CONTINGENCY MANAGEMENT OF PHYSICAL REHABILITATION:

THE ROLE OF FEEDBACK

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Modern advances in technology have allowed for an increase in the precision with which we are able to measure, record, and affect behavior. These developments suggest that the domains in which behavior analysis might contribute are considerably broader than previously appreciated, for instance the area of behavioral medicine. One way the field of behavior analysis can begin to address problems in behavioral medicine is with biosensor technology, like surface electromyography (sEMG). For sEMG technology to be useful in behavioral medicine, specifically recovery from total knee arthroplasty, a reference value (the maximum voluntary individual contraction-MVIC) must be established. The MVIC value allows for the comparison of data across days and may allow the programming of contingencies. However, current MVIC methods fall short. Study 1 compares MVIC values produced by a participant given the typical instruction only method with two alternative methods: instruction + feedback, and instruction + feedback in a game context. Across 10 participants both feedback conditions lead to higher MVIC values then the instruction only condition. Study 2 applies the MVIC techniques developed during Study 1 to an exercise procedure. Using an MVIC value as the criteria for feedback Study 2 compares the same three conditions, however this time assessing for the conditions under which exercise performance is optimal. Across all 9 participants the instruction + feedback in a game context lead to the participant ‘working harder’ and 8 out of 9 participants exceeded the MVIC value more often during this condition then in the other two conditions.

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Introduction

Over the last decade, improvements in computer hardware and software technology have allowed for the development of techniques for the real-time collection and analysis of data on a wide variety of medical and behavioral phenomena (American Institute of Medical Science and Education, 2015). These techniques allow users to collect a wide variety of information along a number of dimensions at very high spatial and temporal resolutions. For example, a combination of sensors and software allow for continuous or on-demand measurement of heart rate, skin temperature, hydration levels, oxygen saturation and the galvanic skin response among many others. The increasing availability of these technologies creates a novel opportunity for measuring and managing the development and organization of behavior at scales previously considered outside the domain of applied behavior analysis.

One such opportunity presents itself in the area of patients recovering from total knee arthroplasty (TKA) or total knee-replacement surgery. The primary cause of TKA is osteoarthritis which is characterized by a steady degeneration of cartilage and bone structure of the affected joint (Carr, Robertsson, Graves, Price, Arden, Judge, & Beard, 2012). This degeneration results in severe pain which is exacerbated by activation of the joint. The relation between activity and pain leads to decreased use of the affected joint directly contributing to muscle atrophy and loss of function (Mizner, Petterson, Stevens, Vandenborne, & Snyder-Mackler, 2005). It is the loss of function which is the primary indicator of the need for TKA (Carr et al., 2012).

Although TKA reliably reduces pain and improves functional range of motion of the knee, weakness of related muscles and reduced functionality have been observed even one year after the procedure is performed (Thomas & Stevens-Lapsley, 2012). By many accounts, the vastus medialis oblique (VMO) is one of the most important muscles to target early and intensively for direct engagement and activation following TKA (e.g., Pozzi, Snyder-Mackler, and Zeni (2013). The VMO is one of four muscles the make up the quadriceps -- vastus lateralis, vastus medialis, vastus intermedius, and the rectus femoris (see Figure 5). Ineffective or improper rehabilitation of the VMO may adversely affect recovery and lead to long term decrease in quality of life. Walsh et al. (1998) found that one year after surgery many adults still faced significant functional deficits. For example, males ascended steps 51% slower and woman 43% slower relative to adults of the same age who did not undergo surgery. Another study comprising 243 patients found that 52% of the patients experienced some level of dysfunction one year post surgery (Noble, Gordon, Weiss, Reddix, Conditt, & Mathis, 2005).

Although a variety of factors interact, it has been suggested that the early failure to engage the muscles that control the action of the knee following TKA is a major contributing factor for both the extended time in recovery and the failure to produce a complete recovery in function (Mizner et al., 2005). In addition, nerve damage during surgery that reduces proprioceptive feedback may further contribute to the difficulty of engaging the relevant muscles (Pap et al, 2000). In behavioral terms, TKA could be set to contribute to the creation of a set of extinction and aversive contingencies that decrease the likelihood of the voluntary muscle activation known to facilitate a full and rapid recovery from TKA. Specifically, small improvements in muscle function are rendered undetectable due to loss of proprioception creating extinction-like contingencies. In more colloquial terms, patients do not know if they are working the right muscles or if they are working them to the right levels (Foley, 2017, personal communication).

Several studies have focused specifically on using technology to establish clinically relevant physical rehabilitation outcomes. Ng, Zhang, and Li (2008) evaluated the utility of an electromyograph by comparing the effects of exercise alone and the effects of exercise combined with auditory and visual feedback based on readings of muscle amplitude via EMG and found a significant difference in VMO flexion acquisition. The participants in the EMG and visual feedback condition learned the response at a significantly faster rate than the exercise only participants. Draper (1990) examined the effect of visually displayed biofeedback plus exercise vs exercise only on overall recovery following anterior cruciate ligament reconstruction surgery. The biofeedback group showed significant improvement following 12 weeks of rehabilitation when compared to the no biofeedback group. In a systematic review, Lepley, Gribble, and Pietrosimone (2012) concluded that the electromyographic biofeedback (EMGBF) was an effective therapeutic modality especially with pathological populations with a special emphasis on knee osteoarthritis.

Despite the clear benefits of electromyographic devices, they are not widely used in the rehabilitative context. Typically, these sensors are burdensome to set up due to many wires, invasive in the case of subcutaneous EMG, and in the case of surface EMGs (sEMG) highly sensitive to even the slightest change in placement from day to day, as sEMG signal detection has a lot to do with the details of the electrode placement and any displacement along any of the axes results in a slightly different measure. As a result, it is common practice to look at values across days or sessions as the proportion of a referential value. The most common method of obtaining the referential value is the maximum voluntary individual contraction (MVIC) procedure (Halaki & Ginn, 2012; Rutherford et al, 2011; Burden, 2010). The MVIC value is the maximum amplitude produced during an isometric exercise following the instruction “flex as hard as you can." One problem with the current MVIC procedure is that at times during standard patient exercises the patient exceeds the MVIC value by almost double (Boren et al, 2011; Clarys, 2010; Jobe et al, 1984). This suggests that the current MVIC procedure may not produce an accurate representation of maximum amplitude.

The purpose of this study was to compare the traditional means of generating MVIC (instructions only) with a system that couples instructions with feedback and another system that embeds the task requirements inside a gaming context for the purpose of determining the environmental arrangements optimal for maximum MVIC production. Prior to MVIC testing all participants were taught to flex the VMO through shaping, ensuring a relatively common history. Afterwards the participants completed the above mentioned MVIC tests in order to determine the optimal contingencies for producing the maximum MVIC. Isolating the optimal contingencies is critical if behaviorists are to have any success developing technology infused contingencies within the rehabilitation context.

Method

Participants

The experimenter obtained IRB approval prior to recruiting any participants. The experimenter recruited participants from undergraduate courses in behavior analysis from the University of North Texas. Participants did not receive any monetary compensation, however; the instructor of participating students did offer extra. Ten healthy college age students at the University of North Texas (4 male, 6 female) served as participants. The recruitment process involved an in-class announcement and a handout with the experimenters contact information.

The only criteria for inclusion included no history of knee surgery or current activity inhibiting knee injury.

Setting

Sessions took place in a variety of locations on or just off of campus of the University of North Texas in Denton, TX. A common feature in all settings was the presence of chairs in which the participant and experimenter sat.

Apparatus

A sEMG device, known as the FlexDot™, measured and recorded the electrical activity of the targeted muscle (VMO) (see Figure 1). The sEMG device returned measures of electrical activity in targeted muscles in micro-volts (1/1,000,000 of a volt) at the rate of 63 measures per second. A strap with connective metal tabs ensured appropriate contact with the skin (see Figure 2). An Android-based smart device (either phone or tablet) collected the data and interfaced with the FlexDot™. Custom written applications allowed for the programing and management of contingencies (see Figures 3 and 4). Additionally, a paper and pen data sheet allowed for the experimenter to track conditions across participants and track client preference and fatigue across the experimental preparations.

Measurement

Muscle flexion of the VMO (right leg only) served as the dependent variable. Flexion was recorded as a relative increase in electrical activity in the targeted muscle. These data were programmatically smoothed (via averaging) to produce 4 punctuated measures of electrical activity per second. The arrangement and management of all contingencies was relative to the average amplitude values described.

Procedures

All participants wore shorts or other athletic apparel. Prior to the start of any testing or experimental manipulations each participant learned to flex the VMO. This helped ensure relative similarity across participants in regard to their history of VMO flexion. After establishing a history of VMO flexion the experimenter began testing for the peak amplitude produced during an individual's contraction of the VMO. The study included 3 conditions (instruction only, instruction + feedback (auditory tone), and instruction + feedback in a game context). The results from these conditions provide information regarding the conditions under which an individual may produce the greatest MVIC value.

Initial Instruction and Set Up

The experimenter described the entirety of the study to the participant during the beginning of the session. During the description process the experimenter fitted the participant with the sEMG device. The purpose of this was to ensure that the experimental conditions resembled potential clinical conditions as closely as possible.

> This small sEMG device will allow me to measure how much you are flexing your quadricep. I am going to place this device on your knee. Please extend your leg and flex your quadricep now.

At this time the experimenter pointed to the vastus medialis oblique (VMO) located approximately 2 finger widths above the knee cap just left of center (Figure 5).

> This teardrop shaped outline is your vastus medialis oblique. It is the primary muscle physical therapists target following total knee replacement surgery. For the remainder of

this session we are going to focus on the muscle amplitude of this muscle.

