only when the second trip is the return trip. But if the order of the two endpoints is reversible, the return trip effect is also induced when the second trip is the same trip as the outward trip. In Experiment 3, I investigated whether repetition of the trip can also make us feel that the second trip is shorter.

4.2 Materials and Methods

4.2.1 *Participants*

There were 36 participants (aged 20-32 years). All participants reported normal or corrected-to-normal vision. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Ethical Review Board of Osaka University, Graduate School of Frontier Biosciences. Written informed consent was obtained from all participants, who were paid for their participation.

4.2.2 *Procedure and tasks*

The experiment consisted of two test sessions, the first trip session and the second trip session. In both sessions, participants were asked to watch a movie recorded while walking. Before each session, they were handed a map of a route they would watch in the movie and instructed to glance at the map during the task, as if they actually were walking the route for the first time. There were two different movies: movie-1 and movie-2 (Fig.4-1). Movie-1 showed a route from “S” to “E” in Fig. 4-1A. Movie-2 showed a route from “S” to “E” in Fig. 4-1B, which meant that the route was the same as that of movie-1 but with the direction of travel reversed. The durations and distances of the two movies were equal (23.8 min, 1.7 km). Seventeen participants watched movie-1 or movie-2 in each session, and the order of movies was counterbalanced (the round-trip group). The other 19 participants watched the same movie-1 or movie-2 in both sessions (the repetition group).

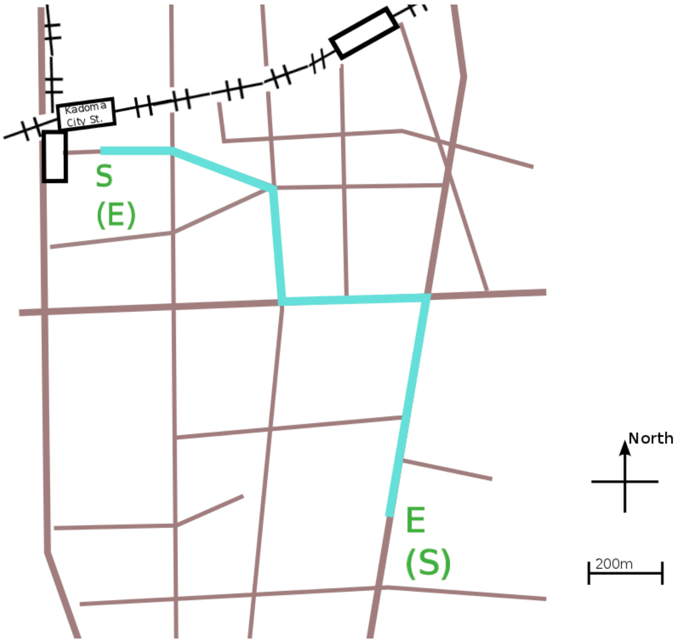


Fig. 4-1. Map of route displayed in movies.

“S” and “S” with parentheses on the maps denote the starting point, and “E” and “E” with parentheses denote the endpoint. “S” and “E” represent these points in movie-1 while “S” and “E” with parentheses represent the points in movie-2. The cyan line represents the route of movies.

Tasks participants were required to perform were the same as with Experiment 2, except that postdictive time perception was evaluated in another way. In this study, postdictive time perception was evaluated with a visual analogue scale (VAS). VAS consisted of a 200 mm horizontal line, with “the first trip was 10 min longer” at the left end, “two trips were the same length” at the center, and “the second trip was 10 min longer” at the right end. The left half of VAS meant that the first trip was longer, being represented from 0 to −100 (mm), and the right half meaning the second trip was longer, from 0 to 100 (mm).

Participants were instructed to remove their wristwatch or any rhythmical devices and not to use verbal nor nonverbal counting strategies such as“1, 2, 3…” during the tasks. Before experimental sessions, there was a practice session in which participants watched a movie and carried out the repeated production of a 3 min interval (RP3) task. The route was different from that used in test sessions. There was a rest interval for 10 min between sessions.

4.2.3 *Apparatus*

I had recorded 3 movies (movie-1, movie-2, and the movie used in the practice session) using a camera (HDR-PJ790V, Sony Marketing Inc., Japan) held in front of the chest while walking. The movies used in the first and second trip sessions were approximately 23.8 min long, and the movie in the practice session was approximately 9.0 min long. Movies were presented on a tangent screen placed 2.6 m ahead with visual angles of 14° × 26° with a projector (TH-LC80, Panasonic Corporation, Japan). The sound was played with a pair of stereo speakers (Z120, Logitech International S.A., Switzerland). Participants were tested individually in a dimly lit room and sat comfortably on a chair. At the start of the movie, a stopwatch was started and I recorded it using the camera to subsequently confirm the times of reports given verbally by participants.

4.2.4 *Statistics*

To assess the independent and combined effects of RP3, a two-way mixed-model analysis of variance (AVOVA) was conducted with the round-trip and repetition groups as a between-subjects factor (Group) and the first and second trips as a within-subjects factor (Trip Session). If a significant interaction was found, within-subject differences were analyzed for each group using two-tailed pair-wise *t* tests. To assess VAS, a two-tailed independent *t* test was used. Also, a two-tailed one-sample *t* test was used for each group to judge whether the estimation was significantly biased. Effect size was estimated using partial eta-squared (η_p^2) and Cohen's *d*. For all statistical calculations, $p < .05$ was accepted as significant. In case of multiple comparisons at follow-up analyses, the Holm correction was used to control for false positives.

4.3 Results

4.3.1 *Ongoing time estimation*

The mean RP3s are plotted in Fig. 4-2. An ANOVA on RP3 revealed that there was no effect of Group ($F(1, 34) = .80$, $p = .38$; $\eta_p^2 = .023$), Trip Session ($F(1, 34) = .76$, $p = .39$; $\eta_p^2 = .022$), nor Trip Session × Group interaction ($F(1, 34) = 1.2$, $p = .29$; $\eta_p^2 = .033$).

