Physiological Reactions and Performance Parameters in Single-Player and Competitive Arm Rehabilitation Game: A Pilot Study

José M Catalán (jcatalan@umh.es)
Universidad Miguel Hernandez de Elche https://orcid.org/0000-0002-3608-1039

Andrea Blanco
Universidad Miguel Hernández: Universidad Miguel Hernandez de Elche

Jorge A Díez
Universidad Miguel Hernández: Universidad Miguel Hernandez de Elche

José V García
Universidad Miguel Hernández: Universidad Miguel Hernandez de Elche

David Martínez
Universidad Miguel Hernández: Universidad Miguel Hernandez de Elche

Arturo Bertomeu-Motos
Miguel Hernandez University of Elche: Universidad Miguel Hernandez de Elche

Nicolás García-Aracil
Universidad Miguel Hernández: Universidad Miguel Hernandez de Elche

---

Research

Keywords: Rehabilitation, Multiplayer games, Interpersonal rehabilitation games, Stroke, Patient engagement, Exergames, Robotics

Posted Date: November 18th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-107354/v1

RESEARCH

Physiological Reactions and Performance Parameters in Single-Player and Competitive Arm Rehabilitation Game: A Pilot Study

José M Catalán*, Andrea Blanco, Jorge A Díez, Jose V García, David Martínez, Arturo Bertomeu-Motos and Nicolas García-Aracil

*Correspondence: jcatalan@umh.es
Biomedical Neuroengineering Group, Miguel Hernández University, Avda. de la Universidad, 03202 Elche, Spain
Full list of author information is available at the end of the article

Abstract

Background: Interpersonal rehabilitation games, compared to single-player games, enhance motivation and intensity level. Usually, it is very difficult to limit the use of the system to pairs of impaired patients who have a similar skill level. Thus, such games must be dynamically adapted so that two players with different abilities can play together. Current algorithms are based only on game performance parameters (e.g., score). In addition, these studies do not include active robotic devices, so the parameters related to the level of robot assistance are not usually included in these studies. This means that the adaptation methods are entirely based on modifying aspects of the game. The aim of this article, is to study the effect that game modality and robot parameters that can be affected by the level of robot assistance (e.g., velocity, reaction time) have on the stress level of the subjects.

Methods: The pilot study has involved 10 unimpaired participants (5 pairs). Each subject sat in front of a robotic rehabilitation platform and grasped the end-effector of the robot with their dominant hand and played two kinds of therapy games: i) a single-player game in 3 difficulty modes; and ii) a competitive game. Robot and game parameters and subject's physiological responses were recording during the therapy games.

Results: The intensity level in the most difficult single-player game mode, is almost equal to the one of the competitive mode ($p = 1.0$). The stress perceived subjectively by participants increases with intensity. They indicate that the stress level in competitive mode is equal or somewhat greater than in high difficulty mode. On the other hand, physiological data suggest that it is somewhat lower in the competitive mode. Therefore, in this mode participants think they experience a higher stress level than they are actually experiencing. In addition, physiological responses show differences between intensity levels, and they also have a good correlation with the measured robot parameters.

Conclusion: Results show that, comparing competitive game with the single-player high-difficulty game, a similar intensity level is remarkable. However, the competitive game increase the stress level to a lesser extent. In addition, feedback from participants suggests that it is necessary to keep a certain stress level to make the activity more challenging, and therefore be more engaging and rewarding.

Keywords: Rehabilitation; Multiplayer games; Interpersonal rehabilitation games; Stroke; Patient engagement; Exergames; Robotics

Background

In the last report from the Stroke Alliance for Europe [1], around 15 million people worldwide suffer from stroke every year. Through the data collected by Global Burden of Disease study in 2015 and demographic projections obtained from Eurostat (statistical office of the European Union, EU), the number of stroke is expected to rise a 34% between 2015 and 2035 in the EU. With the welcome improvements in the survival rate, number of post-stroke people has increase, which increases the need for care and rehabilitation. In 2015, the EU dealt with an estimated combined direct and indirect cost of €45 billion. Reducing the incidence of stroke and the likelihood of long-term disability will help to reduce these costs [2, 3].