The FlexDot™ was then connected to the strap which went around the knee and oriented so that the FlexDot™ rested along the teardrop of the VMO. The battery opening of the FlexDot™ points toward the midline of the leg (Figure 6).

> Sometimes it is difficult to figure out how to flex this specific muscle, this is a particularly common hurdle for patients who have recently gone through total knee replacement surgery as they often lose some proprioceptive feedback. To address this difficulty, I am going to start by teaching you to flex this muscle. At first, you are going to hear a tone if you just barely flex the muscle. This requirement will gradual increase until you are efficiently and effectively engaging the VMO. After you have learned how to flex the VMO, we are going to determine your maximum contraction. We will do this by having you flex 12 times across 3 different conditions. In one condition, you will receive no feedback other than my instruction to flex as hard as you can. In another condition, you will hear a tone every time you meet your goal, and in the final condition you will be playing a game. I will let you know which condition you are in prior to the start of that condition. While you are in the condition, the requirement for feedback (such as a tone will change, sometimes a very little flex will produce a tone and at other times you will have to flex very hard to produce the tone).

Conditions

The study consisted of two phases: initial training and MVIC testing. The MVIC testing occurred across three conditions (described in detail below): (i) instruction only, (ii) instruction + feedback, and (iii) instruction + feedback in a gaming context.

Initial Training

This part served as an initial training condition to ensure that all participants could efficiently and effectively engage the VMO prior to the beginning of the experiment proper. The purpose of this was to avoid potential difficulties in interpreting the data from the testing condition. Once the device was in place, the participant sat in a chair positioning their legs at a 90 degree angle. During training, the criterion for initial feedback (a ding) was set at a value of

150 microvolts. This minimal requirement greatly increased the likelihood that the participant would be able to produce a criterional response and contact the contingency of reinforcement. The subject was then asked to flex the VMO muscle. Criterional responses produced an audible ding and sub-criterional responses ended the trial with no consequence. After the participant had produced two criterional flexions, the amplitude requirement was increased to a value slightly above the maximum value produced in the previous trial. For example; if during the 200 microvolt criterion trial, the participant emitted a flexion of 250 microvolts, the next criterion would be set slightly beyond that value (e.g., 300 microvolts). However, if the participant emitted a value of 2,000 microvolts then the next criteria would be substantially greater, 2,500 microvolts. By the end of training all participants could reliably produce a flexion response with amplitude values equal to or greater than 3,000 microvolts. The duration of training ranged from 20 seconds to 2 minutes. Due to the rapid and variable nature of the training method, systematic data was not recorded as it was not considered critical or relevant to the experimental question.

Maximum Voluntary Individual Contraction

The MVIC testing consisted of three different conditions. Each condition followed the same pattern with the only changes across conditions being the availability or context of feedback. During each condition a block of four trials were presented to the participant three times. During the block of four trials, the criterion for feedback was set at 1,000 microvolts for the first trial, 2,000 microvolts for the second trial, and 3,000 microvolts for the third trial. The criterion for the fourth trial was set at 50,000 microvolts. In this manner, the first three trials in the block established a local history of reinforcement for increasing response requirement and the fourth trial served as the test trial in which the established criterion was impossible to meet.

The maximum amplitude produced during this criterion served as the MVIC. Each participant experienced this block of trials three times in each of the three conditions: instructions only, instructions + feedback, and instructions + feedback in a gaming context. The order in which these conditions were experienced was arranged semi-randomly and counter-balanced across participants (Table 2).

During each trial, the participant had three seconds to flex, following each bout of flexing was a 5 second break. The app used to run the experiment prompted the participant to 'flex' or 'relax' automatically. For example, at the start the instruction + feedback condition the amplitude was set at 1,000 microvolts the experiment would start the session and the app would immediately say ‘flex.’ Following the prompt to ‘flex’ the participant would attempt to engage in a flexion greater than 1,000 microvolts in order to produce a tone, after 3 seconds of flexing the voice app said ‘relax.’ The resting period lasted 5 seconds, during which the participant would take a brief break and the experimenter would adjust the criterial value to 2,000 microvolts. At the end of the 5 seconds the app automatically prompted the participant to flex again, however this time only a flexion exceeding 2,000 microvolts would produce the tone. This pattern was repeated across all trials and conditions. At the end of each condition the participant completed each block (1,000; 2,000; 3,000; 50,000) three times for a total of 12 flexions per condition. After all three blocks were completed the participant took a 30 second break. (Table 1). During this break the experimenter made all necessary changes to the apparatus: turning off the sound in the case of switching to instruction only and switching apps in the case of the instruction + feedback in a game context. Following the participants completion of the final trial, the experimenter removed the device and strap, as well as, answered any questions the participant may have had. After this the session concluded and the participant left.

Results

All participants learned to engage the VMO during the initial training condition. The amplitude requirements began at 150 microvolts. The experimenter increased the criterion following the participant successful reaching the previous criterion requirement. By the end of training, all participants were able to engage the VMO at amplitude values exceeding 3,000 microvolts. Training took an approximate average of 45 seconds (range: 20 seconds-2 minutes). All participants continued to the next phase of the procedure. These data are not presented visually.

The second phase of the study, MVIC testing, started immediately following the conclusion of the initial training phase. Figure 7 shows the average of the three peak amplitudes from each criterion (1,000; 2,000; and 3,000 microvolts) as a percentage of MVIC. The average peak amplitude was obtained by adding together the single highest peak value from each opportunity at that criteria (note there are always 3 opportunities per criteria) and then dividing by 3 (the total number of opportunities) These values were then divided by the maximum MVIC value for that participant (this value was always taken from the instruction + feedback in a game context condition) which allowed for all data to be presented as a percentage of MVIC. The Y-axis shows the percent of maximum MVIC produced during the trial, the X-axis shows the different conditions. The dashed lines represent the criteria (1,000, 2,000, 3,000) as a percentage of MVIC and the error bars show the range of these values from lowest to highest peak amplitude. These data show relative lack of sensitivity to changes in the criteria. No participant showed evidence of a consistent increase in flexion, as measured by amplitude, to match the relative increase in the criteria when examined across all conditions. Participant Two, perhaps, comes the closest to this showing an upward trend as the criteria increases across both the instruction only and instruction + feedback condition. However, during the instruction + feedback in a game context condition this pattern is not present, peak amplitude dips during the 3,000 microvolt criteria requirement. The lack sensitivity in peak amplitude output, relative to criteria changes, following VMO flexion is even more prevalent in the remaining 9 participants.

While no participants displayed a general sensitivity to the specific criteria requirements, there is evidence of differentiation in absolute amplitude produced between the instruction only condition and the remaining two contingency driven conditions (instruction + feedback and instruction + feedback in a game context). For instance, with the exception of a couple of notable outliers; such as the 2,000 microvolt requirement for participant 3, all participants showed evidence of a general increase in performance during the two contingency driven conditions (instruction + feedback and instruction + feedback in a game context) in comparison to the instruction only condition. Participant Five's results highlight this finding well. The amplitude values produced by the participant Five, regardless of the criteria, are on average three to six times greater during the instruction + feedback and the instruction + feedback in a game context conditions, respectively, than those values produced during the instruction only condition. While the programmed criteria values may not show much of an effect on responding the current data does suggest that contingencies have a distinct impact on behavior, even at the microvolt level.

Additionally, Figure 8 shows the peak amplitude from the extinction trials as graphed along a Y-axis of amplitude of muscle potential activity and the X-axis that is separated by condition. This data shows that instruction + feedback in a game context produced the greatest MVIC value, followed by the instruction + feedback condition. This finding is true for all participants. At no point does the instruction only condition produce the highest or second highest MVIC value. Participant 6's data clearly shows the stepwise nature of the three conditions relative to the MVIC for VMO flexion.

Finally, Figure 9 displays the average peak value produced across all three extinction trials. The *y*-axis shows percent of MVIC value and the *x*-axis is divided by condition. The MVIC value represent the highest value produced during the extinction condition, which is different for each participant. The error bars show the range from lowest max peak to highest max peak within the three extinction trials for that condition. It is important to note that the average peak value consisted of three behavioral measures, the maximum from each of the three extinction trials within a condition. One behavioral measure from each extinction trial is taken even if the three highest values all occurred during the same condition. Additionally, each instruction to instruction + feedback, and instruction to instruction + feedback in a game context relation includes an asterisk if the corresponding feedback condition arranged the environment such that the participant produced a statistically significant greater amplitude following VMO flexion.

The consistency of this pattern across all participants both as a measure of maximum peak, minimum peak and average peak further support the conclusion that a game based condition is the ideal environmental arrangement for driving performance in order to produce the max MVIC value. Participants 6 and 7 are ideal exemplars of this finding, whereby at no point is there an overlap in MVIC production regardless of conditions. This means that, even the lowest peak value produced during the instruction + feedback in a game context condition exceeded that of the highest peak value produced during the other two conditions. Alternatively, Participant 10 demonstrates the least robust representation of this effect. While the average of the three peak amplitudes remained the highest in the instruction + feedback in a game context condition the max peak amplitude (MVIC) value occurs in the instruction + feedback condition. Participant 10 is the only example of any condition producing a greater max during the MVIC condition then the instruction + feedback in game condition.

Statistical analysis further supports' the findings described above through visual analysis. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. The degree to which the instruction + feedback in a game context condition exceeded the instruction only conditions was significant, *p*-value less than or equal to .05, for 8 out of 10 participants. Participants 5 and 8 are the only participants where a significant difference between the two conditions is not present (p-value=.07 & ,13) (Table 3). There was also a significant difference between the instruction only and the instruction + feedback conditions, though these findings are less robust. A statistical significance was found for 5 out of 10 participants between these two conditions; Participants 3, 5, 7, 8, and 10 were the only exceptions with *p*-values of (.06, .25, .07, .27, and .14) (Table 4).

