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ORIGINAL RESEARCH

Effects of self-selected task content on the P300 component and reaction times

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Abstract

OBJECTIVES: The purpose of this study was to evaluate the effect of self-selection on motivation by measuring event-related potentials (ERPs) and reaction times (RTs), which are indicators of cognitive processing.
DESIGN: Twenty healthy young Japanese adults participated in this study. The experiment performed had two conditions: a self-selection condition (the participant chooses the target stimulus) and a forced-selection condition (the target stimulus is specified by the others). Participants performed RT tasks under each condition, and ERPs were measured during the tasks. Subsequently, we analyzed the P300 component of the ERPs.
RESULTS: In the self-selection condition, the P300 amplitude was significantly larger, and the RT was significantly shortened compared to the forced-selection condition. There was no significant difference in P300 latency between the self-selection and forced-selection conditions. Participants preferred to complete tasks in the self-selection condition.
CONCLUSION: Our findings suggest that self-selection enhances motivation and task performance. These results are important for promoting the supportive and rehabilitative effects of therapy for clients with reduced motivation.

Introduction

During rehabilitative therapy, it is important to motivate clients, as it is well known that psychological factors such as motivation can improve physical function and independence in performing daily activities (Lenze *et al.* 2004; Talkowski *et al.* 2009; Skidmore *et al.* 2010; Yang & Kong 2013). In particular, intrinsically motivated behavior is important. For example, patients should be encouraged to undertake training to achieve their own goals even if external rewards are not obtained. In the field of psychology, many studies on motivation have been conducted, indicating that self-determination enhances motivation and increases the achievement rate in tasks. Patall *et al.* (2008) conducted a meta-analysis of 41 studies and examined the effect of choice on intrinsic motivation and related outcomes in a variety of settings. Their results indicated that providing participants with options improved inherent motivation, effort, and work performance, among other outcomes.

Recently, neuroscientific studies on motivation have been conducted, most of which have focused on external motivation by using external rewards such as money (Pessiglione *et al.* 2007; Minamimoto *et al.* 2009). However, the neural basis of intrinsic motivation has also been reported using the undermining effect (Murayama *et al.* 2010). The undermining effect acts to lower intrinsic motivation by providing external reward when working on a task on the basis of intrinsic motivation. Several studies have also reported the effect of self-determination on motivation using functional magnetic resonance imaging (fMRI). Activity in regions of the brain reward system, such as the ventromedial prefrontal cortex (vmPFC), pallidum, and midbrain, is higher in conditions in which participants select the tool to be used for the task rather than having the tool specified by others. Moreover, the self-selection condition was found to be associated with significantly better task performance.

Activity in the vmPFC was significantly greater in response to task success than it was in response to failure under the forced-selection condition, but it was not significantly different under the self-selection condition. This supports the psychological theory that failure can be interpreted positively, in addition to success, when there is a strong sense of self-determination (Murayama *et al.* 2015). The anterior insular cortex (AIC), known to be related to a sense of agency, shows greater activation during self-determined behavior, while the angular gyrus, known to be related to a sense of loss of agency, shows greater activation during non-self-determined behavior (Lee & Reeve 2013). Furthermore, activation of the AIC decreases, and the angular gyrus is activated during non-self-determined behavior (Lee & Reeve 2013). Anticipation of choice opportunities is associated with increased activity in a network of brain regions assumed to be involved in reward processing, and participants prefer to have the opportunity to choose (Leotti & Delgado 2011).

These previous studies suggest that it is important to ensure self-determination to increase motivation. In rehabilitation clinical practice, we suggest that allowing clients to choose activities and letting them feel that they have "decided by themselves" may increase their motivation for rehabilitation, enabling clients to participate independently. Since regions of the brain reward system are activated by self-selection, it is predicted that cognitive processing in the brain is promoted, but there are few studies that have examined the effect of self-selection on event-related potentials (ERPs).