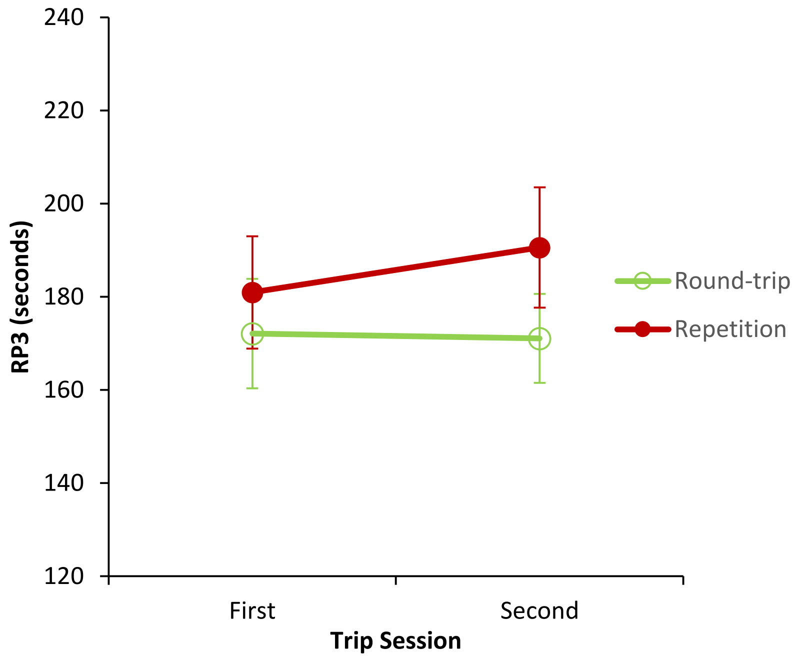


Fig. 4-2. Ongoing time estimation.

Mean RP3 in each condition, calculated across participants. Values are means ± 1SE. RP3, repeated production of a 3 min interval.

4.3.2 *Postdictive time estimation*

The mean VASs are plotted in Fig. 4-3. A two-tailed independent *t* test showed that there was no significant difference between the two groups ($t(34) = -.33$, $p = .75$; $d = .11$). However, I further analyzed the VAS scores by performing one-sample *t* tests for each group. The mean score for the round-trip group was smaller than 0 ($t(16) = -2.4$, $p = .030$; $d = -.58$), and that for the repetition group was also smaller than 0 ($t(18) = -2.2$, $p = .041$; $d = -.50$), indicating that both groups reported that the first trip was longer than the second trip.

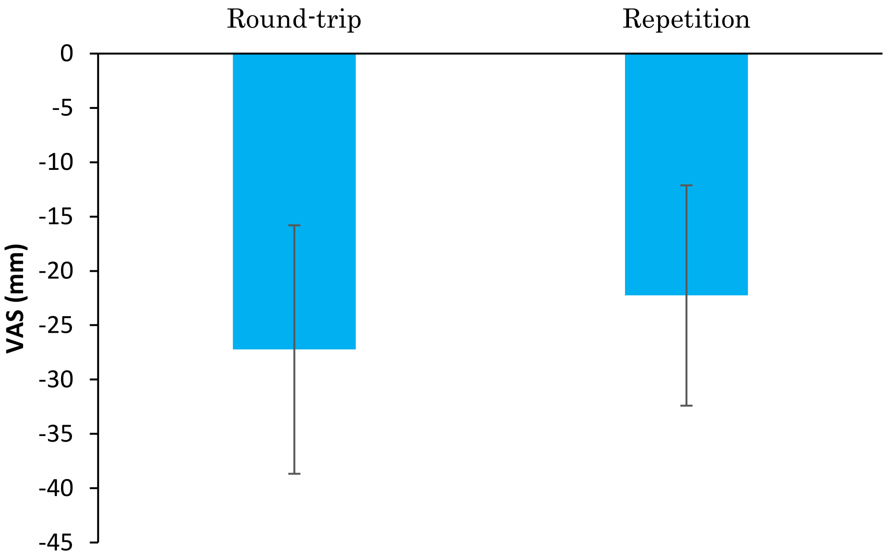


Fig. 4-3. Postdictive time estimation.

Mean VAS score in each group calculated across participants. Values are means ± 1SE. VAS, on a visual analogue scale.

4.4 Discussion

4.4.1 *Repetition of a trip can also shorten subjective time judgments*

The present results showed that not only the return trip but also repetition of the same trip shortens the passage of time judgment. It can be inferred that being aware of the “return trip” may be equivalent to being aware of the “same situation” with the previous event. It seems a more general mechanism that repetition of an event accelerates the passage of time judgment. By recognizing the return trip not as an independent event but as the same situation as with the outward trip, the return trip effect can occur.

The mean VAS score for the round-trip group was -27.2 mm and that for the repetition group was -22.3 mm. -10 mm of the VAS score in this study represents the fact that the first trip was longer by 1 min. The movies in this study were 23.8 min long. The second trip was estimated to be shorter by approximately 10%.

4.4.2 The *absence of the shift toward underestimation in ongoing time perception*

In Experiment 1 and Experiment 2, I showed participants two trip movies like the present study. In these cases, ongoing time perception measured by RP3 shifted to overproduction, that is underestimation, in the second trip session (Ozawa, Fujii, & Kouzaki, 2015). However, in this study, I did not find any changes in RP3. Thirteen of 17 participants exhibited the return trip effect in this study, whereas all10 participants did so in Experiment 1. Although I have discussed that the decrease in internal clock speed does not explain the return trip effect, the absence of the shift toward a slower clock speed may have weakened the return trip effect.

4.5 Conclusion

I found that not only the return trip but also repetition of the same trip shortened passage of time judgments. This suggests that the return trip may be recognized as repetition of the trip, rather than as an independent trip.

Chapter 5: Experiment 4 – Time is lost when you have a good sense of direction: competition between when and where streams

5.1 Introduction

In Experiment 2 I found that those who have a poor sense of direction more strongly experience the return trip effect and that they tend to overestimate or inaccurately estimate time intervals. However, the relationship between time perception and sense of direction is little known. I should further investigate the relationship as mentioned in Chapter 3. First of all, I assumed two hypotheses on the relationship.

