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Unconscious load changer: Designing method to subtly influence load perception by simply presenting modified myoelectricity sensor information

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Systems of presenting myoelectricity sensor information allow users to understand the body's load for various purposes, such as medical rehabilitation and sports training. If there is a method to create the psychological phenomenon of unconsciously increasing or decreasing a user's load perception simply by changing how to present the myoelectricity sensor values, it will help design a more effective system. Therefore, we propose a method to manipulate load perception by presenting modified myoelectricity sensor information. The proposed method aims to induce higher or lower load perception by modifying the actual myoelectric value to a higher or lower value. We implemented a prototype system and evaluated our method for the two types of load perception of weight perception and fatigue perception when handling objects. The result showed that most subjects unconsciously increased or decreased their load perception to match the presented myoelectric value, while the minority subjects got the opposite response from the majority subjects. This result indicates the feasibility of user assistance systems that use this phenomenon for a good purpose, such as systems that slightly reduce the load perception during physical activity. On the other hand, this result also indicates the feasibility of systems that use this phenomenon for a bad purpose, such as systems that increase user's fatigue to harm user's activity. This study provides helpful findings for designing and using sensor information presentation systems considering the psychological phenomenon.

KEYWORDS

information presentation, myoelectricity sensor, psychological effects, cognitive bias, weight perception, fatigue perception, human augmentation, human-sensor interaction

1. Introduction

Systems that present the feedback of sensor information have been used in many fields to help users understand their physical and mental states (e.g., heart rate, respiration, myoelectricity, body temperature, and body movement). One such system presents myoelectricity sensor information. Since myoelectricity changes in response to the amount of force applied and the amount of muscle activity, it can help users understand the load of the body for various purposes, such as rehabilitation and training of various body parts in fields such as medicine, physical therapy, and sports science (Stuckey et al., 1986; Dannecker et al., 2005; Aiello et al., 2006; Holtermann et al., 2010; Giggins et al., 2013; Lim et al., 2014; Son et al., 2015). There are many situations where it is beneficial to understand the load of the body; thus, the use of systems that present myoelectricity sensor information is expected to increase in the future.

In terms of designing information presentations systems that may affect a user's cognition and psychology, many recent studies have shown that it is necessary to clarify the existence and manipulation methods for unconscious phenomena caused by information presentation (e.g., psychological effects, illusions, and cognitive biases) (Adams et al., 2015; Kim et al., 2016; Costa et al., 2018; Futami et al., 2019; Komatsu and Yamada, 2020). For example, some studies have focused on information presentation systems for heart rate sensors (Costa et al., 2016, 2017, 2019). These studies showed that the user's physical and mental state (e.g., anxiety level and cognitive performance) unconsciously matched the presented heart rate sensor information even though the presented heart rate differed from the actual heart rate. In addition, these studies proposed a method to enable users to unconsciously improve their physical and mental state by intentionally manipulating this unconscious phenomenon with information devices such as a smart watch. Such studies have been useful in the design and use of information presentation systems.

If there is a method to create the psychological phenomenon of unconsciously increasing or decreasing a user's load perception simply by changing how to present the myoelectricity sensor values, it will help design a more effective system. Therefore, this study's research questions are as follows. *Is there a psychological phenomenon in which the perception of load changes unconsciously in response to the feedback of myoelectricity sensor information? In addition, is there a method to intentionally manipulate that psychological phenomenon?* In light of previous studies in which physical and mental states were changed unconsciously by the feedback of information that objectively senses the user's state (e.g., heart rate Costa et al., 2016, 2017, 2019, facial expression Yoshida et al., 2013, voice Costa et al., 2018), we assume that the perception of load changes unconsciously to match the feedback of myoelectricity sensor information due to the change in the user's perception of the self-state. For example, it is assumed that the perception of load increases (or decreases) through a psychological phenomenon caused by observing a high (or low) myoelectricity value. Although verification of these research questions provides important implications to users and designers of myoelectricity sensor information presentation systems, to the best of our knowledge, few studies have focused on this verification.

Therefore, this study attempts to answer these research questions to clarify the existence and manipulation methods of a psychological phenomenon where the user's load perception is changed unconsciously by observing myoelectricity sensor information. Then, by using that psychological phenomenon, we propose a method, "Unconscious Load Changer," to manipulate load by presenting myoelectricity sensor information. The proposed method is based on the hypothesis that the user's load perception changes to match the feedback of myoelectricity sensor information even when the sensor information differs from the actual sensor value. The proposed method affects the user's load by presenting myoelectricity sensor information that is simulated as a specific load value, such as high or low load. We implemented a prototype system of the proposed method. The experiments evaluated the effect of our method on the two types of load perceptions: weight perception and fatigue perception when handling objects.

Note that we published the concept of the proposed method in a short paper at the International Symposium on Wearable Computers (ISWC 2021) (Futami et al., 2021a). The previous paper showed the possibility that the effect of the proposed method changes weight perception. This paper added "Section 5. Evaluation 2" which indicates the possibility that the proposed method changes fatigue perception. This paper added "Section 6. General Discussion" based on the effect of the proposed method on load perception. This is the first study to provide implications for discussing the psychological phenomena of observing myoelectric sensor information and what myoelectric sensor information can cause to people through psychological effects.

2. Related study

2.1. Manipulating load perception with psychological phenomena

Changes in load perception are caused by various factors. For example, in the size-weight illusion, the apparent size of an object affects the weight perception of that object (Davis and Roberts, 1976; Nicolas et al., 2012). In the material-weight illusion, the material of an object affects the weight perception of that object (Buckingham et al., 2011). In addition, there is a phenomenon where fatigue perception is affected by the color of an object to be carried (Birren, 2013). A method that used virtual reality (VR) technology to change load perception when handling objects using such a phenomenon has been proposed previously. For example, an existing method changes the color of the object using VR technology to manipulate weight perception and fatigue perception to augment user's endurance (Ban et al., 2013). To manipulate weight perception, another method changes the position of the object in VR space (Taima et al., 2014). In addition, another method changes weight sensation when moving the body by generating and presenting estimated past and future body movements using a head-mounted display (Kasahara et al., 2017). An example other than VR technology includes a method that reduces the underestimation effect in human perception of assistive force by presenting the level of assistive force of a jacket such as a powered suit in real time (Das et al., 2021). These previous studies have demonstrated the effectiveness of approaches that employ the psychological effects of VR technology to change load perception, and they have shown that technology to manipulate load perception can be useful.

Our study is inspired by these previous studies. In this study, we attempt to verify the feasibility of an approach that employs myoelectricity sensor information. The use of myoelectricity sensor information differs from the VR technology used in the previous studies; thus, we expect that the results of our study can be used in different situations from the previous study.