ERPs are of major importance in the study of cognitive processes and the way these processes are implemented in the brain. ERPs are represented on an electroencephalogram (EEG) that is generated in relation to an event. They have superior temporal resolution as compared with fMRI and similar techniques. Additionally, ERP recording is compatible with cognitive experiments measuring RTs. Among ERPs, the P300 component is the most characteristic endogenous component. It is recorded from the scalp as a positive voltage with a latency of approximately 300 ms following an event. The latency and amplitude of P300 are considered to reflect cognitive processing time (Kutas *et al.* 1977) and the amount of attentional resources allocated (Schubert *et al.* 1998), and these measures have been used in numerous cognitive studies. Therefore, in this study, we aimed to examine the effect of self-selection on cognitive processes and task performance reflected by ERPs and RTs.

Material and methods

Participants

Twenty healthy volunteers participated in this study (male, n = 10; mean age, 26.0 ± 4.4 years). All participants had normal or corrected-to-normal vision. None of the participants had a history of neurological or psychiatric disorders. The study was approved by Nishikyusyu University's research ethics committee and conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants, but patients were not told the aim of the experiments to avoid the effect of information and intended bias on all data.

Task and visual stimuli

For the experimental task, we measured visual RTs. We used the pictures of nine famous characters (Fig. 1, A–I) as visual stimuli. By referring to a survey conducted by the Japan Research Center (2016), we selected well-known characters who have a wide range of fans from young to elderly people.

We presented visual stimuli with a Multi trigger system (Medical Try system, Tokyo, Japan). The picture with the character was presented at a size of 15 × 15 cm at the center of a 15-inch liquid crystal display monitor screen against a black background. The stimulus was presented according to the oddball paradigm. The stimulus was randomly presented, with the target presented on 30% of presentations and a non-target stimulus on 70% of presentations, with a total of 40 target stimuli. Each stimulus was presented for 0.5 s and delivered at a frequency of 0.5 Hz.

EEG recordings and analysis

In this study, we used the electromyogram inspection device MEB-2300 Neuropack X1 (Nihon Kohden Corporation, Tokyo, Japan) for EEG measurements and EPLYZER2 (Kissei Comtec Co. Ltd., Matsumoto, Japan) to measure evoked potentials. EEGs were recorded with Ag/AgCl disk electrodes placed at the Fz, Cz, and Pz positions according to the International 10-20 system. Each scalp electrode was referenced to linked earlobes.

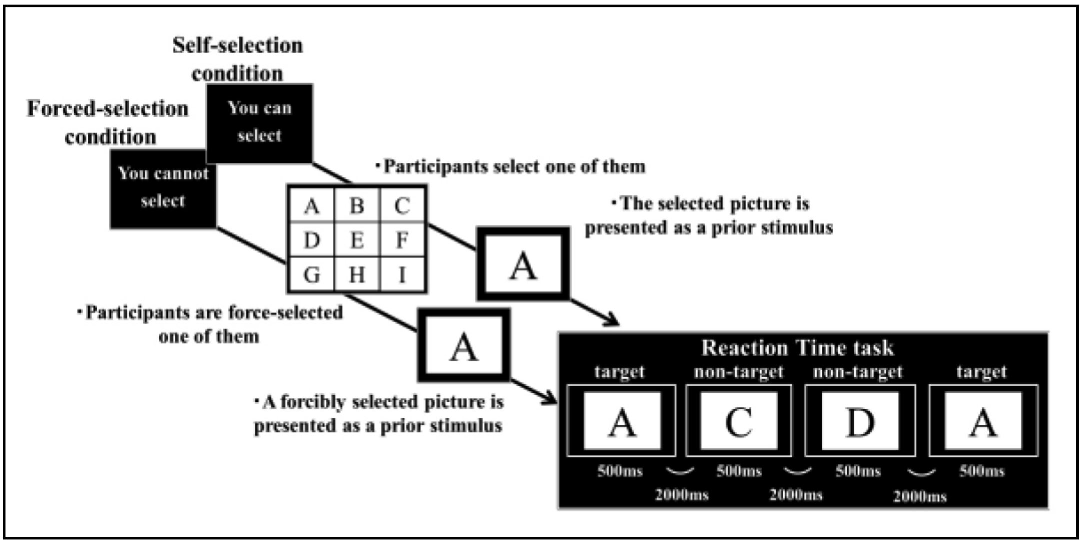

Fig. 1. The procedure for the self-selection and forced-selection conditions
Letters A–I represent the pictures of characters. Self-selection condition: The examiner instructed participants that they could make a selection at the beginning of the experiment. Subsequently, pictures of nine different characters were shown on the computer screen, one of which was selected by the participant. Forced-selection condition: The examiner instructed the participants that they could not make a selection, and a forcibly selected picture of a character was shown on the computer. To prevent the experimenter effect in the forced-selection condition, a third party who was not informed of experimental details selected the target stimulus.