Orientation to time (when it is) and space (where I am) are two essential functionalities, testing of which is indispensable for diagnosing dementia. It is generally accepted that lack of orientation in either domain results from dysfunctions in the medial cortical network that involves the posterior cingulate, the retrosplenial cortices, and the hippocampus (Giannakopoulos et al., 2000; Hirono et al., 1998; Kitagawa, Meyer, Tachibana, Mortel, & Rogers, 1984; Valenstein et al., 1987; Williams et al., 1989). Because both functionalities share the same medial network that is indispensable for memory function, it may be argued that temporal and spatial orientation are both based on common neural resources for memory function (Fig. 5-1A, left). If this were the case, temporal ability should correlate with spatial ability, as long as either functionality is tested in isolation (Fig. 5-1B, left). However, it is reported that the degree of disorientation in either domain does not necessarily correlate with the degree of memory deficit (Hirono et al., 1998). This led me to hypothesize another possibility that neural resources for temporal orientation is distinct from those for spatial orientation, and compete with each other for the limited total resources in the medial network (Fig. 5-1A, right). If this were the case, abilities that would reflect temporal orientation should anti-correlate with spatial ability (Fig. 5-1B, right).

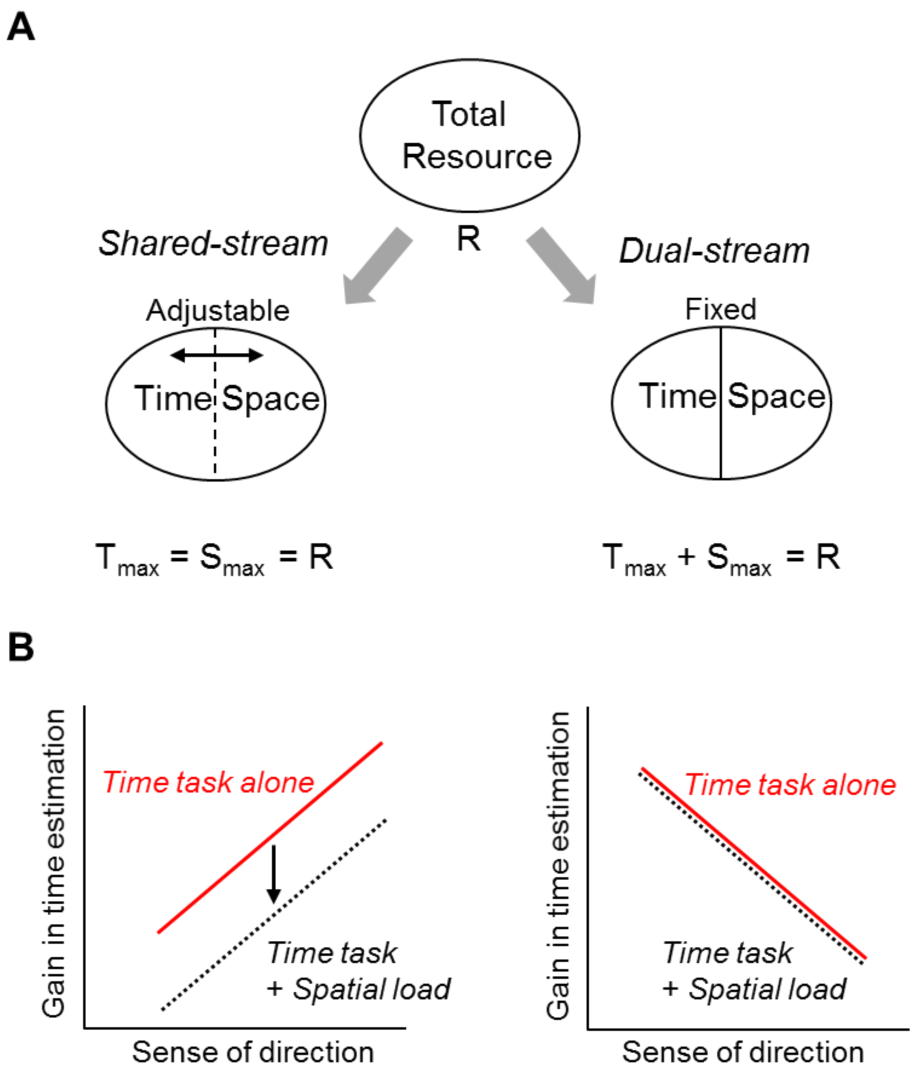


Fig. 5-1. Shared vs. dual-stream hypotheses.

(A) Total resource with size *R* is hypothesized to be shared (adjustable) in one hypothesis (shared-stream) and divided (fixed) in another hypothesis (dual-stream). The maximum resource that can be allocated to temporal functionalities (T_{max}) or special functionalities (S_{max}) equals the total resource (R) in the shared-stream hypothesis, whereas the sum of the two is equal to R in the dual-stream hypothesis. (B) Predictions from the two hypotheses. Assuming the shared-stream hypothesis is true, some ability in the temporal domain (e.g., time estimation) should correlate with that in the spatial domain (e.g., sense of direction) when tested in isolation (B *left*, red solid line; $T_{max} = S_{max} = R$). If the spatial task is also conducted, the score in the temporal domain should become smaller (B *left*, black dotted line; $T = R - S$). Assuming the dual-stream hypothesis is true, the ability in the temporal domain should anti-correlate with that in the spatial domain (B *right*, red solid line; $T_{max} + S_{max} = R$). Additional spatial load would have no effect (B *right*, black dotted line).

In the present study, I aimed to test whether the temporal and spatial functionalities for orientation share the same resources for a common function (shared-resource hypothesis; Fig. 5-1A, left), or each functionality is represented in two distinct streams (dual-stream hypothesis; Fig. 5-1A, right), by investigating the relationship between abilities in the temporal and spatial domains (Fig. 5-1B). To evaluate the ability in the temporal domain, I adopted a time production task with a target duration of 180 s: participants pressed a button twice, first when a movie or jazz music started and second when they believed that the target duration (180 s) had passed from the first button press (Fig. 5-2). The gain in time estimation (180 s/produced time) was used as an index of temporal ability because patients with temporal disorientation is known to yield smaller gain in time estimation when the target duration was longer than 10 s (Richards, 1973; Williams et al., 1989). The ability in the spatial domain was evaluated by using a standardized questionnaire for evaluating the sense of direction (the Sense of Direction Questionnaire-Short Form, SDQ-S) (Kato & Takeuchi, 2003; Takeuchi, 1992), the total score of which has been shown to correlate with actual ability in route learning (Haga, 2003; Kato & Takeuchi, 2003), the accuracy of pointing to a distant target location (Haga, 2003; Kato & Takeuchi, 2003; Takeuchi, 1992), the preference of route survey strategy (Baldwin, 2009) and activities in the middle temporal lobe while performing a maze task

(Ohnishi, Matsuda, Hirakata, & Ugawa, 2006).