To recover the lost abilities in post-stroke patients, it has been shown that they have to carry out intense rehabilitation exercise during several months. However, their motivation is often low causing poor rehabilitation outcomes. Rehabilitation robotic devices have shown very good results to increase the intensity of rehabilitation therapy and the motivation through modifying the difficulty levels on a single-player mode. However, a more promising way to maintain a high-level of motivation during rehabilitation therapies assisted by robotic devices is to use interpersonal rehabilitation games, in which patients cooperate or compete carrying out a certain activity. Several studies demonstrate that interpersonal rehabilitation games get better results in increasing motivation and exercise intensity [4, 5].

Currently, one of the main research topics on interpersonal rehabilitation games is the development of a difficulty adaptation methods. To obtain good outcomes in a competitive or cooperative rehabilitation game, patients should be on an equal footing in order to ensure a properly level of competitiveness. Usually, it is very difficult to limit the use of the system to pairs of impaired patients who have a similar skill level, that is why the system should be adapted to the condition of the patient.

In competitive and cooperative rehabilitation games, the difficulty adaptation methods are based almost exclusively focused on performance [6, 7]. Currently, physiology-based adaptation methods for competitive rehabilitation games are being evaluated [8, 9], but these methods are normally to suit one player [10].

Evaluate the patient's condition and adjust the therapy accordingly is a complex problem. Evaluated systems, to the best of our knowledge, do not include active robotic devices, so the parameters related to the level of robot assistance are not usually included in these studies. This means that the adaptation methods are entirely based on modifying aspects of the game but does not consider the assistance or resistance of a robotic rehabilitation platform. The aim of this article, is to study and analysis the effect that game modality and robot parameters that can be affected by the level of robot assistance (e.g., velocity, reaction time) have on the stress level of the subjects.

Methods

Subjects

A total of 10 subjects (9 males, 1 female) with no motor or cognitive impairment were recruited for the study. They were between 23 and 50 years old, with a mean of 31.6 years and standard deviation of 9.5 years. All of them were right handed. They

were recruited from the staff of Bioengineering Institute of the Miguel Hernández University. Familiarisation with rehabilitation robots or computer games was not consider for exclusion or inclusion.

In case of competitive mode, subjects were paired according to approximate age, gender and handedness (except in one case, that a girl competed with a boy). In two-player games studies, is common to match by gender [5, 11, 12] because significant differences in game experience have been found due to gender [12]. Similarly, significant differences in game experience has been found between young and old players [13]. In addition, both members of a pair were already familiar with each other to some degree.

Experimental Setup

Before starting the experimental session, each participant sat in front of each robot and grasped the end-effector with their dominant hand. Two screens placed in front of each subject displayed the game. Subjects were facing each other. They were not able to see the other and they were instructed not to interact with each other during the game session. However, they were allowed to do it between the end of the game and the beginning of the baseline recording period. Fig. 1 shows an overview of the experimental setup used in this study.

Figure 1 Overview of the experimental setup with two non-real participants.

Game

Fig. 2 shows an overview of the game, which consisting of a point-to-point modality. The player cursor is represented by a hand, whose center corresponds to the real position of the patient's hand holding the robot. Firstly, the player has to wait in the basket until an apple appears (Fig. 2a), then try to reach it faster than the bird and then drop the apple in the indicated basket. For each apple collected, players accumulates a number of points. Movements has to be as linear as possible.

Figure 2 Overview of the game. **a** A screen shot of the single-player game mode. **b** Condition to successfully grasp the apple, where d is the distance of the user cursor to the target, r is the distance to successfully grasp the target and t is the set time to reach the target. **c** Condition to fail the grasp of the apple. **d** A screen shot from the competitive game mode.

An target is considered reached when the distance of the player cursor with respect to the apple, d, is less than or equal to a set distance, r (Fig. 2b). In this study the distance r has been set to 1 cm for all game modes. The time t (Fig. 2b and Fig. 2c) is the amount of time the user has to reach the apple before the bird reaches it.

The basket were the user has to drop back the apple is chosen randomly while guaranteeing both baskets are reached an equal amount of time.