The ground electrode was placed at the Fpz position. To eliminate eye movements or blinks exceeding 100 μV, electrooculograms were also recorded. Electrode impedance was kept below 5 kΩ. The EEG was digitized at a sampling rate of 1000 Hz. The analysis epoch for ERPs was 1000 ms, including a prestimulus baseline period of 100 ms. The peak amplitude and latency of the P300 components were measured at 300–500 ms. When measuring the peak amplitude and latency of the P300 component, some participants showed double peaks of P300. In this case, we selected the largest peak waveform.

Procedure

Following a practice round of the RT task, participants performed the task under two conditions: a self-selection condition and a forced-selection condition. ERP measurements were obtained for each participant in each task (Fig. 2). Each condition was randomly set, and a two-minute break was allowed during the session.

During the practice of the task, pictures not related to the famous characters used in our experiments were used as visual stimuli. In the self-selection condition, the examiner instructed participants that they could make a selection at the beginning of the experiment. Subsequently, pictures of nine different characters were shown on the computer screen, one of which was selected by the participant. In contrast, in the forced-selection condition, the examiner instructed the participants that they could not make a selection, and a forcibly selected picture of a character was shown on the computer in the same way as in the self-selection condition. To prevent the experimenter effect in the

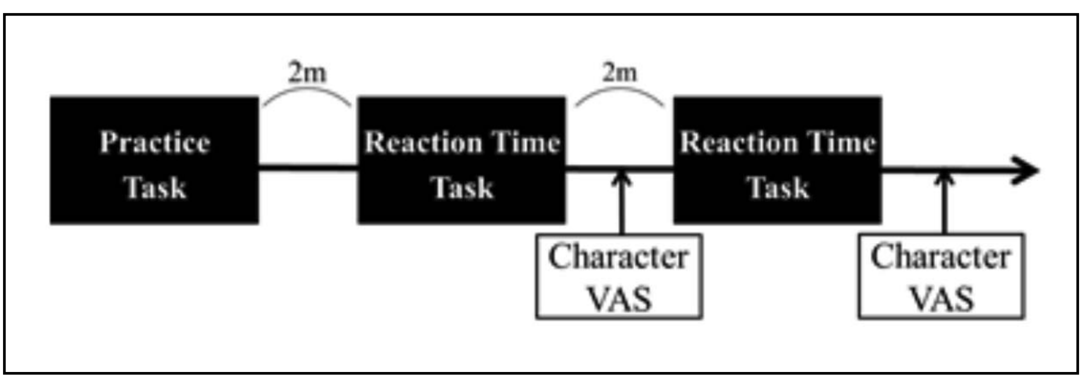

Fig. 2. Depiction of the experimental procedure
For each reaction time task, the self-selection and forced-selection conditions were executed at random. The task under the self-selection condition and the forced-selection condition was terminated when the target stimulus was presented 40 times.

Tab. 1. Mean (±SD) amplitude and latencies of P300 under each condition

		self-select	forced-select			self-select	forced-select
Amplitude (μV)	Fz	4.27±2.23	3.18±1.19	Latency (ms)	Fz	365.1±26.7	359.9±30.0
	Cz	5.42±2.56	4.41±1.24		Cz	358.6±23.1	359.8±30.0
	Pz	5.16±2.37	4.42±1.17		Pz	352.1±23.5	355.6±34.5

forced-selection condition, a third party who was not informed of the experimental details selected the target stimulus. The procedures for the self-selection and forced-selection conditions are shown in Fig. 1.