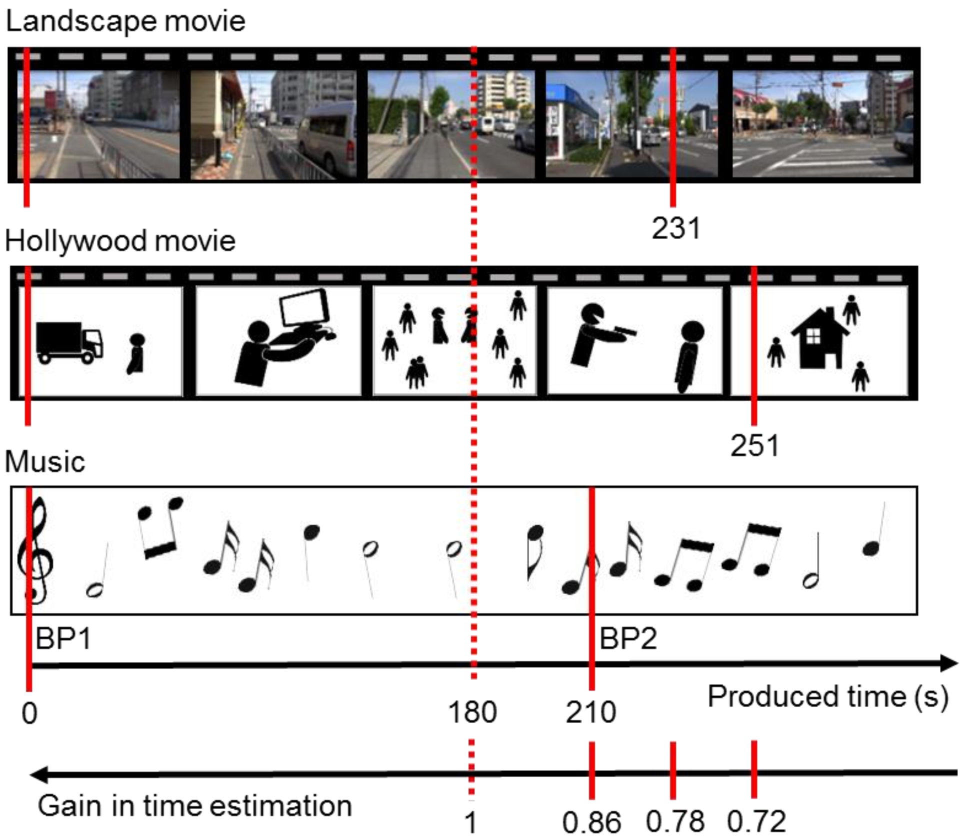


Fig. 5-2. Task procedures of one block.

Participants pressed a button twice, once when either of three stimuli (Landscape movie, Hollywood movie, or Music) started (BP1), and second when the participant thought that 180 s had passed from the first button press (BP2). The interval between the two button presses (BP1 and BP2) was regarded as a produced time. In this particular example, three stimuli were presented in the order of Landscape movie, Hollywood movie, and Music, and the produced times were 231, 251, and 210 s, respectively. It is worth noting that the participants overproduced the target duration, that is, underestimated real time passage as having been 180 s. Gains in time estimation (180 s/ produced time) were 0.78, 0.72, and 0.86, respectively.

Here I show that the gain in time estimation becomes smaller, that is, time is lost as the sense of direction becomes better.

5.2 Methods

5.2.1 *Participants*

Thirty healthy volunteers (12 females) with a mean age of 22.4 (range 20−28 years) participated in the study. All participants reported normal or corrected-to-normal vision. The experimental procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Ethical Review Board of Osaka University, Graduate School of Frontier Biosciences. Written informed consent was obtained from all participants, who were paid for their participation.

5.2.2 *Task procedures*

Participants, seated comfortably on a chair, conducted a prospective time production task in a dim room with a target duration of 180 s while they viewed video clips or listened to music (Fig. 5-2). They were required to press a button twice, first when a visual or auditory stimulus started (BP1) and second when they believed that the target duration (180 s) had passed from the first button press (BP2). Participants were told to watch movies or listen to music and not to use any counting strategies such as “one, two, three, ...” in estimating the target duration. Movies were presented on a tangent screen that was placed 2.6 m ahead with visual angles of 14° × 26° with a projector (TH-LC80, Panasonic Corporation, Japan). The sound was played with a pair of stereo speakers (Z120, Logitech International S.A., Switzerland).

Three types of stimuli were prepared: 1) landscape movies recorded while walking at approximately 4 km/h with a video camera (HDR-PJ790V, Sony Marketing Inc., Japan) held at the chest, 2) Hollywood movie clips taken from *The Matrix* (1999, Warner Bros. Entertainment, Inc.), and 3) jazz music taken from *Out to Lunch!* (1964, Blue Note Records). Five clips of each type were played. Landscape movies were prepared to implicitly activate neural circuits for navigation. The other two stimuli were prepared as visual and auditory controls.

Each participant took part in five blocks of experiments. In each experimental block, the time production task was carried out three times, once with a landscape movie, once with a Hollywood movie clip, and once with a music stimulus with an interval of 5-10 sec between the tasks. From five stimuli prepared for each type one was assigned randomly to each block. Thus, each participant viewed or listened to each of the 15 stimuli (3 types × 5 different stimuli) once in a randomized order. Participants rested 2-4 min between the blocks.

After the experiment was completed, participants were asked to answer 20 items on the Sense of Direction Questionnaire-Short Form (SDQ-S) on a 5-point scale (Kato & Takeuchi, 2003; Takeuchi, 1992). I also calculated two sub-scales: Scale 1, representing an awareness of orientation (from 9 items) (range: 9−45), and Scale 2, representing memory for common spatial behaviors (from the other 8 items) (range 8−40) (Suzuki, 2012).