2.2. Myoelectricity sensor feedback systems

The myoelectricity sensor in our study is the same as EMG(Electromyogram) sensor. Various applications to support users use myoelectricity sensors, such as a biofeedback system to support the rehabilitation and training of various body parts in sports fields and medicine. For example, there are purposes such as musculoskeletal treatment and training after cardiovascular injury (Giggins et al., 2013), gait training (Aiello et al., 2006), pelvic floor muscle training (Dannecker et al., 2005), training for the inner muscles of the arms (infraspinatus) (Lim et al., 2014), a training for low back pain support (Stuckey et al., 1986), a training for upper body (lower trapezius and serratus anterior) (Son et al., 2015), and a scapula training (Holtermann et al., 2010). Many studies have used myoelectricity sensors; however, few studies have focused on the psychological phenomena caused by myoelectricity sensors. Our finding is expected to provide important insights into the design and use of myoelectricity sensor information presentation systems.

2.3. Research focusing on psychological phenomena and cognitive biases caused by information presentation systems

Previous studies have clarified the existence of unconscious phenomena (e.g., illusions, psychological effects, and cognitive biases) caused by information systems and proposed a method that supports users by manipulating them. The necessity of such studies has been emphasized (Dingler et al., 2020). In light of them, we focused on the psychological phenomena of sensor information presentation systems.

There are methods to change users' mental and cognitive functions. Some methods present a different heart rate than the actual one to improve the user's cognitive performance and decrease the user's anxiety level (Costa et al., 2016, 2017, 2019). To reduce the psychological stress caused by others, there are methods to modulate others' voices (Costa et al., 2018) and to make the interpersonal distance between others in VR space (Maeda et al., 2016). To improve users' mental functions in tense situations such as sports, there are methods to present auditory stimuli conditioned to success (Futami et al., 2016) and to present a pseudo-success experience in VR space (Tagami et al., 2017). There are methods to improve cognitive performance or concentration during work, such as visually changing the speed of the clock (Ban et al., 2015), presenting a work productivity log based on framing effects (Kim et al., 2016), modulating audio and visual interface (e.g., a memorization application Futami et al., 2022, learning material video Arakawa and Yakura, 2021), changing facial expressions of dialogue partners from actual ones in collaborative work at online (Suzuki et al., 2017), and the effective visualization of timelines of remaining time on a task (Di Bartolomeo et al., 2020). There is a method to improve the user's emotion by modifying the user's facial expression more than the actual one (Yoshida et al., 2013).

There are methods to change sensation and experience. To manipulate the elapsed time sensation, there is a method that changes the frequency and timing of stimuli [e.g., tactile stimuli from a wrist-worn device Shirai et al., 2021, visual icons on an HMD (Head Mounted Display) Shimizu et al., 2017, auditory stimuli from a speaker Komatsu and Yamada, 2020]. To manipulate satiety, there are methods to change the size of food using VR technology (Narumi et al., 2012) and to change the apparent size of the plate (Adams et al., 2015). There is a method to change the game experience by presenting the game's fitness gauge as less than it actually is (Wuertz et al., 2019).

Furthermore, there are methods to change behaviors and choices. To induce health behavior, there is a step-logging competition application to improve daily walking motivation by competition progress modification based on the psychology of competition (Futami et al., 2021b) and a method to make users choose a healthy meal by presenting others' evaluations that are different from the actual ones (Takeuchi et al., 2014). There is a method of train timetable modification to prevent users' late arrival (Futami et al., 2019), an ambient display to encourage people to take the stairs instead of the elevator (Rogers et al., 2010), methods changing sightseeing routes and store rankings for each user to control tourist flow (Shen et al., 2016a,b). Other examples include an ambient light feedback method to encourage saving behavior such as power consumption (Lu et al., 2015), a presenting news trust indicators to inhibit spreading fake news in social media (Yaqub et al., 2020), and an interface to increase users' thoughtfulness in what they comment to others (Menon et al., 2020).

3. Proposed methods

Here, we describe our hypothesis and the method to manipulate the load perception using a myoelectricity sensor.

3.1. Hypothesis

The flow of the phenomenon is shown in Figure 1. The myoelectricity sensor value changes according to the amount of force applied and the amount of muscle activity. Therefore, when the load on the muscle is higher or lower (e.g., when a heavy or light object is held), the myoelectricity sensor value increases or decreases, respectively. When users have this knowledge and experience, their perception of their load changes in response to feedback from the myoelectricity sensor information, which causes a phenomenon where the load changes unconsciously to match the myoelectricity sensor information. For example, even when carrying luggage of the same weight, a phenomenon that increases perceived load can be caused by observing a high myoelectricity value and vice versa.

The following cases are assumed.

- Case 1) This phenomenon does not exist. Thus, the user's load does not change by the feedback of the myoelectricity sensor information. In this case, we can report that there is no concern that this phenomenon causes some bad situations for people.
- Case 2) Although this phenomenon exists, it occurs with an unpredictable tendency. In this case, this phenomenon cannot be manipulated intentionally. For example, if a user's load changes randomly when a specific pattern of myoelectricity sensor information is presented, it is impossible to manipulate this phenomenon. In this case, there is possible that this phenomenon causes problems. For example, the use of a system of presenting myoelectricity sensor information causes an unexpected increase in the load, leading to some problems (e.g., health damage, productivity decline). Therefore, it is necessary to discuss something to deal with such a problem (e.g., countermeasures, mechanisms, user understanding).
- Case 3) This phenomenon exists and occurs with a predictable tendency. In this case, this phenomenon can be intentionally used and suppressed. For example, if the load changes as predicted when a specific pattern of myoelectricity sensor information is presented, this phenomenon can be intentionally manipulated.

3.2. Design of information presentation

The proposed method presents myoelectricity sensor information that differs from the actual sensor values. This information is simulated as a specific load such as a high or low load. Specifically, we verify our hypothesis in two ways. (1) Presenting high load reproduction information: This method presents the myoelectricity sensor information that is simulated as a high load by increasing the myoelectricity sensor value compared to the actual measured value. This method creates a psychological phenomenon that induces the perception of a heavier load. (2) Presenting low load reproduction information: This method presents the myoelectricity sensor information that is simulated as a low load by reducing the myoelectricity sensor value compared to the actual measured value. This method creates a psychological phenomenon that induces the perception of a lighter load. These methods were designed based on previous studies that demonstrate that sensor information simulated as a specific mental or physical state induces a state that matches the sensor information (e.g., heart rate Costa et al., 2016, 2017, 2019, facial expression Yoshida et al., 2013, and voice Costa et al., 2018).

The sensor information presentation screen is shown in Figure 2. The myoelectricity value is visualized as a widget in gauge format (Figure 2A). The widget can be displayed anywhere on the screen. The gauge form was employed because it is necessary to present sensor information that is easy to understand. When the myoelectricity value is high, the gauge is filled to the top, as shown in Figure 2B. When the myoelectricity value is small, the gauge remains low, as shown in Figure 2C.