Despite some variability in the degree of the effect, that instruction + feedback in a game context had on the MVIC value, the general trend remains. Across 9 out of 10 participants the instruction + feedback in a game context condition produced the highest MVIC amplitude value, suggesting that these contingencies may be optimal for determining the MVIC value in a therapeutic context.

Discussion

The specific purpose of this study was to ascertain the best way to secure an accurate MVIC from individual patients. This measure, when reliably produced, can be important in serving as a reference which allows the participant's performance to be compared across sessions or days. The measure is also important in programming contingencies of reinforcement to support clinically relevant exercises and to monitor compliance. The results of the study show that we were able to reliably generate these measures and that the conditions we programmed were reliable differentiators of the amplitude of muscle activity.

For all participants, the lowest amplitude values of flexion were seen during the instruction only condition. The use of contingencies and feedback, whether in the form of an instruction + feedback or instruction + feedback in a game context, led to an increase in amplitudes relative to the instruction only conditions in which no feedback was programmed. Eight of the ten participants showed a statistically significant increase in amplitude in the gaming condition. The two feedback conditions also showed differentiation; overall, greater amplitudes were observed in the gaming condition relative to the instruction + feedback condition. These findings raise several points for consideration.

First, these data call into question the current standard practice of instructing patients to generate 'as strong a contraction as possible' as a reliable strategy for generating the maximal contraction. The instruction-only condition in the current study, designed to recreate standard clinical protocols generated the lowest intensity responses of all conditions considered. Furthermore, these data were collected after all participants were capable of efficiently and effectively engaging the VMO muscle. This step is typically missing from standard clinical protocols which further raise doubts about the measures generated in the standard clinical practice. If the current findings are to be taken at face value, then a game-based approach may serve to provide a more approximate estimate of the amplitude potential of the muscle than other methods.

It is important to note that the instruction + feedback condition also produced relative increases in amplitude in all ten participants when compared to the instruction only condition, this increase was significant for 5 out of 10 participants. These data may suggest an important role for feedback (or reinforcement) in the testing context independent of the context in which such feedback is provided (game or otherwise). That is, it may be important to ensure, prior to the MVIC test, that the patient can engage the relevant muscle. The arrangement of feedback for small amplitude flexion responses might serve to confirm that the correct muscle is being engaged prior to instruction delivery.

The fact that the gaming context produced the highest amplitude values in a within-subject comparison prompts some interesting questions. Although a component analysis of the properties of feedback was not our concern in this study, we note that both conditions with feedback included an auditory signal to mark a criterional response. The instruction + feedback in a game context condition, however, also included a visual component. We do not, however, have any data on whether or how often the participants made contact with the visual component of the programmed reinforcer in the gaming context. Future research should examine the nature of visual (present in the game based condition) versus auditory feedback, visual + auditory (game based) versus visual only, as well as visual + auditory feedback in a nongame-based format.

Alternatively, it seems reasonable to call into question the entire notion that the instruction + feedback and the instruction + feedback in a game context served as consequential feedback. The amplitude of muscle potential activity produced during the flexion response by all participants in both conditions appears relatively independent of the specific criteria that feedback was based off within those conditions. As seen in Figure 7, participants often over shot the criteria by a considerable margin. The participants' relative insensitivity to the specific criteria might suggest that the effect was better understood as an antecedent intervention or a motivating operation. Perhaps less controversially, the tone or game serve as a keep-going response leading to higher and higher amplitude values over the course of the study regardless of the amplitude requirement. Future studies should attempt to gain a finer understanding of these dynamics.

An important limitation of the study comes from the discrepancy between the population studied and the eventual targets of this effort. This study was conducted with healthy participants to establish the general utility of the procedure but the eventual targets of the protocols developed will be adults recuperating from total knee-replacement surgery. It is possible that some or all of the protocols/procedures developed here will have to be altered for a clinical population. Although we have established the utility of a game-based task to generate MVIC, further investigation into any potential variations between healthy and impaired patients is necessary.

Despite the limitations, the results decisively show that the gaming context reliably produces the highest MVIC values of the three conditions compared. As these values are likely to be closer estimates of the muscle's potential, they are likely to be more beneficial for the purposes of therapeutic programming. These measures may allow for more accurate tracking of patient progress over time and programming therapeutically relevant exercises. Future studies should examine the possibility of arranging an exercise program that is based on individualized MVIC values and contingencies.

STUDY 2

Introduction

The results from Study 1 suggest that instruction + feedback in a game context may arrange the contingencies such that the maximum voluntary individual contraction (MVIC) value produced by an individual during vastus medialis oblique (VMO) flexion may more accurately represent a true maximum contraction. This method yields an important reference measure against which other instances of the response may be compared. The measure also serves as a reference that can be used to customize response requirements in exercise regimens designed to improve muscle function. The current study asks if MVIC values generated through an instruction + feedback in a game context paradigm can be used to program an exercise regimen designed to activate and engage the VMO. In 2003, the National Institutes of Health called for action to be taken by the medical field to develop more effective methods of producing rehabilitative outcomes following total knee replacement surgery (Rankin et al, 2004). The necessity for this action is clear, but the methods by which it can be achieved is less so. The current study seeks to contribute to this goal by comparing healthy volunteers' activation and engagement of the VMO in three different contexts – instructions alone, instructions with feedback, and instructions in a gaming context.

The purpose of the current study, then, is to compare three different methods for programming exercise regimens based on the MVIC values generated during Study 1. The typical practice in clinics is to instruct the patient to engage in the indicated exercises for a prescribed amount of time. Since confirmation that the correct muscle is being used requires physical palpation of the VMO, this feedback by the therapist is often lacking in the standard clinical procedure. This study compares the instructions condition to a condition which combines instructions with feedback and another condition in which instructions and feedback are provided in the context of a game. In each case, the interest is in evaluating if one condition is better than the others in increasing the likelihood of complete and effective compliance with the exercise regimen.

Methods

Participants

The experimenter obtained IRB approval prior to recruiting any participants. Participants were recruited in the same manner as Study 1. A total of nine healthy college-age participants were recruited.

Setting

Sessions took place in a variety of locations on or just off campus of the University of North Texas in Denton, TX. A common feature in all settings was the presence of chairs in which the participant and experimenter sat.

Apparatus

The same sEMG device from Study 1, known as the FlexDot™, measured and recorded the electrical activity of the targeted muscle (VMO) (see Figure 1). All corresponding materials were also identical to that of Study 1.

Measurement

Muscle flexion of the VMO again served as the dependent variable, the grain of data output was the same as Study 1.

Procedures

All participants wore shorts or other athletic apparel. The same training procedure as described in Study 1 was again used to teach VMO flexion. After establishing a history of VMO flexion the experimenter began testing for the maximum voluntary individual contraction using the instruction + feedback in a game context procedure as described in Study 1. During the final phase of the study, the MVIC value for each participant was used to program an individualized exercise routine. This portion of the study was divided across three conditions (instruction only, instruction + feedback, and instruction + feedback in a game context). Within each condition, the participant engaged in 10 flexions, similar to the MVIC test portion an automated voice instructed the participant when to “flex” and when to “relax.” Each bout of flexing lasted 3 seconds and was followed by a 5 second rest. In contrast with the MVIC test phase, the criterion did not change within or across conditions. Throughout the entire exercise routine, the criterion for feedback was set at 75% of the maximum MVIC value produced during MVIC testing. The order of the conditions was rotated across participants so that each condition occurred in each ordinal point 3 times. For example, if Participant 1 experienced the conditions as: instruction only, instruction+ feedback, instruction + feedback in game context, then Participant 2 would experience the conditions as: instruction + feedback, instruction + feedback in game context, and instruction only (Table 5).

Initial Instruction and Set Up

Following the same pattern as described in Study 1 the experimenter described the entirety of the study to the participant while positioning the sEMG and setting up the rest of the apparatus.

Conditions

The study consisted of three phases: initial training, MVIC testing, and MVIC informed exercise. The MVIC informed exercise portion occurred across three conditions (described in detail below): (i) instruction only, (ii) instruction + feedback, and (iii) instruction + feedback in a gaming context.

Initial Training

To ensure that all participants could efficiently and effectively engage the VMO prior to the experiment proper the participant went through an initial training procedure. The training procedure used here was identical to that of Study 1.

Maximum Voluntary Individual Contraction

MVIC testing followed the same procedural outline as that of the instruction + feedback in a game context from Study 1. Unlike Study 1 participants were not required to complete the instruction only or the instruction + feedback conditions of the MVIC test. Following the completion of the MVIC testing the participant rested for 2 minutes. During this period of time the experimenter made all necessary changes to the apparatus and transitioned the participant to the final phase of the experiment.

MVIC Informed Exercise

The exercise procedure consisted of three conditions: instruction only, instruction + feedback, instruction + feedback in a game context. Each condition consisted of 10 trials (10 flexion bouts). The onset for each of these trials was an automated voice prompting the participant to ‘flex.’ The flexion period lasted 3 seconds, after which the automated voice prompted the participant to ‘relax.’ The rest period lasted 5 seconds. Following this period, the pattern continued, and the participant was again prompted to flex. This pattern was completed across all three conditions. During the two feedback based conditions (instruction + feedback, and instruction + feedback in a game context), the criterion for feedback was set at 75 % of the MVIC value (obtained during Phase 2’s MVIC test). For example, if during the MVIC test a participant produced an MVIC flexion value of 5,500, then the criteria for feedback for the exercise procedure would be set at 4,100 (all criteria values were rounded to the nearest 100). In this case, only flexions reaching or exceeding 4,100 microvolts would produce feedback for the participant. No matter what value was produced, no feedback ever occurred during the instruction-only condition.