5.2.3 *Data and Analyses*

I defined an interval between the two button presses as a produced time, and the target duration (180 s) was divided by the produced time to yield a gain in time estimation (subjective-to-actual duration ratio). I excluded data in the first block, and I calculated the mean of the remaining four gains for each stimulus type for each participant. To test whether time estimation correlates or anti-correlates with the sense of direction, a linear regression analysis was applied with the mean gain in time estimation as a dependent variable and the SDQ score as an independent variable. To test whether there is any effect of activating the navigational system we further applied an analysis of covariance (ANCOVA) with the mean gain in time estimation as a dependent variable, the SDQ score (total score, scale 1, or scale 2) as a covariate, and stimulus type (landscape movie, Hollywood movie, music) as a categorical independent variable. To test whether the relationship between time estimation and the sense of direction alters across trial blocks, I calculated the mean of the three gains within each trial block (Block 1, 2, 3, and 4) for each participant, and applied an ANCOVA with the mean gain in time estimation as a dependent variable, the SDQ score as a covariate, and trial block as a categorical independent variable. The gain in time estimation was logarithmically transformed before it was subjected to the regression analysis or ANCOVA. I also excluded outliers of the residuals that exceeded 1.5 times of the interquartile range measured from the 75 percentiles. Only two out of the 90 mean gains (30 participants × 3 stimulus types) were excluded as outliers from the analyses. After the logarithmic transformation and outlier exclusion, the assumption of normality was met for the gain (dependent variable) as well as for the residuals in all analyses (Lilliefors test, $p > 0.05$). I assumed that overproduction (>180 s) of the target interval – underestimation of the produced time as having been 180 s – reflects the direction of deterioration in time perception, as was associated with pathology in the medial temporal lobes (MacDonald, 2014; Mimura et al., 2000; Richards, 1973; Williams et al., 1989).

5.3 Results

5.3.1 *Negative correlation between the temporal and spatial abilities*

The mean gain in time estimation calculated for each stimulus type and participant showed a negative correlation with the total Sense of Direction Questionnaire (SDQ) score (Kato & Takeuchi, 2003; Takeuchi, 1992) (Fig. 5-3, r = −0.46, P = 0.0000080). The ability to appreciate time passage anti-correlated with that for spatial navigation, as predicted by the dual-stream hypothesis (Fig. 5-1B *right*).

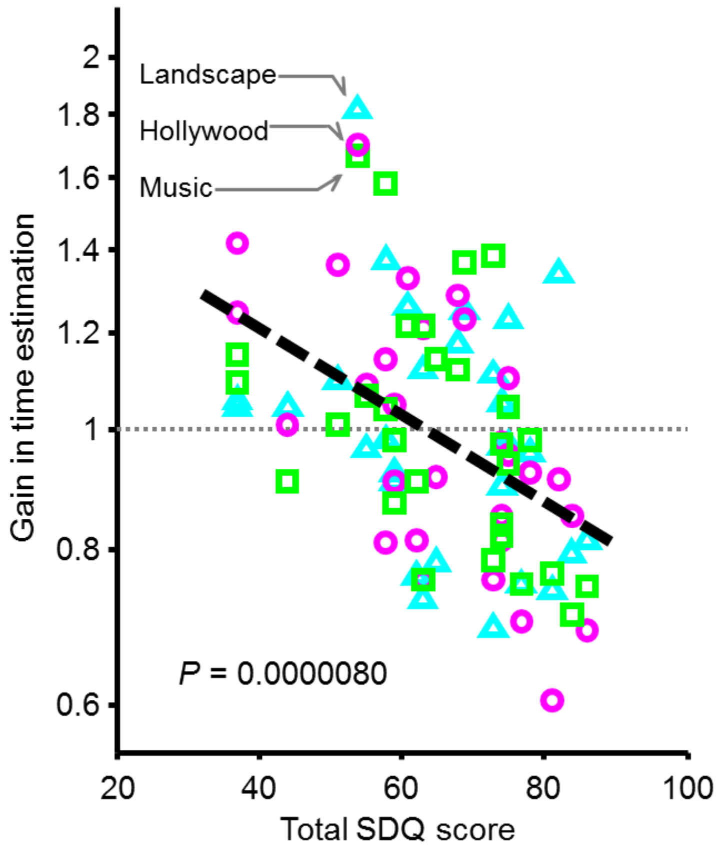


Fig. 5-3. Relationship between time estimation and sense of direction.

The mean gain in time estimation (ordinate) obtained for each experiment is plotted against the total sense of direction questionnaire (SDQ) score. Different colors and symbols show the type of stimulus: Landscape movie (cyan triangles), Hollywood movie (magenta circles), and Music (green squares). Note the negative correlation shown by the linear regression line (P = .0000080).

5.3.2 *Lack of effects of a spatial load on time production*

I presented three different stimulus types in the time production task to test the two alternative hypotheses from a different viewpoint. Assuming a single stream is used for temporal and spatial orientation, temporal functionality would be disturbed when a load for spatial navigation is concomitantly imposed on the single stream (Fig. 5-1B *left*). On the other hand, if the dual-stream hypothesis is true, a load for spatial navigation would be processed independently and would have no effect on time production (Fig. 5-1B *right*). A landscape movie, which was filmed from the viewpoint of a walker, was presented to impose an implicit spatial navigation load on the brain. Additionally, a Hollywood movie or jazz music was presented as a visual or auditory control stimulus (Fig. 5-2). An analysis of covariance (ANCOVA) with the mean gain in time estimation as a dependent variable revealed that the main effect of the total SDQ score was significant ($F(1, 84) = 22$, $P = 0.000010$, $\eta_p^2 = 0.21$), whereas neither the main effect of stimulus type ($F(2, 84) = 0.084$, $P = 0.92$, $\eta_p^2 = 0.0020$) nor the interaction between the total SDQ score and stimulus type ($F(2, 82) = 1.4$, $P = 0.26$, $\eta_p^2 = 0.032$) was significant. The lack of the significant effect of the stimulus type again supports the dual-stream hypothesis.

5.3.3 *Effects of the subscale*s

The results were unchanged when I used as a covariate either of the subscales of the SDQ score: Scale 1, which generally reflects awareness of orientation in the cardinal map coordinate (north-east-south-west), or Scale 2, which reflects memory of landmarks in the environment (Kato & Takeuchi, 2003; Takeuchi, 1992). ANCOVAs with these subscales showed that the main effect of the total SDA score was significant for either scale (Scale 1: $F(1, 84) = 15$, $P = 0.00019$, $\eta_p^2 = 0.15$; Scale 2: $F(1, 84) = 11$, $P = 0.0011$, $\eta_p^2 = 0.12$), but neither the main effect of stimulus type (Scale 1: $F(2, 84) = 0.064$, $P = 0.94$, $\eta_p^2 = 0.0025$; Scale 2: $F(2, 84) = 0.12$, $P = 0.89$, $\eta_p^2 = 0.0028$) nor their interaction (Scale 1: $F(2, 82) = 1.1$, $P = 0.33$, $\eta_p^2 = 0.026$; Scale 2: $F(2, 82) = 0.94$, $P = 0.39$, $\eta_p^2 = 0.022$) was significant.