3.3. Implementation

The prototype system of the proposed method was implemented. The prototype system consists of a laptop [Lenovo ThinkPad X1 Carbon (CPU: Intel Core i7-5600, 2.60 GHz, RAM: 8.00 GB)], an Arduino microprocessor, and a myoelectric sensor (ElectroMyoGraphy from AdvancerTechnologies). The sensor

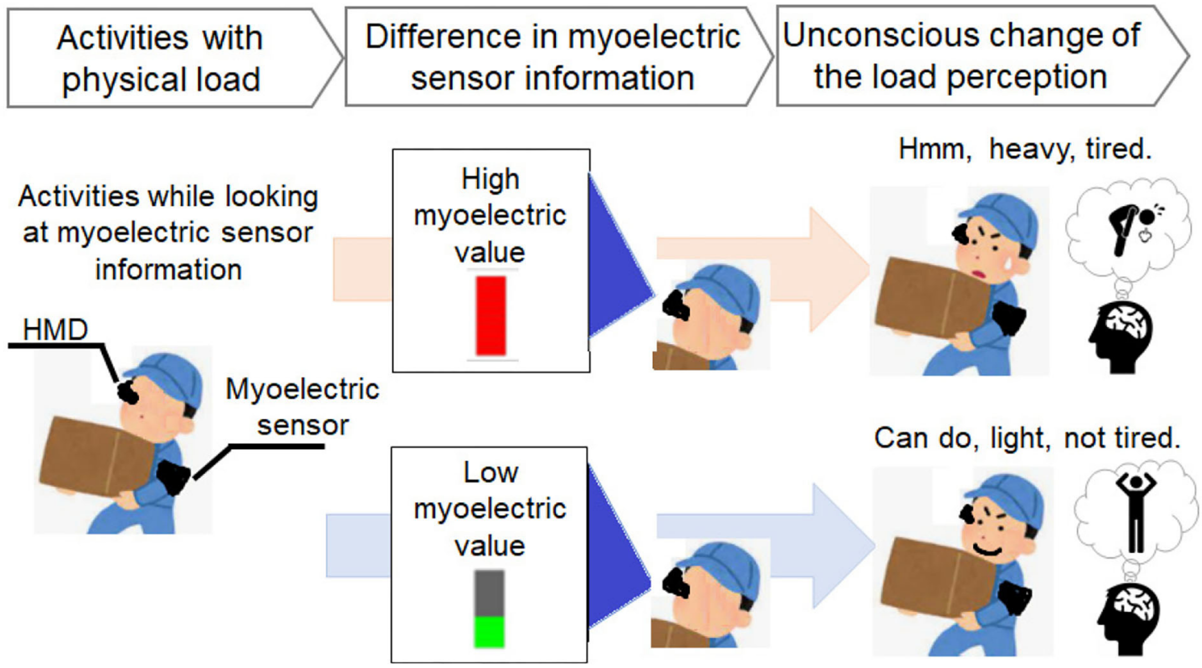

FIGURE 1
Hypothesis. The phenomenon of change in load due to browsing of muscle activity (Futami et al., 2021a).

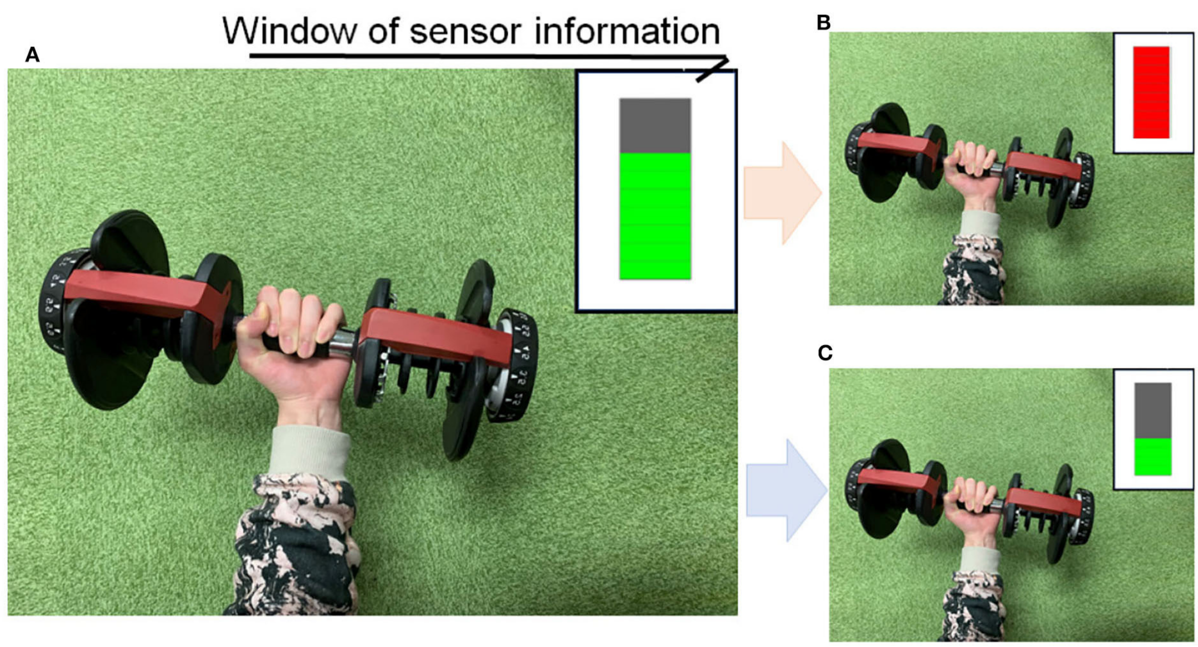

FIGURE 2
Window design of sensor information. **(A)** Presenting myoelectricity sensor information, **(B)** presenting high load reproduction information, **(C)** presenting low load reproduction information (Futami et al., 2021a).

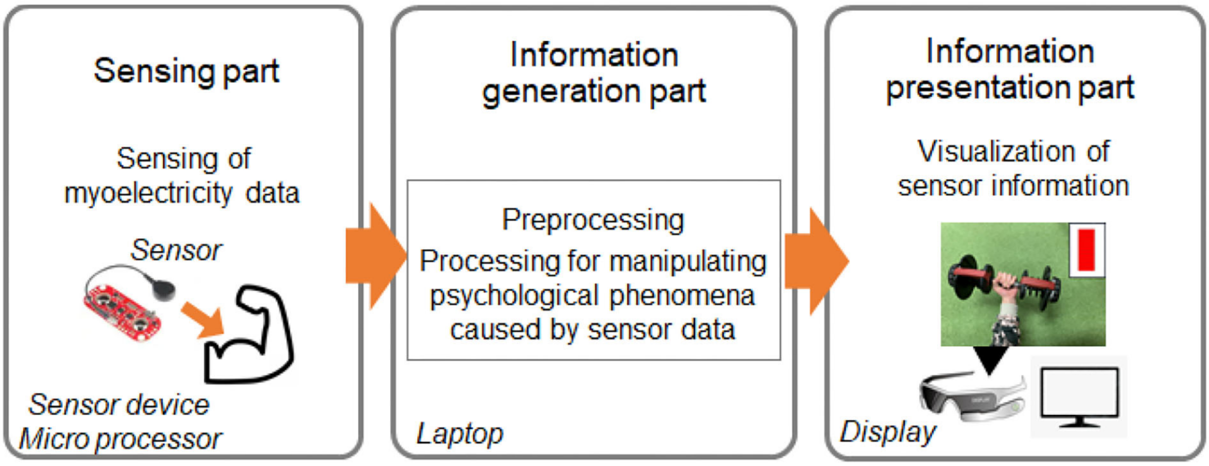

FIGURE 3
Flow and configuration of the system.

size was about 5 × 2.5 cm, its shape was square, the noise was reduced by smoothing the data, its weight was less than 10 g, and it has almost no delay. The software was implemented with Processing and Arduino.