Results

Each participant learned to engage the VMO during the initial training condition. During this phase of the study, the amplitude was gradually increased from 150 microvolts to a requirement exceeding 3,000 microvolts. The training procedure took approximately 1 minute on average (range:20 seconds-3 minutes). Following the initial training procedure, all participants continued to the next phase, MVIC testing.

All participants completed the MVIC testing procedure. This procedure was the same as the game context procedure outlined in Study 1. Once the participants completed all 12 trials (3 at each of the 4 criteria levels: 1,000; 2,000; 3,000; and 50,000 microvolts), the MVIC testing phase was considered complete. The participants then rested while the experimenter determined the MVIC value.

The maximum flexion amplitude produced across all three of the MVIC text criteria (50,000 microvolts) was considered the MVIC value for that participant. The range across participants was distinct (3,335-14,471 microvolts). The magnitude of this range may further support the need for individualized exercise programs for patients recovering from total knee replacement surgery. After obtaining the MVIC value, 75% of that value was used as the criteria for Phase 3 of the study.

The third and final phase of the study, MVIC informed exercise, started approximately 2 minutes following the MVIC testing phase. Figure 10 shows the individualized data for all participants in a single panel. The panel includes 18 graphs, three for each participant (one per condition). Each row shows the data for a single participant and the conditions for all participants are presented: instruction only, instruction + feedback, and instruction + feedback in a game context (as read left to right). This pattern of graphical presentation is held consistent across all participants, for ease of reading the graphs, however the order in which a participant experienced the conditions was controlled for across participants; such that each condition appeared in each ordinal point (1^{st}, 2^{nd}, or 3^{rd}) 3 times each (Table 5).

The *y*-axis shows the amplitude of muscle potential activity produced during VMO flexion in microvolts. The data for each graph is divided into 10 sections using a phase change line, representing each 3 second bout of flexing. The *x*-axis shows quarter second increments.

The dashed horizontal line represents the criterion value for all trials. The criterion was set at 75% of the MVIC value for each participant. If we define optimal performance as meeting or exceeding the criteria at 100% of trial opportunities then the instruction + feedback in a game context arranged the environment to produce the best results for 8 out 9 participants, the only exception being Participant 5 who reached criteria 3 out of 10 times in both the instruction + feedback and the instruction + feedback in a game context condition. The mean number of trials meeting criteria for all participants in the instruction + feedback in a game context condition was 88% and the median was 100%. In contrast, the mean and median for instruction + feedback and instruction only was (37%, 40% and 26%, 10%) respectively.

Figure 11 shows the percentage of trials in which the criteria was met per participant. The *y*-axis shows the percentage of trials reaching or exceeding the criteria and the *x*-axis shows the participants. The three different bars represent the conditions (light grey: instruction only, dark grey: instruction + feedback, and black: instruction + feedback in game). More participants, 6 out of 9, engaged in optimal performance (reaching criteria at 100 % of opportunities) during the instruction + feedback in a game context condition than either the instruction only or the instruction + feedback condition, in which no participants engaged in optimal performance. In addition to more instance above criteria participants on average also reached a peak amplitude faster during the instruction + feedback in a game context condition than in the other two conditions as shown by the full wave forms present in some instruction + feedback in a game context trials, as opposed to the more typical linear growth data pattern in the other two conditions.

Using the data from each trial, the area under the curve was calculated to begin to test for total ‘work’ completed during a trial. Figure 12 shows the average area under the curve across trials in amplitude of muscle potential activity produced by each participant in each condition. The *y*-axis shows amplitude of muscle potential activity in microvolts and the *x*-axis is divided by participants. Each black and grey shaded bar represents a condition: the light most bar is instruction only and the black bar is instruction +feedback in a game context. Again, the instruction + feedback in a game context arranged the environment in a way such that all participants engaged in the most work in this condition. Interestingly, in contrast to Figure 11 this analysis shows a distinct difference in 'work' for Participant 5 when comparing instruction + feedback and instruction + feedback in a game context. If the analysis is strictly limited to percent of trials above criteria only there is no difference between the two conditions however, if the analysis is expanded to the area under a curve ('work') there is a difference of just over 27,000 microvolts between the two conditions. The difference between the remaining two conditions, instruction only and instruction + feedback is less convincing, 5 out of 9 participants engaged in more 'work' in the instruction + feedback condition. The difference between these two conditions was at times as little as 700 microvolts, the max difference being just shy of 10,000 microvolts. In contrast with this, the max and minimum difference between instruction + feedback in a game context and instruction only/instruction + feedback was approximately (30,000 and 38,000 (P8) and 8,000 for both (P3)) respectively.

The findings outlined via visual analysis are further supported by statistical analysis. The degree to which the instruction + feedback in a game context condition exceeded the remaining two conditions, in reference to 'work' completed per trial, was significant, *p*-value less than or equal to .05, for 9 out of 9 participants (Tables 6 and 7). There was also a significant difference between the instruction + feedback and the instruction only condition for 5 out of 9 participants. No statistical difference was found between Participant 3 (.32), Participant 6 (.21), Participant 7

(.29), and Participant 9 (.08) (Table 8). While the effect of feedback as an auditory tone alone in comparison to instruction only is perhaps not convincing the impact of the game context is. Regardless of the comparison condition the game arranged the environment such that all participants engaged in significantly more work.

Perhaps due to the nature of the response and contingencies, there is some variability in the degree of the effect of instruction + feedback in a game context on exercise performance. However, the results of the current study broadly support the use of an instruction + feedback in a game context procedure when designing an exercise procedure. Across 8 out of 9 participants, this conclusion is demonstrated regarding percentage of trials above criteria and for all participants this conclusion is supported when analyzing work as a metric of area under the curve. This suggests that such an arrangement of the contingencies may have some therapeutic value in a clinical context.

Discussion

The specific purpose of this study was to ascertain the conditions under which optimal work in an MVIC informed exercise program occurs. Identifying the contingencies under which optimal performance occurs and assessing the utility of MVIC informed exercise may help further inform and eventually optimize the current procedural practice within the physical therapy setting. If such advances are made, functional recovery following total knee replacement may improve. The results of this study show clear differentiation across the programmed conditions, further supporting the notion that such a procedural practice may have an impact if adapted for physical therapy.

All participants engaged in the most ‘work’ during the instruction + feedback in a game context condition and eight out of nine participants met or exceeded the criteria at a higher percentage of opportunities in the instruction + feedback in a game context condition than in either of the other two conditions. Despite the similarity in form of feedback between the instruction + feedback condition and the instruction + feedback in a game context condition the two conditions do not share a similar impact level, regarding performance. Comparing both conditions to the instruction only condition shows that across all participants, performance was better in the instruction + feedback in a game context condition then in the instruction only condition, both in terms of percent of trials above criteria and average area under the curve, ‘work.’ In contrast 5 out of 9 participants engaged in more ‘work’ in the instruction + feedback condition and only 4 out of 9 participants had a higher percentage of trials above criteria when compared directly to the instruction only condition. This suggests that feedback alone may be inadequate for optimizing performance during an exercise procedure.

Interestingly, regardless of the condition order, participants always met criteria during the first trial of the instruction + feedback in a game context condition, this is true for no participants in the instruction + feedback condition and only one participant in the instruction only condition. This along with the rate in which criteria was met during the instruction + feedback in a game context condition in contrast to the other two conditions (Figure 10) suggests that perhaps the game has some antecedent properties which begin to drive performance even prior to the participant contacting the contingency. Future research should isolate the variables within the game to further investigating the controlling features that lead to more optimal performance.

While these findings call into question standard practice, which most closely compares to the instruction only condition, caution should still be taken to not over generalize these findings.

The current study worked exclusively with healthy patients and before any clinical practice changes are suggested these findings from the current study should be replicated in a clinical setting. Additionally, the current study assumes that an area under the curve analysis of total amplitude production during flexion within a trial may accurately capture ‘work’ and that conditions that produce more ‘work’ may improve total recovery. While logically sound, such an assumption can only be confirmed following implementing the procedure through the recovery process and perhaps comparing recovery to the norm or across knees (in the case of double knee replacement surgery).

Despite some limitations and the need for future investigation the data from the present study shows much promise. If the findings from the current study maintain when tested amongst compromised patients, the approach to physical therapy could be dramatically changed through the analysis and implementation of contingency infused technology. Using feedback and a game based format may not only improve performance during mandatory exercises, but also improve compliance due to the preferential nature of a game over the standard exercise format.

GENERAL DISCUSSION

The broad purpose of the endeavor of which these studies are a part of is to identify the potential role for behavioral science in the rehabilitation process following TKA (total knee replacement surgery). There is broad consensus in the orthopedic community (i.e., surgeons, physical therapists and other rehabilitation specialists) that behavioral factors account for a large part of the success or failure of post-operative rehabilitation. These factors include relearning the use of atrophied muscles, such as the vastus medialis oblique (VMO), and complying with the programmed exercise regimens designed to facilitate recovery. The formal (and informal) results of this study begin identifying the role that behavior analysts can and should play in the recovery process.

These studies do not provide all the answers to the problem of physical rehabilitation nor does it attempt to do more than scratch the surface. What it does is answers questions, provides proof of concept and with some luck paves the road for further pursuit. The framework that so many behaviorists adhere to can be applied across a spectrum of problems and by doing so, old solutions can be improved upon and new solutions can emerge. The goal of an applied science should not stop at answering a question or applying it to a realm of comfort but to expand to tackle issues of social significance. The framework behind the science of behavior environment relations is ideally suited for tackling these issues. By diversifying and making use of the technology available, the field can truly begin to address an inordinate amount of issues; improving the world. The recovery process for individuals undergoing orthopedic surgery is just one-step; a step that we are currently taking.