5.3.4 *General decreases in gain with repetition*

Each participant performed one practice block and four test blocks of experiments, in each of which the time production task was carried out three times, once for each type of stimulus. When the data were analyzed for each of the four test blocks, I found that the gain in time estimation was negatively correlated with the total SDQ score across all trial blocks. However, the y-intercept of each regression line shifted toward underestimation as the experiment proceeded (Fig. 5-4). An ANCOVA with the mean gain in time estimation as a dependent variable and trial block as a categorical independent variable showed that the main effects of the total SDQ score and trial block were significant (SDQ: $F(1, 115) = 20$, $P = 0.000019$, $\eta_p^2 = 0.15$; Block: $F(3, 115) = 3.5$, $P = 0.017$, $\eta_p^2 = 0.084$) while the interaction was not significant ($F(3, 112) = 0.029$, $P = 0.99$, $\eta_p^2 = 0.00079$). Post-hoc pair-wise comparisons showed that the gain in the fourth block was significantly smaller than that in the first block after Bonferroni correction.

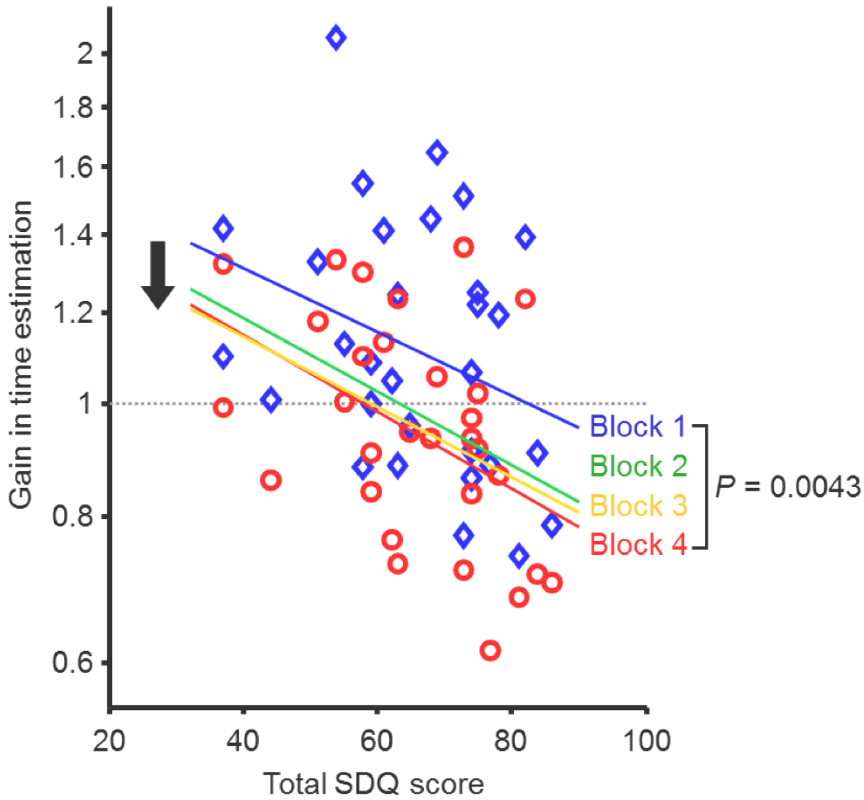


Fig. 5-4. Across-block decreases of gain in time estimation.

The mean gain in time estimation (ordinate) in the first block (blue diamonds) and the fourth block (red circles) is plotted against the total SDQ score. Note a parallel shift of the regression lines (one for each test block 1, 2, 3, and 4) in the direction of underestimation (arrow). The shift was significant between those for Block 1 and Block 4. A bracket with p-value indicates a significant difference after Bonferroni correction.

5.4 Discussion

I have here clearly shown that the ability in the temporal domain to estimate a target duration of 180 s anti-correlated with the sense of direction that was quantified by a standardized questionnaire. The results were unchanged whether participants were viewing a Hollywood movie or listening to jazz music. I further showed that implicit addition of a load of spatial navigation, by presenting a landscape movie, did not enhance the tendency of temporal underestimation. All these results support the dual-stream hypothesis that there are two distinct streams in the cortical network, one for processing temporal and the other for processing spatial information.

As for an addition of a spatial load, it could be argued that I should have imposed not an implicit but rather an explicit spatial task to enhance the tendency of underestimation. I should note here that participants with a high total SDQ score (> 60) generally underestimated the time of 180 s (Fig. 5-3). According to the argument, I should expect to observe further underestimation with an explicit spatial task. Contrary to this argument, Haga (2003) reported that participants with high total SDQ scores (mean = 78, s.d. = 7.1) *overestimated* the duration of a video taken from the viewpoint of a car driver (duration = 210 s) when they had been explicitly instructed to memorize the route in the video. The participants reported that the video was 364 s (s.d. = 181 s) in duration, which was more than 70% longer than the actual duration (210 s). The tendency of overestimation was significantly stronger (mean = 543 s, s.d. = 255 s) in the participants with low total SDQ scores (mean = 48, s.d. = 9.5). Thus, it is not likely that the tendency of underestimation would have been enhanced even if I had used an explicit spatial task.

I have assumed that smaller gains in time estimation reflect poorer ability in the temporal domain because patients with temporal disorientation generally underestimate time passage (Richards, 1973; Williams et al., 1989). However, it may be questioned if overestimation (gain > 1, underproduction) reflects superior ability. I would like to argue that overestimation is at least advantageous, not to say superior, as compared to underestimation so as not to miss a target deadline. Let us suppose for example that we pour hot water to prepare a cup of instant noodles that is optimally cooked after 180 s. In this particular situation, underestimation (overproduction) ends up in overcooking, which unfortunately cannot be undone. On the other hand, overestimation (underproduction) can be recovered just by waiting for some seconds. In catching a train, for another example, underestimation ends up in missing the train. By contrast, overestimation is rewarded by a successful boarding at a smaller cost of waiting for a while. Decent underestimation is thus generally better in cost performance than an overestimation of the same size whenever we have a target deadline.