Figure 3 shows the three main components of the prototype system. First, a myoelectricity sensor senses myoelectricity data. The myoelectricity sensor is attached to the biceps with a band. The sampling rate was 200 Hz. Second, information to present is generated. Here, the sensor values are preprocessed. The sensor data is smoothed by a simple moving average (SMA) with constant window size (100 ms). The Root Mean Square (RMS) makes the sensor value a positive value. There is supposed to be a certain delay in the sensor response due to pre-processing (e.g., smoothing of the data every 100 ms). Then, the sensor data to present is created. Here, the high load reproduction information is created by increasing the actual measured sensor value by 50%, and the low load reproduction information is created by reducing the actual measured sensor value by 50%. The section of an experiment explains this detail. Then, the sensor information is processed into the gauge display format consisting of 10 blocks. Here, an appropriate information presentation display presents the sensor information *via* the laptop. Such a display contains a head-mounted display or an external display.

4. Evaluation 1

We conducted an evaluation to verify whether the proposed method can change the weight perception of luggage hold. Weight perception is one of load perception. A total of 13 subjects (university students, from 20 to 25 years old) participated in the experiment.

Task and procedure

Outline: The outline is as follows. The experimental task was to hold the luggage while observing the sensor information, estimate the weight of the luggage, and answer it. There were two pieces of luggage of the same weight. The conditions of sensor information changed for each luggage. There were two types of conditions: the high load reproduction condition and the low load reproduction condition. From this flow, we evaluated the change in the weight perception of luggage due to the difference in sensor information.

Details: The details are as follows. The experiment consisted of two stages: a preparation stage and an effect measurement stage.

(1) The stage for preparation as follows. First, the subjects were not informed of the purpose of the experiment and were explained that the experiment was to estimate the weight of luggage while observing sensor information. Next, a myoelectricity sensor was attached to the biceps of the subject's dominant arm. Next, the subject conducted the task to understand that the myoelectricity sensor value changes depending on the weight of the luggage held. Several dumbbells were placed in front of the subject. The weights of dumbbells were 1.5, 2.5, 3.5, 4.5, and 5.5 kg. Subjects lifted the dumbbells in order, starting with the lightest one, and checked the weights and sensor values of the dumbbells. At this point, the sensor values to observe were actual measured values in the time-series waveform of raw data. The subject lifted the dumbbells while understanding the weight of dumbbells.

(2) The effect measurement stage was conducted as follows. The experimental environment is shown in Figure 4A. Here, a display device and two pieces of luggage were placed on a table. The weight of each luggage was 1,500 g, and their

sizes were 190 mm in width, 260 mm in length, and 40 mm in height. The experimental task consisted of lifting luggage, holding lifting, unloading luggage, and estimating the weight of the luggage. This task was performed for each luggage. The time interval between placing the first luggage and lifting the second luggage was about 5 s. In addition, the posture while holding the luggage was designed to approximate the same state as shown in Figure 4B. The subjects held the luggage up to the line of sight and looked at the sensor information that was displayed on the display device in front of them. The holding time of the luggage was 5 s. The condition of the sensor information was changed for each luggage. Here, two conditions were high load reproduction and low load reproduction, as shown in Figure 4B. The order of using each luggage was randomized. Regarding the sensor information, the high load reproduction condition showed approximately eight gauge blocks and the low load reproduction condition showed approximately three gauge blocks. At this time, each subject's myoelectricity value recorded when holding the 1.5 kg dumbbell was set to five gauge blocks. The high load reproduction condition showed a value that increased the sensor value by 50%, and the low load reproduction condition showed a value that reduced the sensor value by 50%. Note that we did not use a head-mounted display to present the sensor information to eliminate the possibility that subjects would be affected by using a device that was not accustomed to wearing or that was burdensome to wear. In addition, there are existing systems that display myoelectricity data on a stationary computer screen; thus, we consider this to be a practical experimental situation.

4.1. Results

The weight perception results are shown in Figure 5. The error bars indicate the standard error. Here, a larger value on the vertical axis means that the weight was perceived as heavier. A Shapiro-Wilk test was conducted, which showed that the data had normality ($p > 0.1$). A paired t-test showed a significant trend between the conditions ($p < 0.1$). This means that changes between conditions are not enormously significant. The average weight estimation for all subjects was 2,142 g in the high load reproduction condition and 2,005 g in the low load reproduction condition. In addition, Figure 6 shows the individual differences in the change in the weight perception between conditions. This value was obtained by subtracting the weight perception in the low load reproduction condition from the weight perception in the high load reproduction condition. Therefore, the positive direction of this value indicates that subject's perception changed corresponding to the sensor information as expected. In contrast, the negative direction of this value indicates that subject's perception was opposite to the expectation. Approximately 62% (eight subjects) responded as expected, 23% (three subjects) responded in the opposite direction of expectation, and 15% (two subjects) did not respond (i.e., no effect). Responded as expected means the tendency that changes the weight perception to match the presented sensor value. For example, that response means a tendency for the weight perception to be higher when viewing higher sensor values than when viewing lower sensor values. Responded in the opposite direction of expectation means the tendency that changes the weight perception against the presented sensor value. No effect means that the weight perception does not change depending on the presented sensor value.

4.2. Discussion

According to the change in sensor information conditions, the weight perception changed with a certain tendency. Specifically, the weight perception increased when the displayed myoelectricity value increased. This indicates that weight perception changes unconsciously to match the displayed

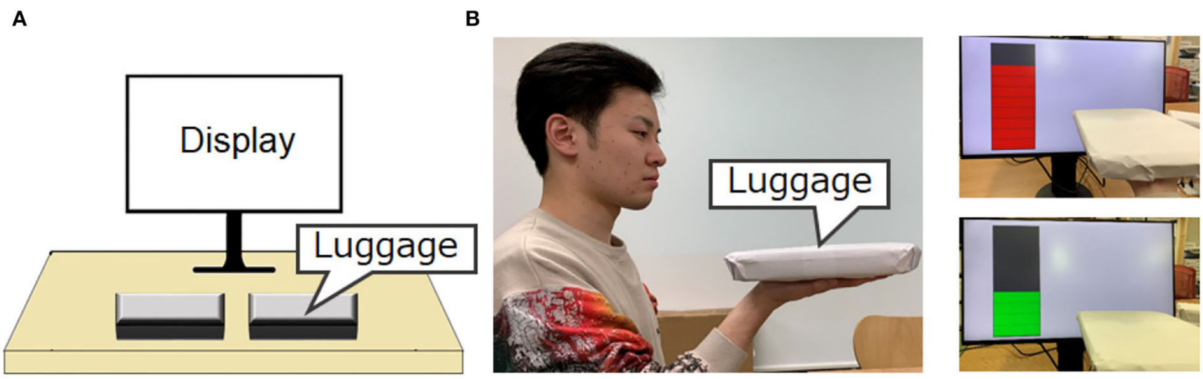

FIGURE 4
(A) Placement of luggage, **(B)** posture when holding luggage and how to view the presented information (Futami et al., 2021a).