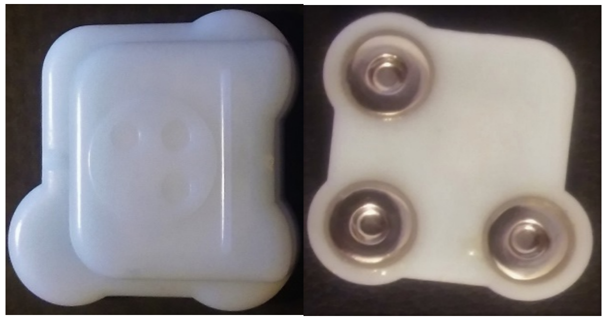

Figure 1. FlexDot™, a Bluetooth capable electromyography device.

The line running across the FlexDot™ run parallel to the two active electrodes and should be oriented to rest between the motor point of the target muscle, in this case the VMO. The 3rd electrode, in the far right corner of the device, is the ground. The relatively limited distance between the ground and the other two electrodes is among the key technological breakthroughs making this research possible.

Figure 2. An elastic strap with a slide buckle and 3 open snaps.

Snaps serve as the electrode conductors avoiding the need for sticky alternatives or invasive procedures such as subcutaneous electrodes. The elastic strap allows the EMG device to be secured around the knee with ease.

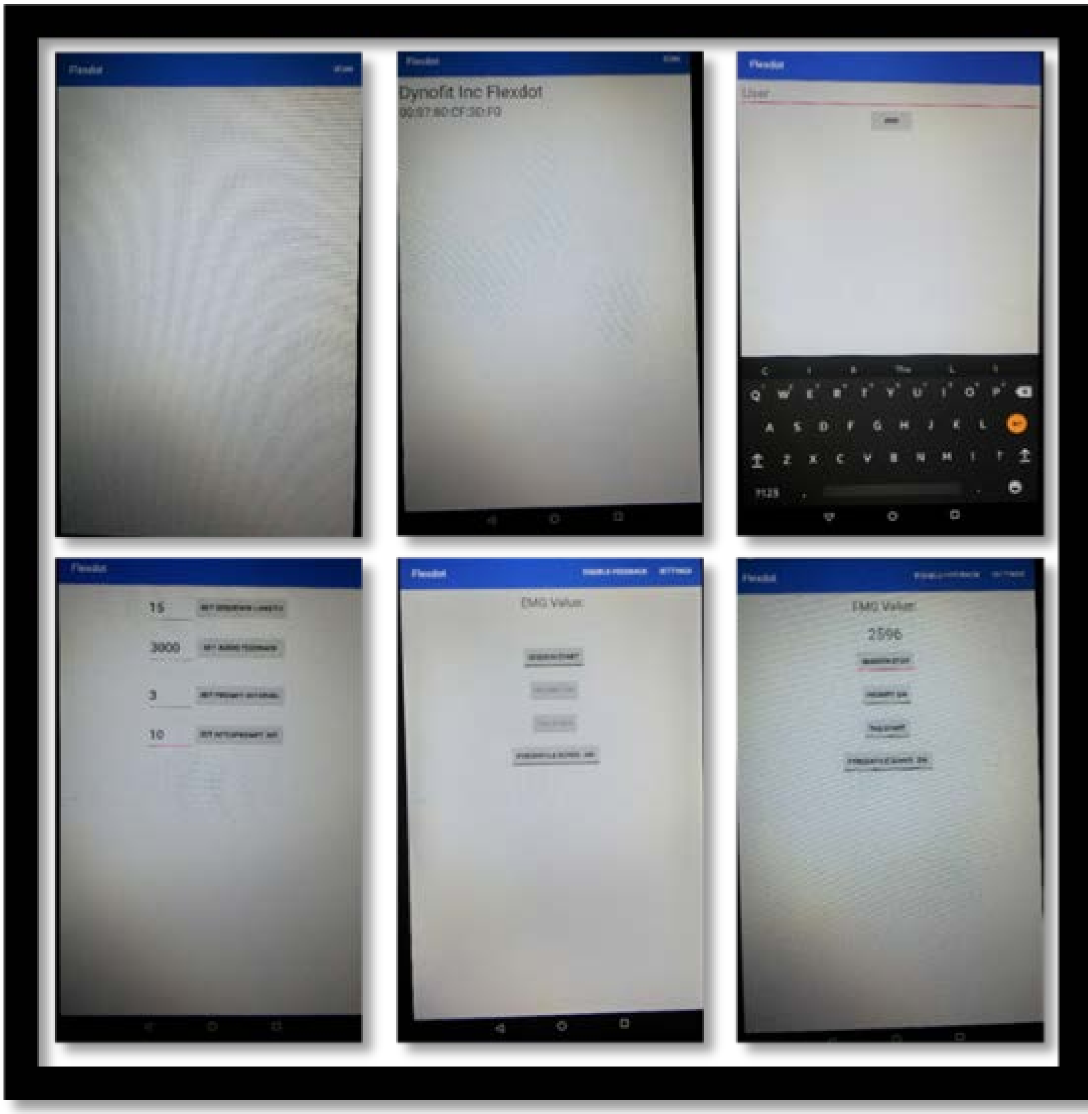

Figure 3. Screen shots of the app used during the instruction only and instruction + feedback conditions [left to right].

1. Hit scan on top left corner.
2. Select device.
3. Add user/participant.
4. Adjust smoothing from 62 data points a second to 15, set criteria value.
5. If instruction only click disable feedback at top of screen then session start. If auditory feedback condition just click session start.
6. Session begins and amplitude readings should appear rapidly on screen.

Figure 4. Screens shots from the app used for the game based portion of the study (left to right).

1. Click settings.
2. Set amplitude requirement.
3. Start game. Ball will rise to top and ding when criteria is met.

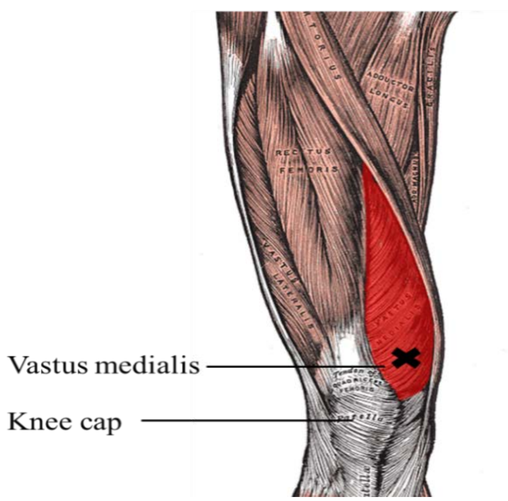

Figure 5. Teardrop portion of the vastus medialus oblique (VMO). (Source: Wikipedia, https://commons.wikimedia.org/w/index.php?title=File:Vastus_medialis_muscle.png&oldid=313949626.

Figure 6. FlexDot™ and strap affixed to leg.

The FlexDot™ is attached to strap by connecting the FlexDot™ to the 3 snaps on the strap. The strap is then placed around the leg and shifted so that the active electrodes face out and the dot rests on the teardrop portion of the VMO. After everything is aligned the strap is tightened to the point of security but not past the point where comfort is loss.

Table 1

Study 1: Amplitude Sequence for Each Condition (in microvolts)

Trial Number	Instruction Only	Instruction + FB	Instruction + FB in Game
1	1,000	1,000	1,000
2	2,000	2,000	2,000
3	3,000	3,000	3,000
4	*Test-50,000*	*Test-50,000*	*Test-50,000*
5	1,000	1,000	1,000
6	2,000	2,000	2,000
7	3,000	3,000	3,000
8	*Test-50,000*	*Test-50,000*	*Test-50,000*
9	1,000	1,000	1,000
10	2,000	2,000	2,000
11	3,000	3,000	3,000
12	*Test-50,000*	*Test-50,000*	*Test-50,000*

Note. Every participant engaged in a flexion at each of the 12 criteria values before advancing to the next condition.

Table 2

Study 1 Condition Order

Participants	First	Second	Third
P1	Instruction + FB	Instruction Only	Instruction + FB in Game
P2	Instruction Only	Instruction + FB	Instruction + FB in Game
P3	Instruction + FB	Instruction Only	Instruction + FB in Game
P4	Instruction Only	Instruction + FB	Instruction + FB in Game
P5	Instruction Only	Instruction + FB	Instruction + FB in Game
P6	Instruction + FB	Instruction Only	Instruction + FB in Game
P7	Instruction + FB	Instruction Only	Instruction + FB in Game
P8	Instruction + FB in Game	Instruction + FB	Instruction Only
P9	Instruction + FB in Game	Instruction Only	Instruction + FB
P10	Instruction + FB in Game	Instruction Only	Instruction + FB

Note. The order of the conditions was semi-randomly arranged to account for sequencing effects. Each condition occurs either first or last a minimum of three times, however the game condition did not occur second at any point.