In each condition, the selected (or forcibly selected) picture was taken as the target stimulus, and the remaining eight pictures were taken as the non-target stimuli. RTs were measured after participants responded to the target picture on the computer screen. In both conditions, participants counted the number of times that the target stimulus was presented without talking. Participants were instructed to push a button as soon as possible after the target stimulus was presented. In addition, participants indicated how much they liked the character (self- or forcibly selected) in each condition using a visual analogue scale (VAS). The VAS was a 10 cm line marked from 0 (not at all) to 10 (like a lot). When the experiment finished, we confirmed in which condition the participants worked more positively on the task.

<u>Data analysis</u>

For analysis of the P300 component, the peak amplitude and latency were subjected to Wilcoxon signed-rank tests (self-selection condition vs. forced-selection condition) at each electrode (Fz, Cz, and Pz). Behavioral data (mean RTs) were subjected to paired t-tests (self-selection condition vs. forced-selection condition). To understand whether differences were statistically meaningful, Cohen's *d* value (>0.2 indicates a small effect, 0.5-0.8 indicates a medium effect, >0.8 indicates a large effect) for t-tests and *r* values (>0.1 indicates a small effect, 0.3-0.5 indicates a medium effect >0.5 indicates a large effect) for Wilcoxon signed-rank tests were used. For the correlation analysis, the relationship between P300 amplitude and VAS ratings, used to tell how well-liked a character is, was measured using Pearson's correlation coefficient. Statistical analyses were performed with SPSS version 24.0 (IBM Corp., Armonk, NY).

Results

We analyzed data from 17 participants who completed 20 or more target trials under each condition (Cohen & Polich 1997), while excluding artifacts such as eye movements (male, n = 8; mean age, 26.3 ± 4.6 years).

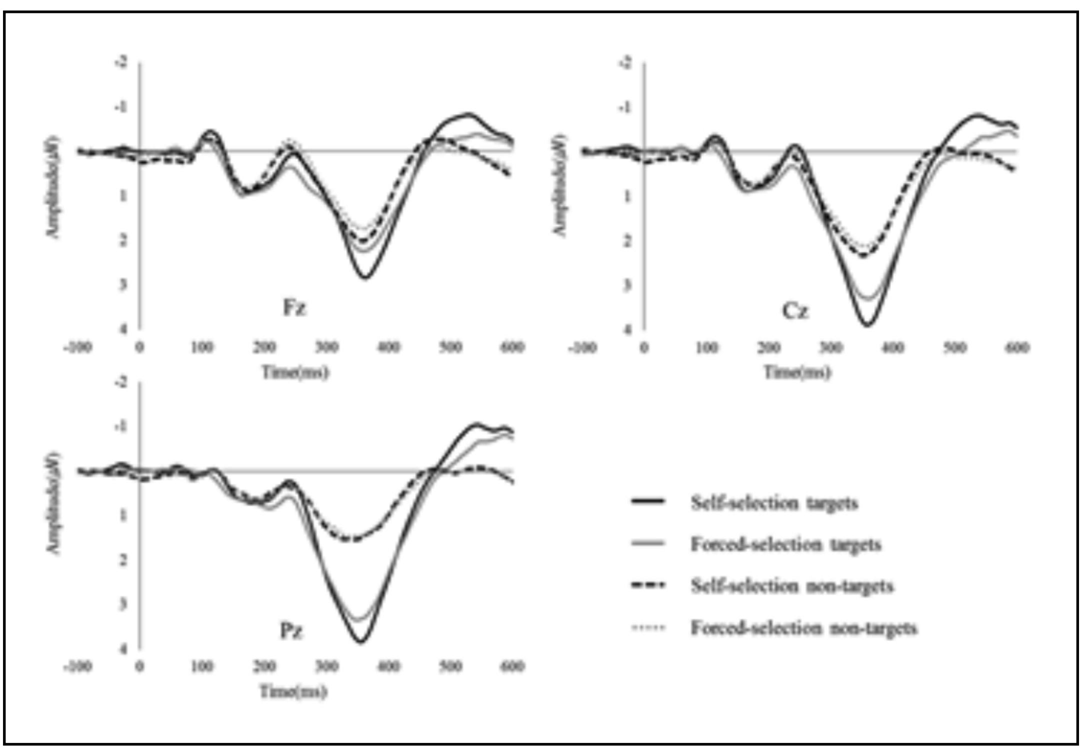

Fig. 3. Grand-average ERP waveforms of P300 at each electrode (Fz, Cz, and Pz)