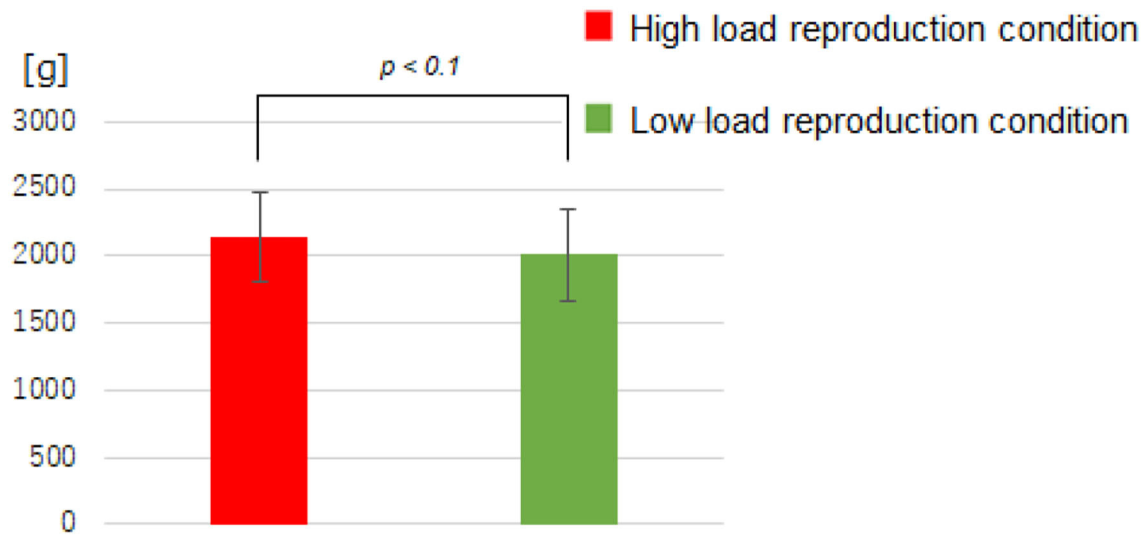

FIGURE 5
Results of Experiment 1. The average value of the weight perception for each condition (Futami et al., 2021a).

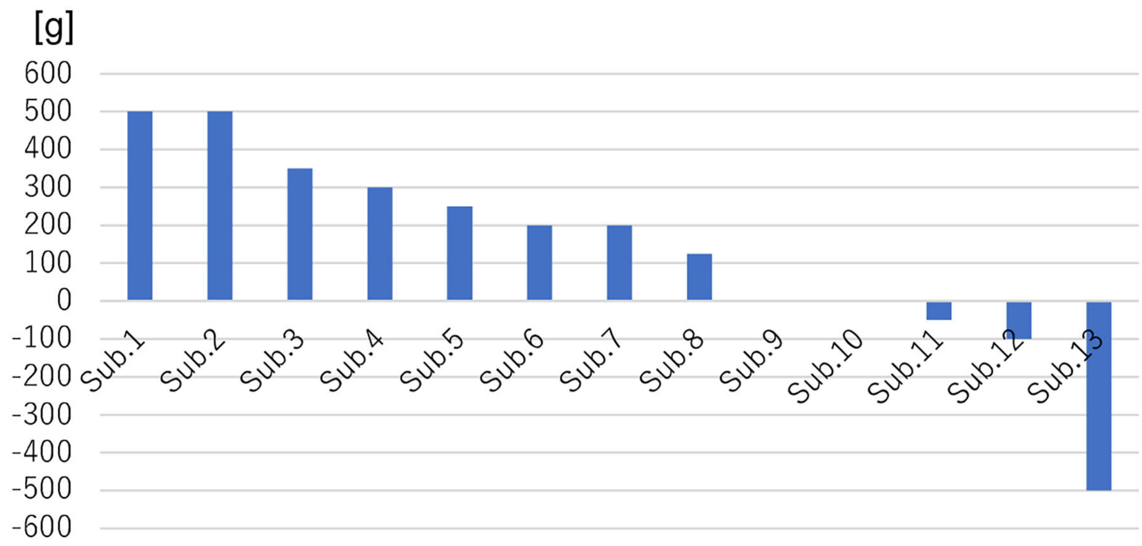

FIGURE 6
Results of Experiment 1. Individual differences in changes in weight perception between sensor information conditions (Futami et al., 2021a).

myoelectricity sensor information. This also indicates that weight perception can be changed intentionally by changing myoelectricity sensor information.

The results also showed individual differences in the change in the weight perception caused by the myoelectricity sensor information. The majority of the subjects, about 62% (8 subjects), responded as expected, and the weight perception tended to change to match the sensor information. Some subjects perceived a difference of up to 500 g in the same luggage weight between conditions. That 500 g was approximately 33% of 1500 g of the weight of the luggage. On the other hand, about 23% of the subjects (3 subjects) responded opposite to the expectation, and the change in the weight perception occurred reversely against the sensor information.

Previous studies also reported individual differences in psychological phenomena caused by such information presentation. For example, in the experiment for seven subjects to evaluate a method that unconsciously raises the pitch of the voice by the real-time modulated speech sound feedback, about 57% of them (4 subjects) responded as expected, about

29% of them (2 subjects) responded opposite to expectations, and about 14% of them (1 subjects) were unaffected (Adams et al., 2015). The ratio of the tendency of subjects' responses in our study is similar to one in the previous study. We consider that the previous paper is helpful as a prior example of the percentage of individual differences in the effect of modification feedback of biometric information. Given that unconscious phenomena, such as psychological phenomena, illusions, and cognitive biases, can cause expected responses in many people and different responses in some people, it can be inferred that there are also individual differences in the psychological phenomenon of myoelectric sensor information.

5. Evaluation 2

Evaluation 1 showed a change in weight perception. Evaluation 2 evaluated whether the proposed method changes the fatigue perception through the change in the weight perception. The number of subjects was eight subjects. They were college students, from 20 to 25 years old, right-handed, and male. Previous studies have shown examples that fatigue changed according to the perception of the weight of luggage (Ban et al., 2013; Birren, 2013). Therefore, a similar phenomenon is assumed to occur in our study.