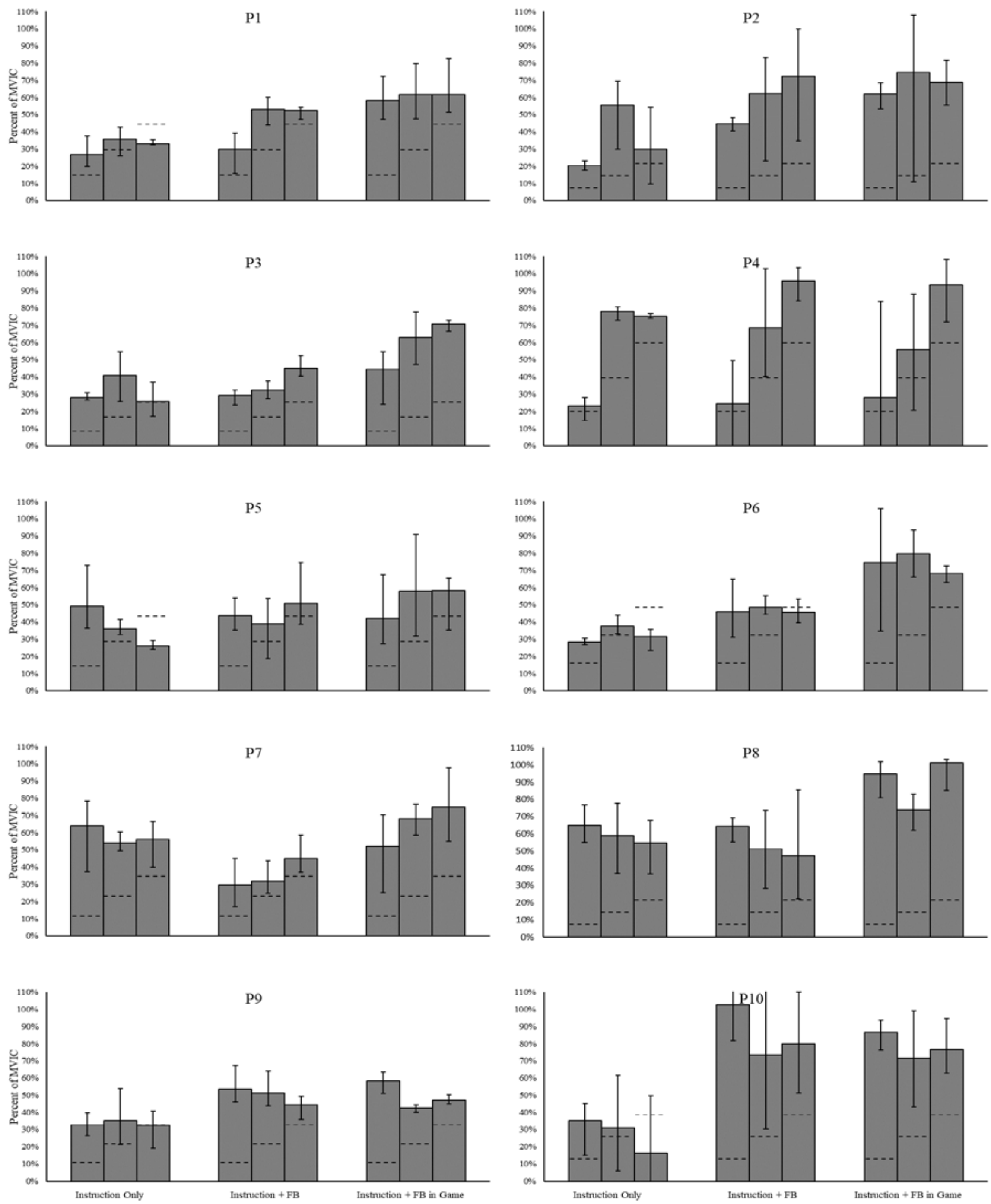

Figure 7. Study 1: Average of the three peak amplitudes from each criterion (1,000; 2,000; and 3,000 microvolts) as a percentage of MVIC (*y*-axis = % of MVIC produced; *x*-axis = conditions). The dashed lines represent the criteria (1,000, 2,000, 3,000) as a percentage of MVIC. Error bars show the range of these values from lowest peak to highest peak. Condition labels for the two feedback condition are abridged to the following: instruction + feedback=Instruction + FB, and instruction + feedback in a game context=Instruction + FB in Game.

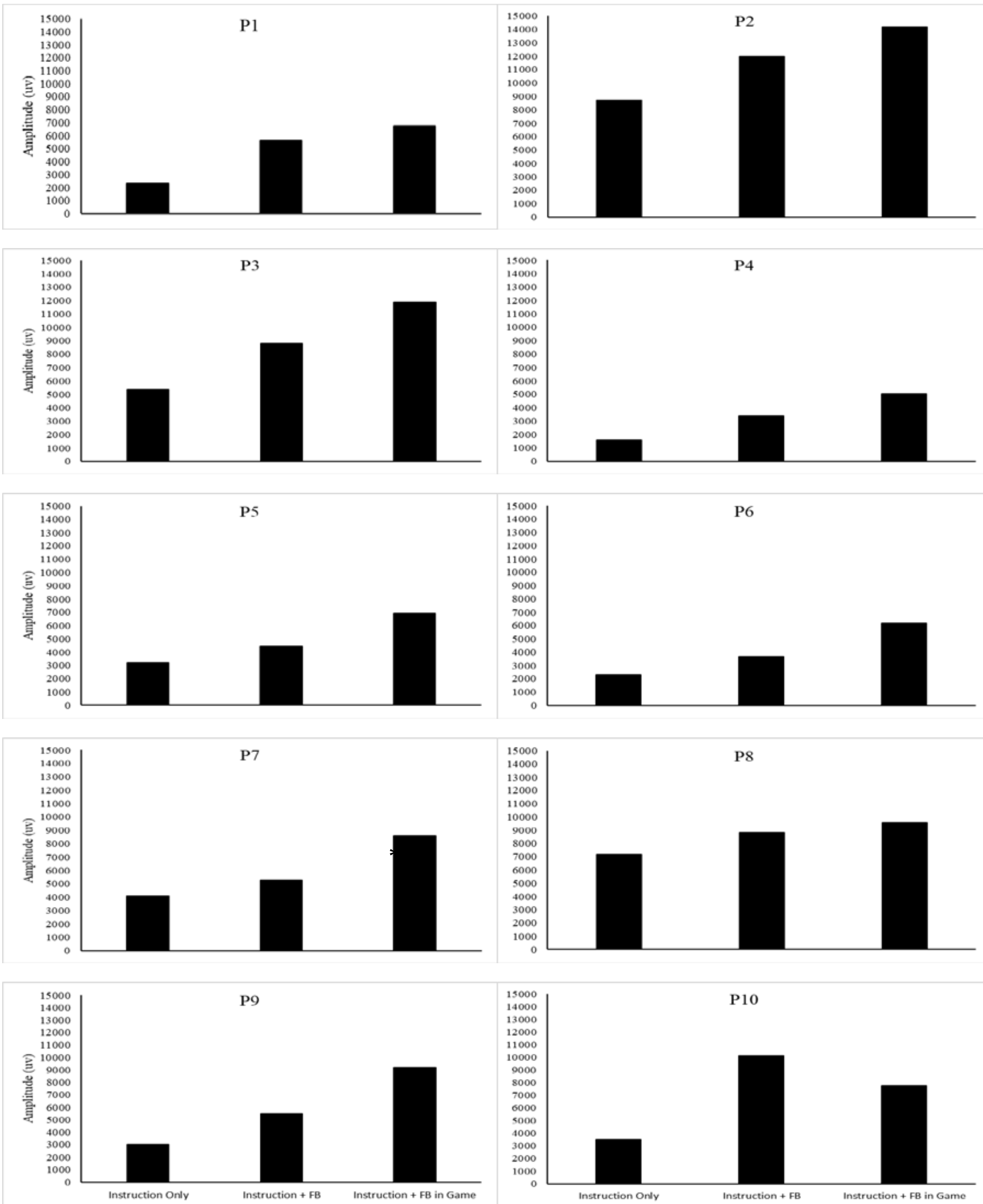

Figure 8. Study 1: Peak amplitude from the extinction trials (*y*-axis = amplitude of muscle potential activity in microvolts; *x*-axis = conditions). Bars show the MVIC value from each extinction (or 50,000 microvolt) criteria value. Condition labels for the two feedback condition are abridged to the following: instruction + feedback=Instruction + FB, and instruction + feedback in a game context=Instruction+ FB in Game.