There are two game modalities:

- A Single-player game modality (Fig. 2a). In this modality participants takes a certain number of apples freely or competing against the bird. In the latter case the difficulty level is adjusted by setting t parameter. The goal consist in scoring as many points as possible.

- A multiplayer game modality. This modality consists of a competitive game where 2 players participate simultaneously (Fig. 2d). Participants play against each other and try to get more points than the other. Points will be assigned according to the order of arrival at the basket, so participants have to take the apple and leave it in the basket before its competitor. During the game, players are able to see the score and the position of others. In this study only 2 players will participate.

Arm Rehabilitation Robot

In this study, two identical robotic devices for upper limb have rehabilitation been used [14, 15]. This rehabilitation platform consists of a robotic system with 2 actuated degrees of freedom. It must be attached on a table and is used sitting on a chair.

Since players are unimpaired subjects, robotic platforms did not provide any assistance or compensation.

Study Protocol

Firstly, the purpose and procedure of the study was explained to both participants. After they agreed to perform the experimental session, participants were fitted with a Zephyr BioHarness^{TM} and they were seated in front of rehabilitation robotic system. Then, the Shimmer3 Galvanic Skin Response (GSR) sensor unit were placed on the non-dominant hand of each participant.

Two instances of the game are executed, one on each of the rehabilitation platforms and one for each player.

Each participant will perform the different single-player game modes in the same order (Fig. 3):

1. Free Mode. In this mode there is no competitor, which means that there is no time limit.
2. Moderate Difficulty Mode. The time t was set as 2 seconds. In this case players have a virtual rival, the bird. So, although it is easy to win, they have to increase the intensity with respect to the free mode.
3. High Difficulty Mode. In this mode, it is hard for the player to beat the virtual competitor since the time t was set as 0.7 seconds.

They were carried out simultaneously and separately, in this way, both participants were ready at the same time to perform the competitive mode at the end.

It is important to note that in the free mode and the competitive mode no difficulty level is configured. Therefore, the intensity level is only self-imposed by the participants.

For this study, it has been decided not to randomize the conditions. This decision was made following a thorough previous evaluation of the data. The goal of this study is to evaluate the player reaction to different game modes with different intensity levels. It has been observed that if a participant moves from the difficult to the easy, in terms of difficulty level, performance in the second one is conditioned. Player self-imposes an intensity level that is usually higher than desired. This means that physiological data changes do not reflect the effect produced by the intensity levels imposed by the different game modes, but rather those unnecessarily imposed by the participant.

The number of apples will be set to 21 in all cases, in order to prevent a tie in the competitive mode. The game allows us to configure the range of motion of the rehabilitation robot in order to match it with the range of movement of the patient. In this study, subjects does not have any motor or cognitive impairment, so the range of movement has been set to a radius of 5 cm for all of them in order they all travel the same distances.

In the protocol, the duration of each game mode is not determined. The number of points a subject earns per apple is not influenced by the amount of time required for the subject to catch it. So, the only goal of the participant is to be able to catch the 21 apples. In this way, the stress level is solely influenced by the intensity level introduced by the virtual or real rival.

Before each session there is 5 minute rest period where the physiological signals are recorded to compute the baseline for each participant (Fig. 3). This period is employed to relax the subject so that previous condition stress level does not affect to the next one.

Figure 3 Study protocol. The conditions are carried out sequentially. Before each condition a baseline recording period of 5 minutes is carried out.

Estimation of exercise intensity

Velocity has been proven to be a good estimation of energy consumption during arm rehabilitation therapies in post-stroke patients [16, 17]. Therefore it acts as an objective measure of exercise intensity.

The maximum velocity value has been extracted from the speed profile described by the users in every trial. Root mean square (RMS) and mean values of the hand velocity were also computed for each trial. The RMS velocity value of the hand is closely related to the energy expenditure during upper limb exercise, compared to estimates based on heart rate response, electromyography activity or oxygen consumption [16, 17, 18]. The mean velocity value was also calculated. This value together with the maximum one, have been computed to have more information when studying differences in intensity levels between the different game modes.

Furthermore, the reaction time was measured in every trial as the time since the apple visually appears until the player starts to move towards it.