5.1. Task and procedure

Outline: The outline is as follows. One trial of the experimental task consisted of a fatigue measurement before the task, the task to move the luggage while observing the sensor information, and a fatigue measurement after the task. Two trials of this task were conducted by changing the conditions of the sensor information. There were two types of conditions for sensor information: the high load reproduction condition and the low load reproduction condition as the same as Evaluation 1. In each trial, the luggage was changed, but the weight of the luggage was the same. From this flow, we evaluated the change in fatigue due to the difference in the conditions of sensor information.

Details: The details are as follows. The experiment consisted of two stages: a preparation stage and an effect measurement stage.

(1) The preparation stage was conducted the same as Evaluation 1. The subjects were provided with an explanation in which this experiment is to answer the fatigue after the task to move the luggage while watching the myoelectricity sensor information. Next, they attached a myoelectricity sensor to the biceps of the dominant arm. Next, they conducted the task to understand that the myoelectricity sensor value changes depending on the weight of luggage to hold as the same as Evaluation 1.

(2) The effect measurement stage is conducted as follows. One trial of the experimental task consisted of four parts: fatigue measurement before the task, the task to move luggage, fatigue measurement after the task, and rest period. The fatigue caused by the task was defined as the difference between the fatigue before and after the task. In the fatigue measurement, the participants answered the degree of the fatigue on a 10-point scale, where 1 was "not tired at all," and 10 was "extremely tired." This method of measuring subjective fatigue was based on the previous study by Ban et al. (2013). This one trial was repeated twice for different conditions. There were two conditions for the sensor information: the high load reproduction condition and the low load reproduction condition. The content of the sensor information was the same as in Experiment 1. The rest period was set at about 3 minutes, and the necessary rest was taken for each subject so that the fatigue before the task would be the same. For each trial, the luggage was changed, but the weight of the luggage was the same. The order of the two types of conditions was random.

The task to move luggage

In this task, moving the three pieces of luggage was repeated. Details were the following. The experimental environment was as shown in Figure 7A. There was a table, a display, and three pieces of luggage stacked in a predetermined position *Right* on a table. All luggage had the same appearance and weight. The weight of the luggage was 1,500 g, and its size was 170 mm in width, 240 mm in length, and 60 mm in height. The subject repeatedly moved these packages one by one and placed them in the next predetermined position *Left*, thereby piling up three luggage in the next predetermined position *Left*. Next, the subject repeatedly moved these packages of *Left* one by one and placed them in the first predetermined position *Right*, thereby piling up three luggage in the first predetermined position *Right*. This movement of the luggage was performed five times round trips. Figure 7B shows the posture at the task. Sensor information was displayed on display in front of the subject and came into view of the subjects when moving luggage. The posture of holding the luggage was instructed to reproduce roughly the same state as the same as Evaluation 1. Specifically, the subjects held the luggage up to the line of sight while moving it, and they also looked at the sensor information that was displayed on the screen in front of them. This task was based on the previous study by Ban et al. (2013).

5.2. Results

The results of the fatigue perception for each condition are shown in Figure 8. The error bars indicate the standard error. The larger the value on the vertical axis, the larger

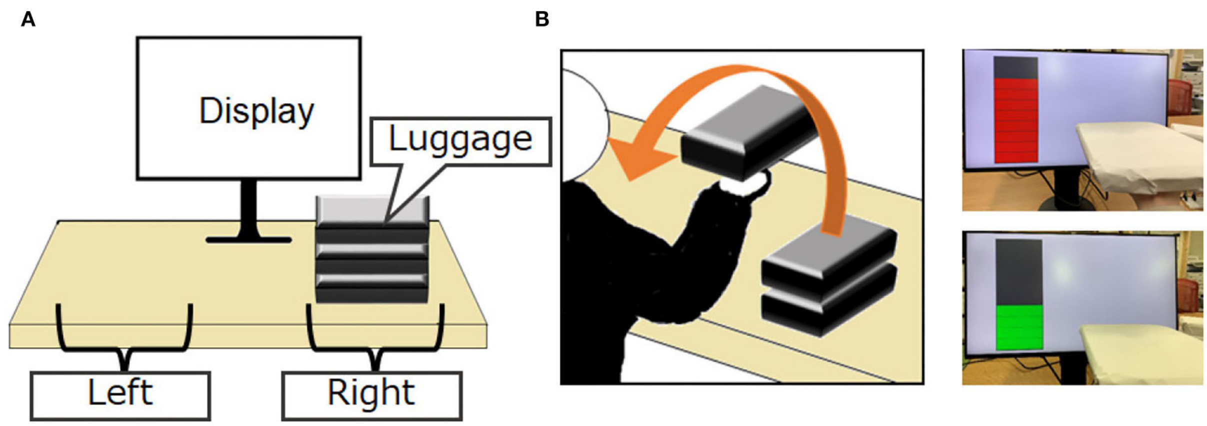

FIGURE 7
(A) Placement of luggage. **(B)** Posture when moving luggage, and how to see the presented information.

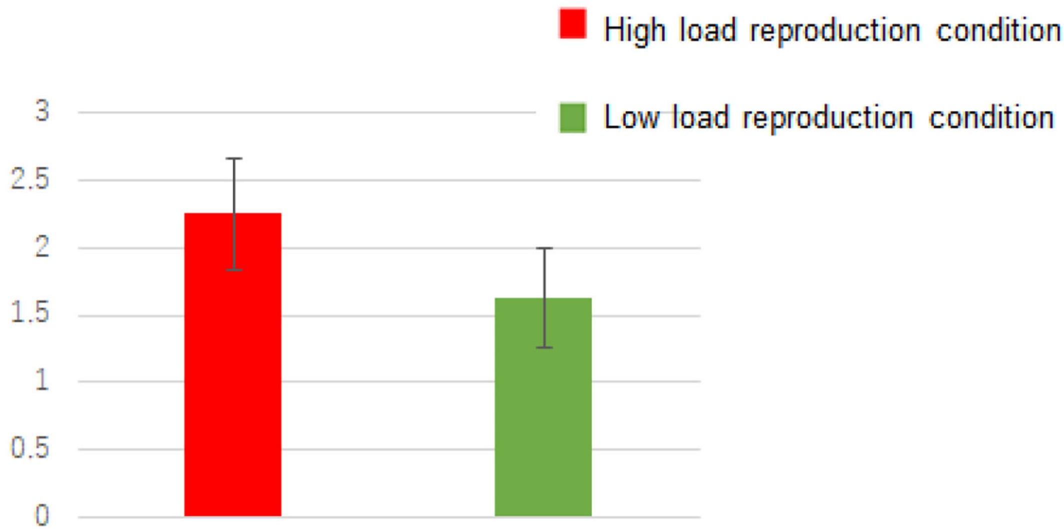

FIGURE 8
Results of Experiment 2. The average value of the fatigue perception for each condition.

the fatigue perception. A Shapiro-Wilk test was conducted, which showed that the data had normality ($p > 0.1$). A paired t-test showed no significant difference between the conditions. The average value of the fatigue perception was 2.25 in the high load reproduction information condition and 1.63 in the low load reproduction information condition. In addition, Figure 9 shows the individual differences in the change in the fatigue perception between conditions. This is the value obtained by subtracting the fatigue perception in the low load reproduction condition from that in the high load reproduction condition. Therefore, this value's positive direction indicates that the subject's perception changed to match the sensor information as expected. On the other hand, this value's negative direction indicates that the subject's perception was opposite to the expectation.