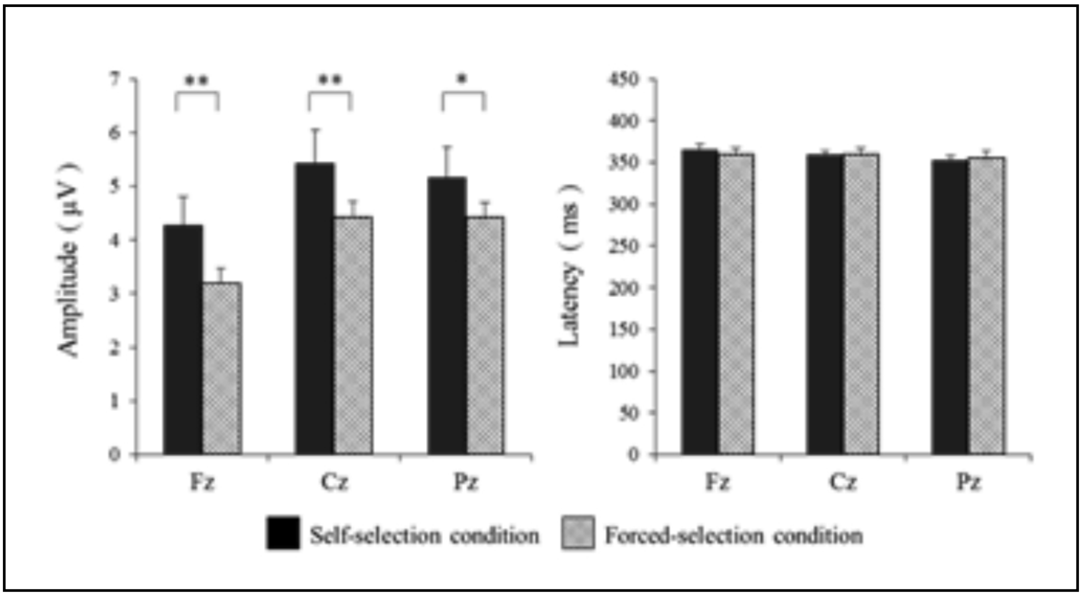

Fig. 4. Comparison of P300 amplitude and latency between the self-selection and forced-selection conditions (Wilcoxon signed-rank test, *$p < 0.05$, **$p < 0.01$)
P300 amplitude is significantly larger in the self-selection condition compared to the forced-selection condition at all electrode positions. P300 latency did not significantly differ between the self-selection and forced-selection conditions at any electrode position.

Nine of the 17 participants first performed under self-selection conditions.

The amplitude and latency results for P300 are shown in Table 1, and the grand average waveform of each condition for the 17 participants is shown in Fig. 3.

P300 amplitude and latency

Results for P300 amplitude and latency are shown in Figure 4. We observed a significant increase in P300 amplitude in the self-selection condition compared to the forced-selection condition at all electrode positions (Fz: $p < 0.01$, $r = 0.74$; Cz: $p < 0.01$, $r = 0.64$; Pz: $p < 0.05$, $r = 0.48$). In contrast, there was no significant difference in P300 latency between the self-selection and forced-selection conditions at any electrode position.

There was no significant correlation between P300 amplitude and the favorite character's VAS score in the self-selection condition (Fz-0.01: $p > 0.05$; Cz-0.09: $p > 0.05$; Pz-0.13: $p > 0.05$). Even in the forced-selection condition, there was no significant correlation between P300 amplitude and the favorite character's VAS score (Fz-0.13: $p > 0.05$; Cz-0.20: $p > 0.05$; Pz-0.22: $p > 0.05$).

Behavioral results

Results for the RTs and coefficients of variation (CV) are shown in Figure 5. Participants had a mean RT of 355.4 ± 34.8 ms in the self-selection condition and 368.4 ± 25.9 ms in the forced-selection condition, showing a significant shortening under the self-selection condition ($p < 0.05$, $d = 0.42$). The CV was calculated from the mean and standard deviation of the RT. The CV was 0.12 ± 0.03 in the self-selection condition and 0.14 ± 0.02 in the forced-selection condition, which represented a significantly smaller value in the self-selection condition ($p < 0.05$, $d = 0.67$).