Estimation of task performance

Score were calculated during all sessions. This parameter is used extensively as a measure of exercise performance [8, 19]. It allow us to evaluate whether or not the participants are able to achieve the objective of the game. However, it may not be representative of the patient's physical and psychological state. Because of this, in the discussion of the results we will study it together with the results of the Intrinsic Motivation Inventory (IMI), the physiological signals and the exercise intensity parameters.

Measurement of physiological response

Two Shimmer3 GSR+ sensor units were used, one for each subject. This device has a built-in signal-processing unit that sends the resulting information to the main

processing unit via Bluetooth. The output measure is the galvanic skin response (GSR) between two reusable electrodes placed on two fingers of the hand. GSR is a common measure in psychophysiological paradigms and therefore often used in affective state detection. In this study, electrodes were placed on the proximal phalanges of the index and middle finger of the hand not used to control the robot (non-dominant hand). GSR signal were processed using a band pass filter of 0.05 - 1.5 Hz (frequency range of the Skin Conductance Response, SCR) in order to remove the artefacts that do not correspond to the GSR.

Heart rate measurement (HR) is common in rehabilitation games by single patients [20] but it is also beginning to be used in competitive rehabilitation games [10]. To measure the electrocardiogram (ECG) the Zephyr BioHarness^{TM} (Zephyr Technology Corporation) physiological monitoring telemetry device has been used. The BioHarness transmits signals to be received by Bluetooth. This device also has a built-in signal-processing, so received signal is very clean. We only apply a 0.004Hz high pass filter to remove the DC component of the signal. HR has been extracted from the ECG signal, but Time-domain indices of Heart Rate Variability (HRV) have also been extracted. HRV is widely used to measure the mental workload and the stress level caused by some activity [21, 22, 23, 24]. Time-domain indices of HRV extracted are the Standard Deviation of NN intervals (SDNN) and the Root mean square of successive RR interval differences (RMSSD) [25]. These two parameters are the most related to the stress level of a person.

All physiological signals were normalized by the min-max normalization method.

0.1 Subjective assessment of experience

IMI is widely used in rehabilitation game research [26, 27, 28, 29]. This subjective questionnaire measures four aspects of engagement: enjoyment/interest, effort/importance, perceived competence and pressure/tension. While there are many versions of the IMI [30], we have decided to use a reduce version that has already been used in previous similar studies [31, 6, 4].

Statistical Data Analysis

In the statistical study, a normality test was carried out using the Shapiro-Wilk test. There are evidence to suggest that some parameters are not normally distributed.

One-way Repeated Measures ANOVA was employed for normally distributed parameters. Mauchly's test of sphericity has been used to evaluate whether the sphericity assumption has been violated. If sphericity is violated, repeated measures ANOVA was corrected using Greenhouse–Geisser correction when epsilon is $\epsilon <= 0.75$ and Huynh–Feldt correction when epsilon is $\epsilon > 0.75$. In the post-hoc analysis, the assumption of equal variances across groups (homoscedasticity or homogeneity of variances) has been study with the Bartlett's test. Tukey post-hoc tests or Games-Howell Post-Hoc Test were used depending on the Bartlett's test result.

On the other hand, Friedman test was used for not normally distributed parameters. In post-hoc analysis, Holm-Bonferroni Method was used to adjust for family-wise error rate correction.

Finally, the magnitude of the Spearman's rank correlation coefficient (r_s) was obtained to study how one variable affects another.

Results

Exercise intensity

In Fig. 4 the evolution of the mean velocity over the number of targets in every condition is shown. This evolution is represented by the blue line, while shaded blue area contains the mean velocity values of all participants.

Figure 4 Evolution of mean velocity value during the activity in each mode represented consecutively. Shaded blue area contains the mean velocity values of all participants.

Fig. 5 show parameters directly related with the exercise intensity, among which are root mean square, mean and maximum velocity values of hand trajectories.

Figure 5 Exercise intensity related parameters. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the first and third quartiles.