The results show individual differences in the effects on the fatigue perception caused by the sensor information. About 62% of them (5 subjects) responded as expected, 24% of them (2 subjects) responded in the opposite direction of expectation, and 13% of them (1 subject) did not respond (i.e., no effect).

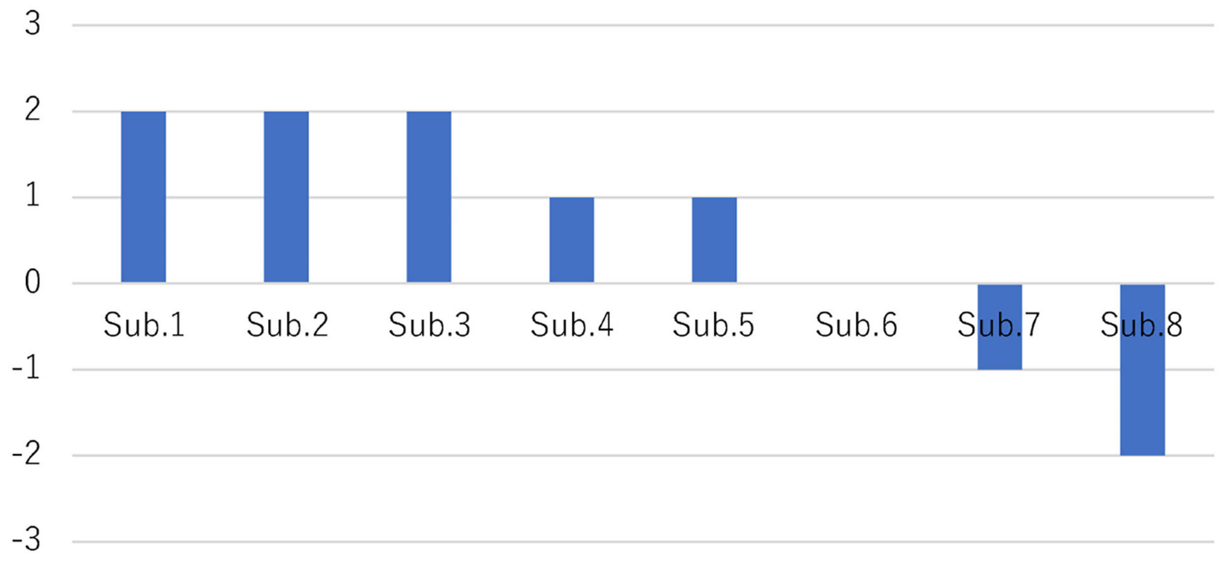

FIGURE 9
Results of Experiment 2. Individual differences in changes in the fatigue perception between conditions.

5.3. Discussion

The results showed the possibility that the myoelectricity sensor information could affect fatigue. A specific trend change occurred in the fatigue perception according to the change in the conditions of sensor information, although there was no significant difference. Specifically, the fatigue was larger in the condition in which the myoelectricity value was displayed larger. This means that the fatigue was perceived unconsciously to match the myoelectricity sensor information. The difference in the fatigue perception between the conditions is assumed to become clearer as increasing the time of the task.

The results also showed individual differences in the effects that the myoelectricity sensor information causes on fatigue perception. The majority of the subjects, about 62% (5 subjects), responded as expected, and the fatigue perception tended to change to match the sensor information. On the other hand, about 25% of the subjects (2 subjects) responded in the opposite way to the expectation, and the change in the fatigue occurred reversely against the sensor information. This ratio of individual differences was similar to the results in Evaluation 1, and the previous study (Adams et al., 2015) mentioned in Evaluation 1.

From this result, we confirmed the possibility that the change in the fatigue perception occurs unconsciously to match the myoelectricity sensor information and that the change in the fatigue perception can be manipulated intentionally. In addition, we confirmed that there are individual differences in the psychological phenomenon of fatigue caused by the myoelectricity sensor information.

This experiment did not investigate how the actual myoelectric values and task completion time changed in response to changes in fatigue perception. For example, higher fatigue perception may induce slower movement and longer task completion time. We plan to verify this point in the future.

6. General discussion

The result of our study found existence and a manipulation method example of a psychological phenomenon that the user's load perception unconsciously changes according to the feedback of myoelectricity sensor information. This result contains implications for the design and use of systems that present sensor information related to load perception. Here, we will discuss the possibility that this phenomenon can be utilized for positive or negative purposes.

6.1. Lightside of using psychological phenomena of myoelectricity sensor information for user support

The result shows the feasibility that the phenomenon caused by myoelectricity sensor information can be used for supporting the unconscious change of the load perception. It is difficult for almost all people to change the load perception by their conscious effort. However, such changes were caused by using our proposed method using the sensor information. It is also worth noting that the phenomena caused by our proposed method occurred instantaneously and did not require any additional user preparation and user effort. Technology that can manipulate this phenomenon is assumed to be used to support the maintenance and change of the appropriate load perception.

There are possibilities that the proposed method can be applied to various systems that use myoelectricity sensor information. For example, the proposed method allows the users to perceive a lighter load even when dealing with the same load during rehabilitation, physical activity, and sports training. To gain tolerance for high loads in important situations in sports and work, the users can train them by making themselves feel high loads in the training phase. To support the experience of games and entertainment, the users can get appropriate physical and mental load. Such support systems are expected to enable users to improve their performance, motivation, and experience.

As described above, the results of our study can be helpful for the development of technologies that cause the change of the user's load for a good purpose.

6.2. Darkside of using psychological phenomena of myoelectricity sensor information

The results found that the phenomenon of changing the load was unconsciously caused by the system presenting the myoelectricity sensor information. This indicates that those systems can change the user's load in the wrong direction causing negative situations that are undesirable for the body, mind, and experience. (1) The following examples are about changes in mind and body. In scenes of supporting physical training or tasks, sensor information causes unintentional increases in the physical and mental load, and it causes negative situations. With a system (from *Wellness* Inc.) that is used during walking and rehabilitation, 40% of the users become unwell from some point of view, and 5% of them get health hazards. With a system (from *Evil* company) used during work, the users' productivity decreases by 30% 2 days a week through the change in the user's fatigue. (2) Next, the following examples are about changes in experience and behavior. With a system for games and experiential entertainment applications, some users are given the undesired entertainment experience by changing the load in a bad direction. With a system used in daily life, the psychological phenomena of a higher load are caused at a particular location in the city, and then it induces people to enter and purchase at vicinity facilities of food, drink, and rest, which benefit specific organizations.