Finally, when questioned after the experiment, 16 of the 17 participants (94%) responded that they took to the challenge of the task more positively in the self-selection condition than they did in the forced-selection condition.

Discussion

In this study, we examined the effect of self-selection on P300 and RTs. We observed that in the self-selection condition, P300 amplitude increased significantly, and RTs were significantly shortened. However, there was no significant difference between the conditions in P300 latency. When questioned after the experiment, 94% of participants reported approaching the task more positively in the self-selection condition.

The amplitude of P300 reflects attention resource allocation, and during an intrinsically motivating and interesting task, P300 amplitude increases compared to a control task. This suggests that the dynamics of intrinsic motivation are reflected by the amplitude of a specific ERP component, such as P300 (Jin *et al.* 2015). In a study investigating psychological effects in a brain-computer interface (BCI) controlled with ERPs, P300 amplitude was significantly greater in the most motivated participants compared with the least motivated participants (Kleih *et al.* 2010). Furthermore, Baykara *et al.* (2016) investigated training effect on auditory P300 in a BCI and reported a significant correlation between motivation and P300 amplitude. Studies investigating motivation during attention tasks have

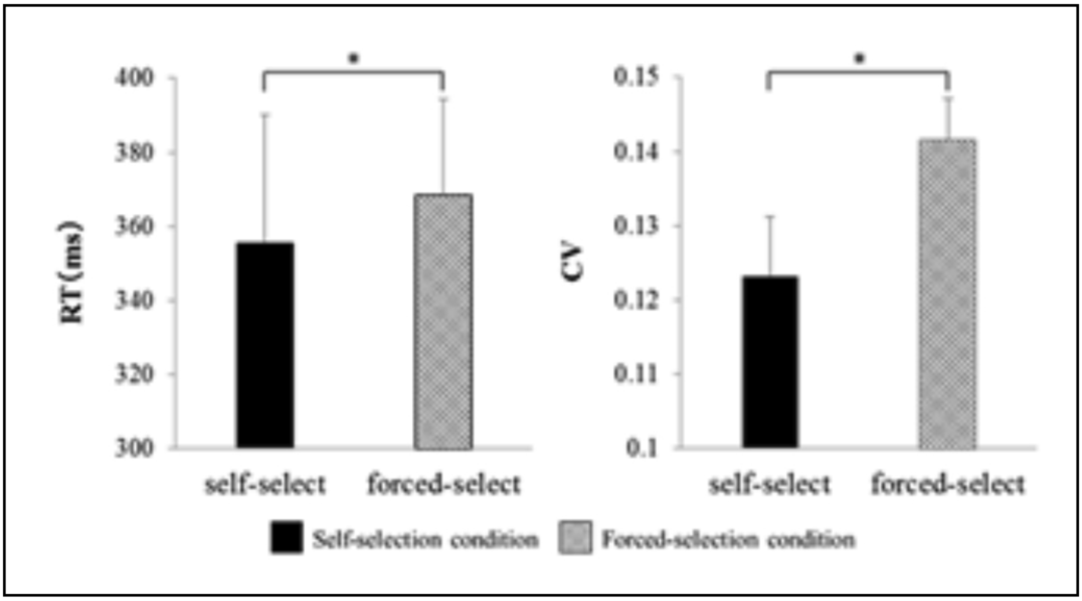

Fig. 5. Comparison of RT and CV between the self-selection and forced-selection conditions (paired t-test, $*p < 0.05$) RTs were significantly shorter in the self-selection condition, and CV was significantly smaller in the self-selection condition.

reported that motivation has effects on both orienting and reorienting of exogenous spatial attention (Engelmann & Pessoa 2007) and that motivation enhances the effects of attention (Engelmann *et al.* 2009).