Root mean square velocity value shows significant differences between conditions (One-way Repeated Measure ANOVA $p = 0.0001$). Paired comparisons show all single-player modes are significantly different, except in case of the free mode with respect to the moderate difficulty mode ($p = 0.32$). Regarding competitive mode, we obtain an statistically significant difference with respect to free mode ($p = 0.0002$) and the moderate difficulty mode ($p = 0.027$) but not in the high difficulty mode, where we get that they are very similar ($p = 1.00$), which suggests that intensity level is almost the same.

On the other hand, analysis shows significant differences between groups for mean velocity value (One-way Repeated Measure ANOVA $p = 0.0001$). In pairwise comparison, we obtain that difference between free mode and moderate difficulty mode is not significant ($p = 0.41$), however, free mode is significantly different to high difficulty mode ($p = 0.0018$) and competitive mode ($p = 0.0019$). Moderate difficulty mode has a certain trend toward significance with respect to high difficulty mode ($p = 0.094$) and competitive mode (0.1). Finally, as in the previous case, high difficulty mode is very similar to competitive mode ($p = 1.0$).

Analysis also shows significant differences between the game modes for the maximum velocity value (Friedman Test $p < 0.0001$). In fact, paired comparisons show all modes are significantly different ($p < 0.007$), even high difficulty mode with respect to competitive mode ($p = 0.047$).

Regarding the reaction time, analysis also shows significant differences between conditions (Friedman Test $p = 0.002$). Paired comparisons show free mode is significantly different respect to moderate and high difficulty mode ($p = 0.048$ in both cases) but not with respect to the competitive mode ($p = 0.12$). Moderate difficulty mode has a barely statistical significant difference with respect to the high difficulty mode ($p = 0.05$), but is not significantly different to competitive mode ($p = 0.29$). Furthermore, difference between competitive mode and high difficulty mode narrowly eluded statistical significance ($p = 0.085$).

In the post-hoc analysis we found a moderate correlation between the reaction time and root mean square velocity value ($rs = -0.66$, $p < 0.001$). This result

suggests that the reaction time appears to be inversely proportional to the increase in intensity.

Task performance

Fig. 6 contains several graphs that show the results of the parameters related to exercise performance.

Figure 6 Representation of the parameters related with the exercise performance. (**a**) Graphical representation of the game score, separated between winners and losers of the competitive mode. (**b**) Graphical representation of the Interest/Enjoy parameter from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the first and third quartiles. The table collects the non-normalized values of all parameters.

In case of the score, we found significant differences between game modes (Friedman Test $p < 0.0001$). In fact, paired comparisons show all modes are significantly different, except in case of free mode and moderate difficulty mode as they are identical (Fig. 6a).

In the post-hoc analysis we found a moderate correlation between the score and root mean square velocity value ($rs = -0.58$, $p < 0.001$) and a weak correlation between score and the reaction time ($rs = 0.37$, $p = 0.003$).

On the other hand, analysis also shows significant differences between conditions for Interest/Enjoy parameter from Intrinsic Motivation Inventory (Friedman Test $p < 0.0001$). In fact, paired comparisons show all single-player game modes are significantly different ($p < 0.05$). In case of competitive mode, results indicate that it is not significantly different to high difficulty mode ($p = 0.12$), but it is to the rest.

Post-hoc analysis suggest that Interest/Enjoy parameter is also correlated with root mean squared velocity value ($rs = 0.37$, $p = 0.003$) and with the reaction time ($rs = -0.19$, $p = 0.038$). In addition, we found that this parameter is also correlated with the score ($rs = -0.68$, $p < 0.001$).

Stress level

Physiological response signals used to estimate the stress level are illustrated graphically in Fig. 7a and 7b. Parameters from Intrinsic Motivation Inventory related to the stress level are also illustrated in Fig. 7c.

Figure 7 Graphical representation of the parameters related to the stress level. (**a**) Results of the Galvanic Skin Response (GSR) and the Heart Rate (HR). (**b**) Results of the Heart Reat Variability time-domain measures. (**c**) Results of the Pressure/Tension and Effort/Importance parameters from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the first and third quartiles. The table collects the non-normalized values of all parameters.

Galvanic Skin Response (GSR, Fig. 7a) shows significant differences between groups (One-way Repeated Measure ANOVA $p = 0.005$). However, in pairwise comparison no significantly different pairs are found. Only in case of free mode with

respect to the high difficulty mode a certain trend toward significance is observed ($p = 0.079$) and also between moderate and high difficulty mode, where difference is close to the limit of significance ($p = 0.19$). The rest are statistically similar ($p > 0.4$).