These problems can occur accidentally or unexpectedly; moreover, these problems can be caused intentionally due to someone's malicious intent to benefit a particular country, organization, or individual. Therefore, it is necessary to design and use the system as considering such possibilities. The following is an example of countermeasures. (1) Users should understand and manage the changes that occur when they use the system. The system should have a simple mechanism for testing and grasping such a user's change, and the simple mechanism should be used before using the system or at regular intervals (e.g., several months). (2) The system should have a mechanism to prevent bad psychological phenomena in each situation where the system is used. For example, in situations that should not make the user's load unnecessarily high, the system should have a mechanism that always causes psychological phenomena that reduce the load.

The following points should also be considered in light of the results showing that different sensor information has different effects on the mind and body. The value and standard of the myoelectricity sensor can change depending on various factors (e.g., a difference in sensor accuracy, sensor mounting position, visualization method, and settings that depend on each system developer). Therefore, the sensor information about the same user's state doesn't necessarily become the same in different systems, and differences in sensor information can occur in different systems. For this, each system is assumed to cause different effects on users. Therefore, when any bad situations are caused, it will be needed to investigate whether the phenomenon of a particular system causes those situations.

Based on the results of our study, we can assume that systems that present myoelectricity sensor information can cause negative problems. We should provide knowledge that is useful in designing information devices and applications to prevent such problems. These are considered to be related to the entire system that uses sensor information, in addition to the system that uses myoelectricity sensor values or information related to load perception.

6.3. Individual differences in the psychological phenomena of myoelectricity sensor information

The results showed individual differences in the psychological phenomena caused by the myoelectricity sensor information. Such individual differences were the same as in the previous studies. For example, there were individual differences in the effects of real-time modulated speech sound feedback that unconsciously changes the pitch of the voice (Adams et al., 2015). In addition, in the method of manipulating the psychological effects of heart rate feedback, some users obtained unexpected effects that differ from the majority of users (e.g., distracted/decreased attention Costa et al., 2019, increased anxiety Costa et al., 2017). Most studies focusing on psychological phenomena caused by information presentation systems have not reported individual differences in effects. However, it seems inevitable that there are such individual differences since not everyone experiences the same psychological effects and cognitive biases.

Reasons for the individual differences in this study are considered as the following. The first reason is that individual personality characteristics caused individual differences. For example, it can be assumed that subjects with a straightforward personality reacted as expected and subjects with a rebellious spirit reacted against the sensor information because of their thoughts of doubt. The second reason is that learning about the relationship between myoelectricity and load perception was insufficient at the time of the experiment. For example, if the relationship between myoelectricity sensor value and the load perception is sufficiently learned through a long-term life of watching myoelectricity sensor information, the number of users who respond as expected is assumed to increase. It is necessary to investigate the causes of such individual differences in studies dealing with psychological phenomena caused by information presentation systems. Although this paper judged an effect based on the subjects' answers, in cases where the subject has personality traits of syncretistic tendencies or cooperative mentality, it is possible that the subject's answer was caused not due to psychological phenomena, but by rational judgments based on the indicator of the gauges as a reference. Exploration of such individual differences is the future study.

Reporting and knowing the results of such individual differences are necessary and important for designing and using information presentation systems, including systems that present myoelectricity sensor information. If all studies only report the results of the majority's responses that are as the expectations, no one will discuss how to deal with these individual differences. If the wrong knowledge that everyone gets the majority's expected effects is spread among the users and developers of the system, new problems will arise. For example, it is assumed that the widespread use of the same systems can cause problems where many people get good effects while some get bad effects unnoticed. Therefore, it is desirable for studies dealing with psychological phenomena of information presentation systems to report individual differences in effects, such as subjects who obtained unexpected effects.

6.4. Future study

(1) In the future, we will verify various people to generalize our findings to a wider attribute of people since the number of subjects was about 10 and the subjects of this experiment were young university students. On the other hand, since the previous study (Adams et al., 2015; Isoyama et al., 2021) focusing on psychological phenomena of information presentation systems showed the necessary verification results with about 10 people, we consider that our experiment also obtained the necessary verification results to understand and discuss our focused effect. (2) Our experiments had no condition for the presentation of actual sensor values (i.e., without sensor value modification). Therefore, it has not been verified whether the high/low load reproduction information condition has a higher/lower perceived load compared to the actual sensor value condition. We will verify it in the future. On the other hand, this paper will be useful for understanding the trends and individual differences in the effects on load perception by sensor information modification. For example, in the prior experiment (Adams et al., 2015) of the vocal pitch modification feedback method, to understand a trend in the effect of pitch modification, only the comparison of two conditions (i.e., one higher and one lower than the actual pitch) were used. (3) This paper did not investigate how the actual myoelectric values changed in the experiments, while previous studies of physical fatigue control using VR technology have shown examples of perception changes extending to actual myoelectric values (Ban et al., 2013). Whether the effect of the myoelectric sensor modification feedback occurred only on the perception or on the actual body will be investigated in the future. (4) In addition, although our experiment only used the sensor information of the arm, we will verify whether the same phenomenon occurs for other body parts. (5) Furthermore we will apply the proposed method to practical situations such as sports training. (6) We will also identify the factors of individual differences in psychological phenomena caused by sensor information by using personality data (e.g., personality measurement, brain data, and lifestyle).

7. Conclusion

In this study, we verified the existence and manipulation methods of psychological phenomena in that the user's load perception is unconsciously changed by myoelectricity sensor information. Then, we proposed a method, Unconscious Load Changer, to manipulate the load perception by presenting the myoelectricity sensor information that is different from the actual sensor value and is simulated as a specific load such as the high load and low load. We implemented a prototype system and evaluated the effect of our method on the two types of load perception of weight perception and fatigue perception when handling objects. The result indicated that the load perception of the majority of subjects unconsciously increased or decreased so as to match the presented myoelectric value. This showed the psychological phenomenon of myoelectricity sensor information and the feasibility of the proposed method to manipulate the psychological phenomenon. We also discussed the possibility that this phenomenon can be utilized for positive or negative purposes. Many studies have used myoelectricity sensor information; however, this is the first study to focus on psychological phenomena caused by viewing myoelectricity sensor information while performing load-related tasks. The results of this study are expected to have implications for the design and use of sensor information presentation systems, including myoelectricity sensor information.

Data availability statement

The datasets presented in this article are not readily available because the dataset for this study does not have permission to be released to outside parties. Requests to access the datasets should be directed to KF, futami@fc.ritsumei.ac.jp.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Commission of Ritsumeikan University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

KF, TS, and KM: conceptualization and methodology. TS: software. KF and TS: validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, and visualization. KF and KM: supervision and project administration. KF: funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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