The negative correlation was consistently observed across the four blocks of the experiments (Fig. 5-4). However, it is worth noting that the y-intercept of the regression line was the largest in the first block and gradually decreased thereafter (Fig. 5-4). A similar general decrease in the gain was observed in my previous study as well (Ozawa et al., 2015). I speculate that we generally set a stringent safety margin for time estimation in the initial occasions but ease the margin thereafter.

The results were unchanged when I used as a covariate either of the subscales of the SDQ score: Scale 1, which generally reflects awareness of orientation in the cardinal map coordinate (north-east-south-west), or Scale 2, which reflects memory of landmarks in the environment (Kato & Takeuchi, 2003; Takeuchi, 1992). The results suggest that both components of sense of direction are implemented in pathways that are distinct from those used to appreciate time passage.

How are the two streams for time and space separately represented in the brain? One probable mechanism is the allocation of separate cortical regions communicating to the hippocampus for each functionality. In agreement with this possibility, focal lesions in the right medial cortical network are reported to produce pure topographic disorientation on which way to go (right retrosplenial lesion) (Takahashi, Kawamura, Shiota, Kasahata, & Hirayama, 1997) or landmark agnosia (right parahippocampal lesion) (Takahashi & Kawamura, 2002), each of which may correspond to the loss of sense of direction measured by each subscale of the SDQ score. By contrast, no study has reported pure temporal disorientation due to a focal lesion. Temporal disorientation is reported to occur after bilateral lesions (Harvey & Arthur, 1975). The functionality for time might be more diffusely distributed than that for space. Another likely way to implement the two streams is to allocate different neuron groups within the same cortical region. Within the hippocampus, for example, recent studies have revealed the existence of time cells that are crucial for the perception of long-range intervals(Howard & Eichenbaum, 2015; MacDonald, 2014; Mankin et al., 2012) (Jacobs, Allen, Nguyen, & Fortin, 2013), in addition to place and grid cells for navigation (Chen, He, Kelly, Fiete, & McNamara, 2015; Ekstrom et al., 2003; J. Jacobs et al., 2013). Some neuron ensembles encode either time or space in particular (MacDonald, Lepage, Eden, & Eichenbaum, 2011). It is possible that cell groups for temporal and spatial processing form respective functional domains, or columns, within a focal region, as has been reported in many cortical regions (Fujita, Tanaka, Ito, & Cheng, 1992; Hubel & Wiesel, 1977; Mountcastle, 1957).

On the other hand, it is also reported that some hippocampal neurons encode both dimensions of time and space (MacDonald et al., 2011). Eichenbaum (Eichenbaum, 2014) suggested that the temporal dimension is integrated with spatial mapping in the hippocampus. Neural representations and interactions of the "when" and "where" streams, which are shown to be substantially distinct in the present study, merit further investigation.

5.5 Conclusion

I found that time is lost when participants had a better sense of direction. From the findings, I conclude that there are two distinct streams, one for when and the other for where, that compete with each other for the limited neural resources.

Chapter 6: General Discussion

6.1 Summary of the return trip effect

Previous research suggests that 73% of people have experienced the return trip effect in their daily life (van de Ven et al., 2011), but the illusion has not been replicated in the laboratory in a strict sense. I here investigated the return trip effect using ecological visual stimulus that lasted 30 min to mimic our audio-visual experience in our daily trip and a time production method and a passage of time judgment. In Experiment 1, I clearly showed that the return trip effect can be induced in the lab. Results from Experiment 1 further suggest that the effect was not due to the change in the importance of time, adaptation to the length of trip duration, or the change of internal clock speed. In Experiment 2, I examined whether the decrease in the novelty of landscapes is essential and showed that the return trip via the new route can also cause the return trip effect. The results suggest that the return trip effect is induced not by adaptation to the route of trip but by being aware of the "return trip." In Experiment 3, I showed that repetition of the same trip could shorten the passage of time judgment during the second trip. The results clearly show that the "return trip effect" does not necessarily require that the second trip be a "return" trip, as long as it is equivalent in length and in route to the first trip.

6.2 Relativity-to-reference model

Based on the results of these experiments, I propose a new account, namely, that the interaction between time expectation and perception will cause the return trip effect (Fig. 6-1). In this model, I assume that when we work on an event, we expect the duration of that event in advance. It is known that expectation of future task duration is underestimated, especially when the actual task duration exceeds 10 min (Roy, Christenfeld, & McKenzie, 2005; Roy et al., 2008). Assuming this tendency, our expectation for the outward trip should be underestimated (1 in Fig. 6-1). After the outward trip, we compare expectations and perceptions of time and feel that the outward trip was longer than we expected (2). Based on this feeling, we extend our expectation for the return trip (3). After the return trip, we compare expectations and perceptions of time. The comparison leads us to feel that the return trip was shorter than we expected (4). I call this model a "**relativity-to-reference model**" for the return trip effect.

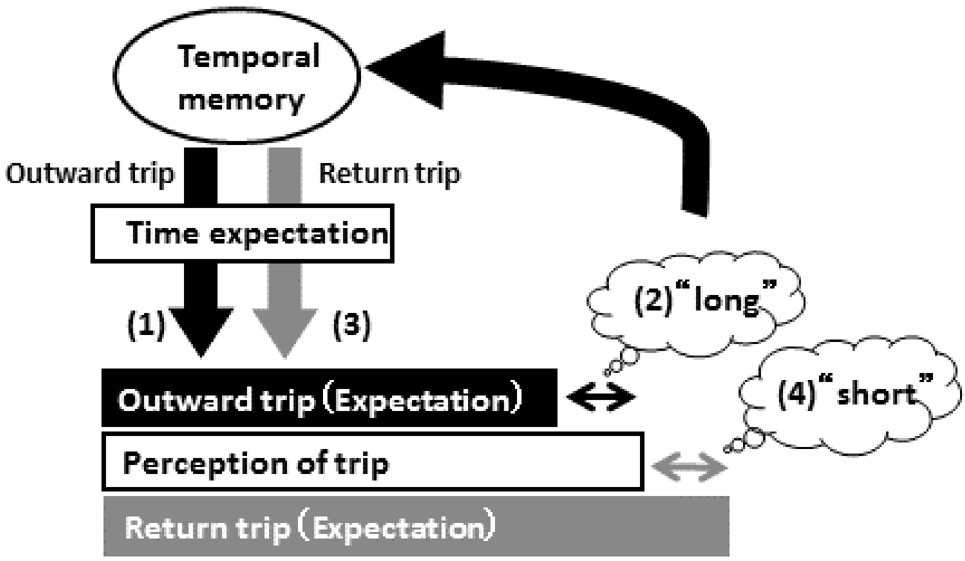


Fig. 6-1. A relativity-to-reference model for the return trip effect.