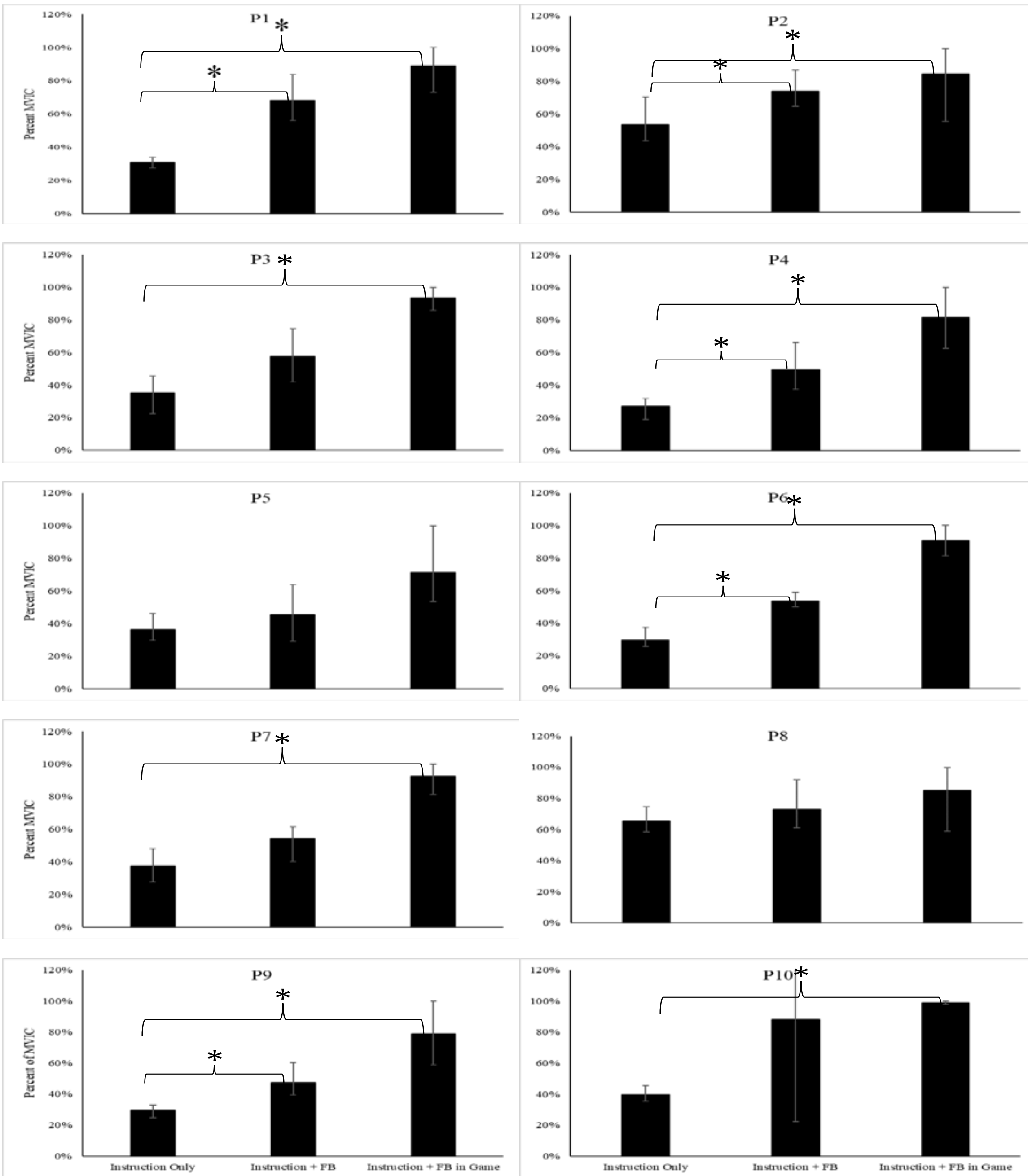

Figure 9. Study 1: Average peak value produced across all three extinction trials (*y*-axis = MVIC [max amplitude output during one of the extinction trials]; *x*-axis = conditions). The bars represent the range of these 3 values showing the lowest peak amplitude and the highest or (MVIC). The asterisk denotes significant difference between the corresponding conditions. Condition labels for the two feedback condition are abridged to the following: instruction + feedback=Instruction + FB, and instruction + feedback in a game context=Instruction + FB in Game.

Table 3

Study 1: t-*Test Two-Sample Assuming Unequal Variances (Instruction-Instruction + FB in a Game Context)*

Participants		MEAN Instruction	MEAN Game	*t*-Score	*p*(T ≤ t) one tail
*	1	2077	6001	-6.97	.01
*	2	7193	12748	-4.77	.004
*	3	4167	11080	-7.42	.003
*	4	1371	4591	-9.66	.0003
	5	2528	4962	-2.29	.07
*	6	1860	5600	-9.29	.0004
*	7	3195	7960	-6.71	.001
	8	6300	8143	-1.39	.13
*	9	2763	7252	-4.02	.03
*	10	3096	7676	-20.11	.001

The results of a two-sample *t*-test assuming unequal variances between the peak values produced during the extinction condition for both instruction and instruction +fb in game condition, for a total of 6 values (3 from each condition). The data is arranged by participant and can be read from left to right: mean value of the 3 peak amplitudes during instruction, mean value of the three peak amplitudes during the instruction + feedback in game, *t*-score, and *p*-value. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. Overall there was a significant difference for 8 out of 10 participants. The asterisks mark all significant *p*-values.

Table 4

Study 1: t-*Test Two-Sample Assuming Unequal Variances (Instruction-Instruction + FB)*

	Participants	MEAN Instruction	MEAN I + FB	*t*-Score	*p*(T ≤ t) one tail
*	1	2077	4592	-4.46	.02
*	2	7193	10196	-2.52	.03
	3	4167	6802	-1.93	.06
*	4	1371	2492	-2.34	.05
	5	2528	3141	-.79	.25
*	6	1860	3309	-5.10	.003
	7	3195	4659	-1.87	.07
	8	6300	6999	-.68	.27
*	9	2763	4354	-2.52	.04
	10	3096	6845	-1.44	.14

The results of a two-sample *t*-test assuming unequal variances between the peak values produced during the extinction condition for both instruction and instruction + feedback, for a total of 6 values (3 from each condition). The data is arranged by participant and can be read from left to right: mean value of the 3 peak amplitudes during instruction, mean value of the three peak amplitudes during the instruction + feedback condition, *t*-score, and *p*-value. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. Overall there was a significant difference for 5 out of 10 participants. The asterisks mark all significant *p*-values.

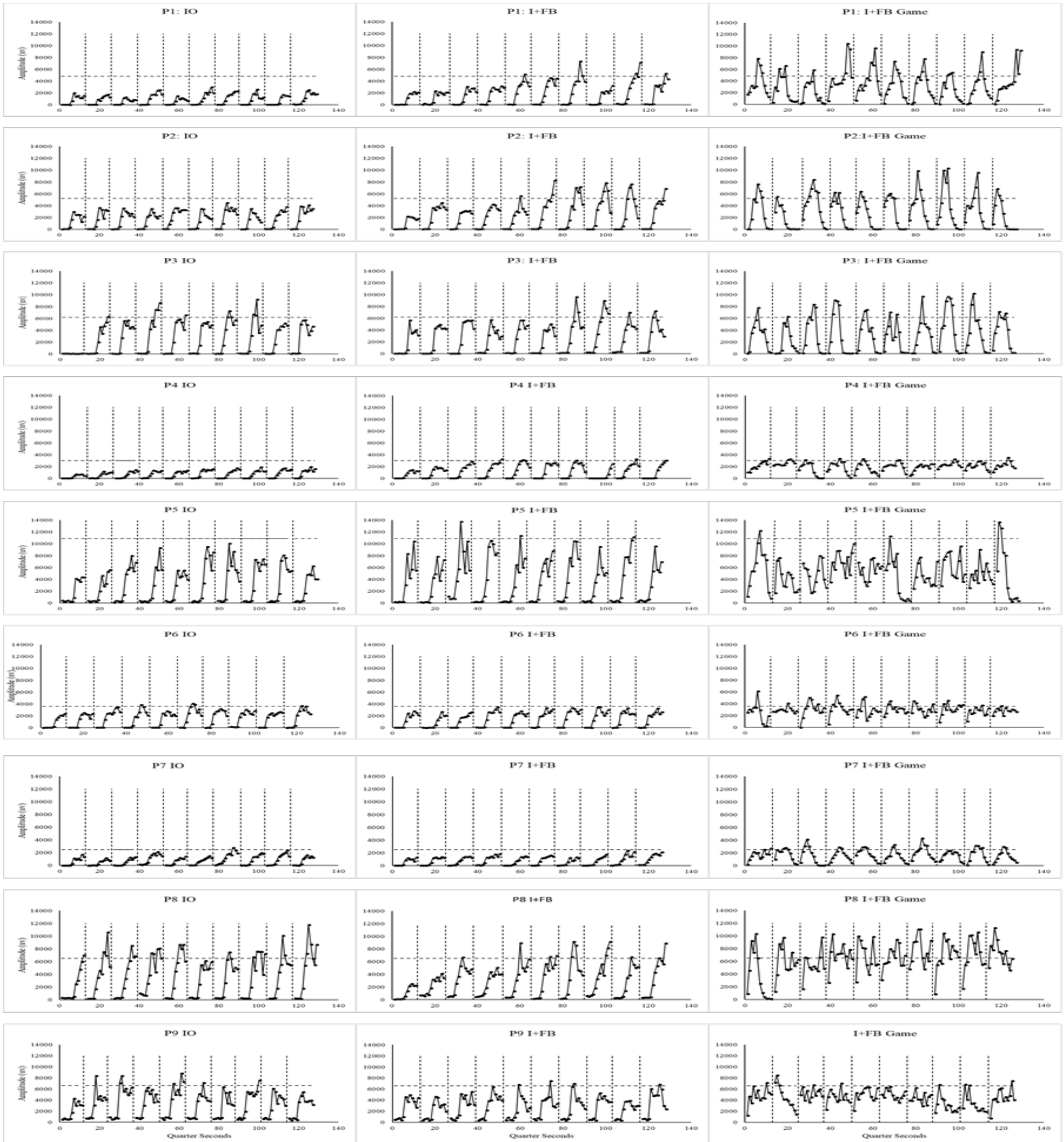

Figure 10. Study 2: Individualized data for all participants (*y*-axis = amplitude of muscle potential activity in microvolts; *x*-axis = quarter second increments). The dashed vertical lines represent each trial (10 in total) and the dashed horizontal line represents the criteria for all trials (this value is 75% of the participants MVIC). Each row represents the data for a single participant and read left to right shows the following conditions: instruction only, instruction + feedback, instruction + feedback in a game context.

Table 5

Study 2 Condition Order

Participants	First	Second	Third
P1	Instruction Only	Instruction + FB	Instruction + FB in Game
P2	Instruction + FB	Instruction + FB in Game	Instruction Only
P3	Instruction + FB in Game	Instruction Only	Instruction + FB
P4	Instruction Only	Instruction + FB	Instruction + FB in Game
P5	Instruction + FB	Instruction + FB in Game	Instruction Only
P6	Instruction + FB in Game	Instruction Only	Instruction + FB
P7	Instruction Only	Instruction + FB	Instruction + FB in Game
P8	Instruction + FB	Instruction + FB in Game	Instruction Only
P9	Instruction + FB in Game	Instruction Only	Instruction + FB

Note. The order of the conditions was arranged to account for sequencing effects. Each condition occurs in each ordinal point at least 3 times.