Although the origin of P300 is not clearly defined, there are several reports suggesting brain regions that are related to P300 (Polich 2007). The P300 wave recorded from the scalp comprises at least two subcomponents: P3a and P3b (Knight & Scabini 1998). P3a occurs irrespective of task execution and is related to attention mechanisms passively induced by external stimuli (i.e., passive attention). In contrast, P3b occurs when detecting a target stimulus in accordance with the instructions of a task (i.e., active attention) (Squires *et al.* 1975). P3a is associated with brain regions such as the dorsolateral prefrontal cortex, inferior parietal cortex, and cingulate cortex, while P3b is associated with brain regions such as the ventrolateral prefrontal cortex, superior temporal sulcus, intraparietal sulcus, and medial temporal lobe (Halgren *et al.* 1998). In the current study, it is possible that our results reflect the P3b subcomponent, because the task carried out required positive attention to the target stimulus, and P300 occurred predominantly in central and parietal regions rather than frontal regions. Previous studies have clearly shown that P300 amplitude increases when motivation is high or when attention is positively directed to a target stimulus. Therefore, our results show that motivation for the task increased during self-selection, which in turn increased the attention resource allocation for the target stimulus and increased the P300 amplitude.

We did not observe a significant correlation between P300 amplitude and the favorite character's VAS score in either condition. P300 amplitude is considered to reflect the degree of interest in a stimulus (Suzuki *et al.* 2005). Therefore, we predicted that the P300 amplitude for a specific character increased as the subject's liking of them increased, but our results did not confirm this. However, we suggest that this result reflects changes in motivation for the task determined by the self-selection condition, rather than changes due to preference. Although interest and preference are considered to be important factors in motivation, we suggest that motivation is enhanced by self-selection irrespective of preference.

P300 latency and RT are scales reflecting the time of intentional processing of stimulus information from the outside. Some studies suggest that there is a correlation between P300 latency and RT (Kutas *et al.* 1977; Pfefferbaum *et al.* 1983), while others do not (McCarthy & Donchin 1981). P300 latency reflects the time from stimulus input to the completion of stimulus evaluation. RTs reflect the response to the stimulus in addition to stimulus evaluation that is reflected by P300 latency (Duncan-Johnson 1981). In the current study, we did not observe any significant differences in P300 latency between the conditions, but RTs were significantly shorter in the self-selection condition. That is, under the self-selection condition, we suggest that within information processing, stimulus evaluation processing did not change. Nonetheless, faster processing could be performed during response. P300 latency is longer in tasks in which identification of the stimulus is difficult (McCarthy & Donchin 1981). Thus, in this study, P300 latency may not have been affected by the different conditions, since stimulus presentation was simple. In addition, RTs are often used as a test of attention. The CV for the RT indicates variations in attention, with smaller values indicating greater concentration on a task. In this study, we observed not only shorter RTs but also smaller values for CV in the self-selection condition. We suggest that not only is the reaction process faster due to self-selection, but also that subjects may be able to focus more intensively on the task at hand.

Finally, we observed that many participants preferred the self-selection conditions. Within self-determination theory (Deci & Ryan 1985), self-determination is a sense that one is acting spontaneously without being bound by anything. In situations in which there is an increased feeling of self-determination, there is an increase in intrinsic motivation. Therefore, satisfying the need for self-determination can greatly contribute to intrinsic motivation. Choice is a means whereby individuals can control their environment, and a sense of control is thought to be important for well-being (Ryan & Deci 2006). We suggest that the reason that participants preferred the self-selection condition was that they were not compelled by others and had an increased sense of self-determination by being able to make selections.

Several limitations to our study should be noted. In rehabilitation clinical practice, we often provide activities that are familiar to clients to enhance their motivation. Therefore, in this study, we used images of characters that are generally popular as visual stimuli. However, since the characteristics of the images including character color, body parts, and size were not sufficiently adjusted, the waveform of P300 may have been influenced by these factors. Furthermore, participants in this study were limited to young people, and the images they were able to select were also limited. Future research requires the establishment of methods that have greater clinical components. Despite these limitations, the present study is important as it provides basic data to enhance motivation in rehabilitation practice.

Conclusions

Our findings suggest that self-selection enhances an individual's ability to perform positively in tasks and leads to better outcomes. In rehabilitation, supporting the client's self-determination may lead to better quality of life. However, since the neural mechanisms underlying these processes in self-selection remain unclear, further research is needed.

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Disclosure

The authors have no potential conflicts of interest to disclose.

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