6.3 Variance in the return trip effect

I found in Experiment 2 that variance in the return trip effect was explained by sense of direction and, in Experiment 4, that the ability to appreciate time anti-correlated that of spatial navigation. If the relationship between temporal and spatial domains underlies the relationship between the return trip effect and sense of direction, the relativity to reference seems to explain the inter-subject differences of the return trip effect. Those who have a poor sense of direction and a tendency to overestimate time perceive the length of the outward trip as being longer and may feel more strongly the violation of the expectation in the outward trip. This feeling could strengthen expectations of the return trip, leading to the salient return trip effect.

6.4 Why do we not experience the return trip effect in a familiar region?

We often experience the return trip effect in our daily life in an unfamiliar familiar region. However, empirically speaking, when we are in a region familiar to ourselves, such as when we commute with a habitual route, the return trip effect seems to disappear. As mentioned above, I propose that underestimation of expectation of a first trip duration and the extension of expectation of the return trip are critical points. Although in a familiar region, we are aware of the "return trip" when making the return trip. The absence of the return trip effect seems to be a matter of expectation of an initial trip. Tobin and Grondin (2012) examined the impact of task duration knowledge with experienced swimmers. They revealed that time estimation of unknown tasks is susceptible to the effect of the secondary task. In contrast, temporal judgment on the learned task is less susceptible to the effects of the secondary task and more accurate. Even in merely visualizing physical activity, the effect of task duration knowledge can also be observed. Likewise, when we travelby a route several times, duration knowledge is acquired and helps us to expect the trip duration accurately, leading to the disappearance of the return trip effect.

6.5 Future directions

According to the relativity-to-reference model, underestimation of expectation for the initial trip leads to elongation of expectation for the second trip. Compared with time perception, expectation has been very little known. Although underestimation of expectation for a future task is well known (Roy et al., 2005; 2008), the reason for this tendency has not been adequately investigated. Expectation of future task duration must of course be based on past experiences. In other words, we can say that it is time estimation for a task done long before. When we estimate time intervals during or just after tasks, our estimations are passably accurate (Bisson et al., 2012; S. Tobin et al., 2010; S. Tobin & Grondin, 2012). This evidence may suggest that our time estimation gradually loses gain not only during the task (Experiment 4) but also after the task.

Understanding expectations of time will provide insightful suggestions about our subjective feelings of time in daily life.

We may explain other situations related to subjective feelings of time by using the relativity-to-reference model. I introduced in Chapter 1 that time flies when we have fun, whereas it drags when we have pain. We wish fun times would last a long time and that pain will end as soon as possible. These wishes may extend or shorten time expectations. I use time "expectation" instead of time "prediction" in the relativity-to-reference model because I assume that those wishes for future events could be a critical factor for our subjective feelings of time.

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Research Achievements

International Journal Papers

1. Ryosuke Ozawa, Keisuke Fujii, Motoki Kouzaki. The Return Trip Is Felt Shorter Only Postdictively: A Psychophysiological Study of the Return Trip Effect. *PLOS ONE*, Public Library of Science, 10(6), e0127779, 2015. doi:10.1371/journal.pone.0127779

2. Ryosuke Ozawa, Shigeru Kitazawa. Time is lost when you have a good sense of direction: competition between when and where streams, in revision.

International Conferences

3. Ryosuke Ozawa, Keisuke Fujii, Motoki Kouzaki. The return trip effect is postdictively induced and breaks the relationship between time perception and parasympathetic nervous system activity. 17th World Congress of Psychophysiology, Hiroshima, Japan, 2014/9/25

4. Ryosuke Ozawa, Shigeru Kitazawa. Time flies when you have a good sense of direction. 31st International Congress of Psychology, Kanagawa, Japan, 2016/7/26

5. Ryosuke Ozawa, Shigeru Kitazawa. Why do we feel the return trip being shorter? Workshop/symposium: philosophy of mental time Ⅳ - time, experience, and consciousness, Osaka, Japan, 2016/2/1

6. Ryosuke Ozawa, Shigeru Kitazawa. Time flies when you have a good sense of direction. International Symposium on the Science of Mental Time, Tokyo, Japan, 2015/9/12-13

7. Ryosuke Ozawa, Shigeru Kitazawa. Time is lost when you have a good sense of direction. Time in Tokyo: International Symposium on temporal perception and experience, Tokyo, Japan, 2016/10/11-12

Domestic Conferences

8. Ryosuke Ozawa. Why does the return trip feel shorter? CiNet Friday Lunch Seminar, Osaka, Japan, 2015/12/4

9. 小澤良祐・藤井慶輔・神﨑素樹，往復効果における身体活動の影響，日本基礎心理学会第33回大会，東京, 2014/12/7

10. 小澤良祐，なぜ帰り道は短く感じられるか？，第 6 回早稲田大学心理学コース研究発表会，東京, 2016/2/20

Awards

11. 日本学術振興会特別研究員 DC2 (平成 27-28 年度), 「往復効果の認知神経メカニズム」

12. 日本学術振興会特別研究員 PD　採用内定 (平成 29-31 年度), 「どのように時間を覚えるか？-回想的時間知覚の神経基盤の多面的解明-」

Media coverage

13. Context Matters When It Comes to Travel Time. *Scientific American*, 2015/06/11

14. The trip back home often seems to go by faster -- but why? *Los Angeles Times*, 2015/06/10

15. The science behind why the return-trip always feels shorter than the trip there. *The Washington Post*, 2015/06/11

16. The return trip effect: why the trip home always feels shorter than the trip there. *VOX*, 2015/06/10

17. Scientists discover the ‘return trip effect’ is only felt retrospectively. *The Christian Science Monitor*, 2015/06/11

18. Scientist try to explain why the trip home always seems shorter. *USA TODAY*, 2015/06/14

19. Why return journeys really DO feel shorter. *Daily Mail*, 2015/06/10

20. Perché il ritorno sembra più breve dell'andata? *Le Scienze*, 2015/06/11

21. Science says return trips often feel quicker and shorter whey they really aren’t. *Business Insider Australia*, 2015/06/11, etc., over 8 countries and over 30 articles.