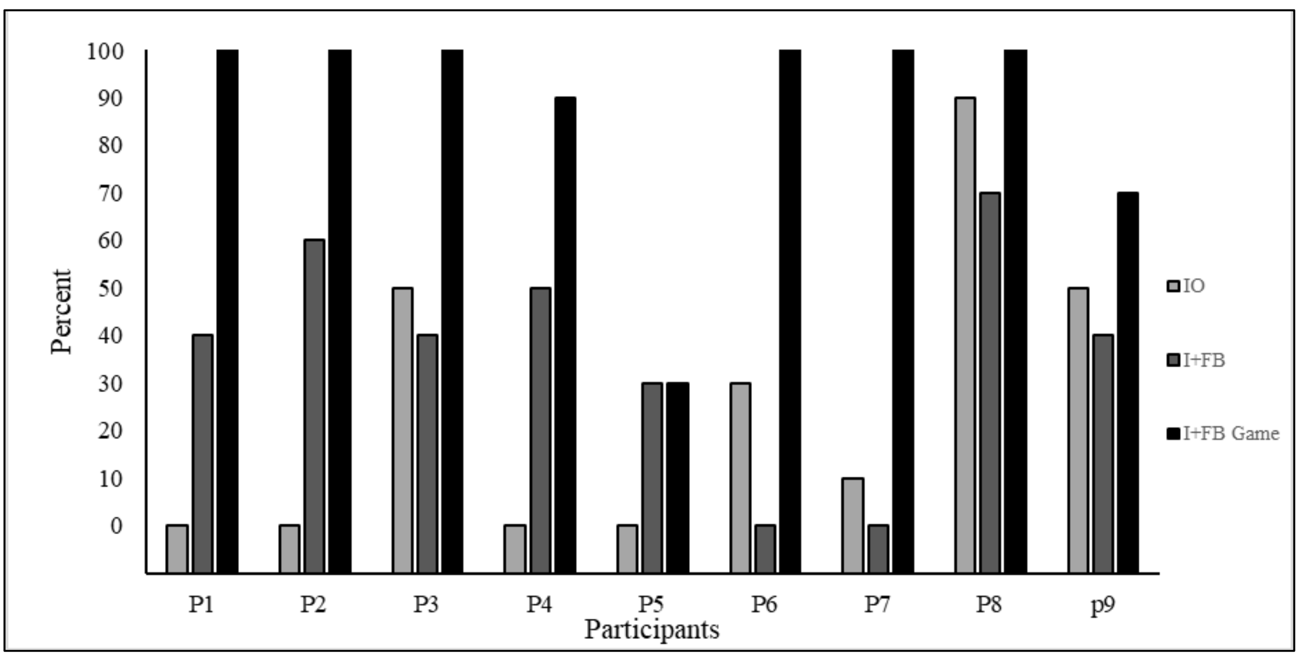

Figure 11. Study 2: Percentage of trials in which the criteria was met per participant (*y*-axis = % trials at or above criteria; *x*-axis = participants). The grey scale bars represent the specific condition (light grey: instruction only, dark grey: instruction + feedback, black: instruction + feedback in a game context).

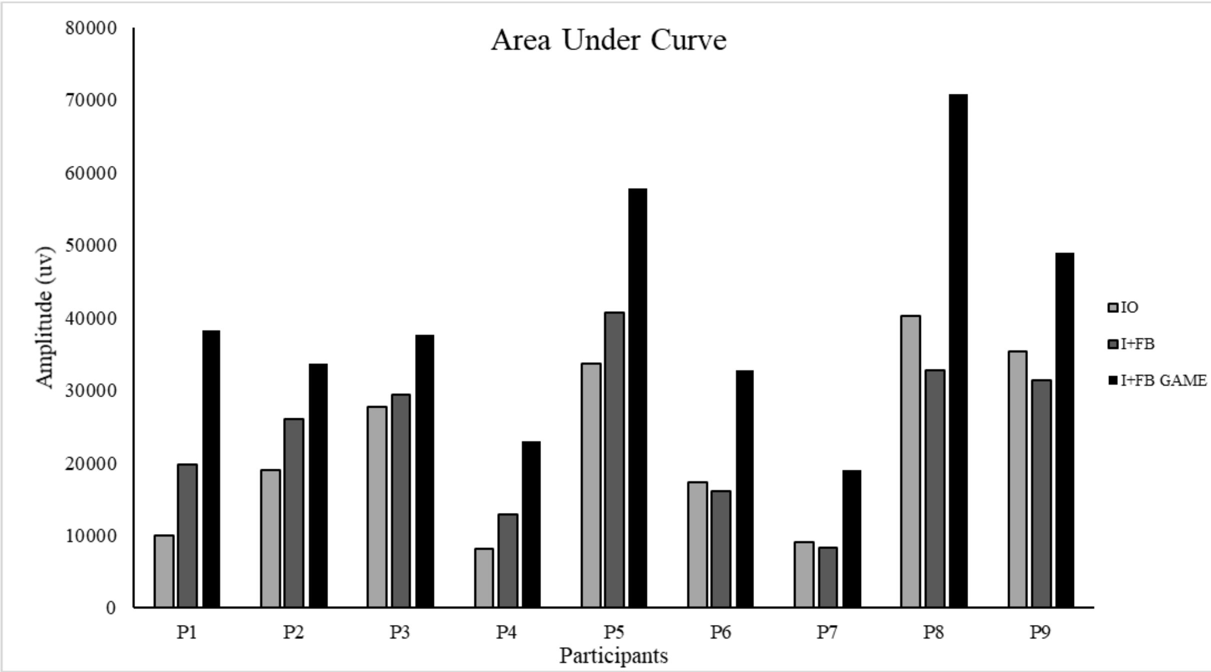

Figure 12. Study 2: Average across trials in amplitude of muscle potential activity produced by each participant in each condition (y-axis = amplitude of muscle potential activity; x-axis = participants). The grey scale bars represent the specific condition (light grey: instruction only, dark grey: instruction + feedback, black: instruction + feedback in a game context). The data presented here shows the average area under the curve across all 10 trials within a condition. These data approach a representation of average work engaged in during a 3 second bout of flexion.

Table 6

Study 2: t-*Test Two-Sample Assuming Unequal Variances (Instruction-Instruction + FB in a Game Context)*

	Participants	MEAN Instruction	MEAN I + FB in a Game Context	*t*-Score	*p*(T ≤ t) one tail
*	1	9963	38257	-9.529	.000001
*	2	18987	33733	-5.05	.0001
*	3	27765	37592	-2.57	.01
*	4	8103	22938	-14.09	.00000000001
*	5	33706	57870	-5.67	.00001
*	6	17331	32788	-9.46	.00000001
*	7	9016	19043	-8.30	.0000001
*	8	40220	70753	-6.56	.000003
*	9	35359	48922	-4.35	.0002

Results of a two-sample *t*-test assuming unequal variances between the area under the curve (work) values from each trial within the conditions, 10 values per condition and 20 in total. The data is arranged by participant and can be read from left to right: mean value of the 10 area under the curve calculations during instruction, and mean value of the 10 area under the curve calculations during the instruction + feedback in a game context condition, *t*-score, and *p*-value. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. Overall there was a significant difference for 9 out of 9 participants. The asterisks mark all significant *p*-values.

Table 7

Study 2: t-*Test Two-Sample Assuming Unequal Variances (Instruction + FB- Instruction + FB in a Game Context)*

	Participants	MEAN I + FB	MEAN I + FB in a Game Context	*t*-Score	*p*(T ≤ t) one tail
*	1	19687	38257	-5.35	.00003
*	2	26062	33733	-2.18	.02
*	3	29452	37592	-2.91	.005
*	4	12868	22938	-6.33	.000005
*	5	40657	57870	-4.21	.0003
*	6	16079	32788	-10.90	.000000001
*	7	8349	19043	-11.16	.0000000008
*	8	32678	70753	-7.93	.0000002
*	9	31449	48922	-6.61	.000004

Results of a two-sample *t*-test assuming unequal variances between the area under the curve (work) values from each trial within the conditions, 10 values per condition and 20 in total. The data is arranged by participant and can be read from left to right: mean value of the 10 area under the curve calculations during instruction + feedback, and mean value of the 10 area under the curve calculations during the instruction + feedback in a game context condition, *t*-score, and *p*-value. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. Overall there was a significant difference for 9 out of 9 participants. The asterisks mark all significant *p*-values.

Table 8

Study 2: t-*Test Two-Sample Assuming Unequal Variances (Instruction-Instruction + FB)*

Participants		MEAN Instruction	MEAN I + FB	*t*-Score	*p*(T ≤ t) one tail
*	1	9963	19687	-4.59	.0003
*	2	18987	26062	-2.73	.009
	3	27765	29452	-.47	.32
*	4	8103	12868	-3.27	.003
*	5	33706	40657	-2.04	.03
	6	17331	16079	.81	.21
	7	9016	8349	.58	.29
*	8	40220	32678	1.90	.04
	9	35359	31449	1.50	.08

Results of a two-sample *t*-test assuming unequal variances between the area under the curve (work) values from each trial within the conditions, 10 values per condition and 20 in total. The data is arranged by participant and can be read from left to right: mean value of the 10 area under the curve calculations during instruction, and mean value of the 10 area under the curve calculations during the instruction + feedback condition, *t*-score, and *p*-value. A one-tail *p*-value was used as it was expected that the skewness in data would always fall within the right end of the tail. Overall there was a significant difference for 5 out of 9 participants. The asterisks mark all significant *p*-values.

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