Post-hoc analysis reflect a clear correlation between the GSR and the score ($rs = -0.29$, $p = 0.016$). Results also suggested that GSR is almost correlated with the root mean square velocity value ($rs = 0.28$, $p = 0.051$) and with the reaction time ($rs = -0.18$, $p = 0.08$). We also observe a reliable trend toward significance in case of the correlation between GSR and the Interest/Enjoy parameter from the Intrinsic Motivation Inventory ($rs = 0.28$, $p = 0.051$).

Regarding HR (Fig. 7a), results show differences between game modes (One-way Repeated Measure ANOVA $p = 0.0001$). Paired comparisons show that free mode is significantly difference respect to high difficulty mode ($p = 0.04$) and competitive mode ($p = 0.01$). Moderate difficulty mode narrowly eluded statistical significance respect to competitive mode ($p = 0.06$) and high difficulty mode ($p = 0.11$).

Post-hoc analysis suggest that HR is moderate correlated with the root mean square velocity value ($rs = 0.55$, $p < 0.001$) and with the reaction time ($rs = -0.54$, $p < 0.001$). We also observe that HR is correlated with the score ($rs = -0.47$, $p = 0.004$). On the other hand, HR is weak correlated with Interest/Enjoy parameter from the Intrinsic Motivation Inventory ($rs = 0.27$, $p = 0.017$).

On the other hand we have the HRV time-domain measures. In case of SDNN (Fig. 7b), results show a reliable trend toward significance between game modes (One-way Repeated Measure ANOVA $p = 0.065$). However, in the pairwise comparison, we did not observe any significant difference. Among all the single player modes, we obtain that they are very similar ($p > 0.99$), only in the pair-wise comparisons with the competitive mode some differences are observed, but they are far from being significant ($p < 0.55$). For the RMSSD (Fig. 7b), we also don't get any significant difference (Friedman Test $p = 0.92$). However, a clear trend is observed in the median value of both parameters, which is in line with the results of the pairwise comparisons.

In Fig. 7c, parameters from the intrinsic motivation inventory related with the stress level are shown. Regarding the Pressure/Tension parameter, we found significant differences between conditions (One-way Repeated Measure ANOVA $p < 0.0001$). Indeed, we found in the pairwise comparison that all modes are significantly different from each other, except for the high difficulty mode with respect to the competitive mode ($p = 0.2$). Similar results have been obtained for the statistical analysis of the Effort/Importance parameter (One-way Repeated Measure ANOVA $p < 0.0001$). In this case, results also suggest that all modes are significantly different from each other, except for high difficulty mode with respect to the competitive mode ($p = 0.43$).

In the post-hoc analysis, a correlation with the root mean squared velocity value is found in both Pressure/Tension ($rs = 0.72$, $p < 0.001$) and Effort/Importance ($rs = 0.43$, $p = 0.01$). This is also the case of the reaction time ($rs = -0.4$, $p = 0.001$ and $rs = -0.21$, $p = 0.026$ respectively). Results also suggest that both are correlated with the score and the Interest/Enjoy parameter. We also note that Effort/Importance is strong correlate with the GSR ($rs = 0.68$, $p < 0.001$) and

presents a correlation with a statistical trend towards significance with respect to the HR ($rs = 0.2$, $p = 0.098$). In case of the Pressure/Tension, this parameter is correlated with HR ($rs = 0.51$, $p = 0.001$) and GSR ($rs = 0.45$, $p = 0.014$).

Discussion

It should be pointed out that differences between conditions are largely down to the definition of the different games modes. Therefore, although importance will be given to statistically significant differences between groups, since in this study we aim to measure differences in the effects produced by different game modes, in the discussion of the results, special attention will be given to the trend of parameters between modes, although these are not statistically significant.

Differences in exercise intensity

As indicated above, for the design of the study protocol it was decided not to randomize the conditions so that the velocity adopted would not be affected by the previous mode. This effect can be appreciated in Fig. 4. For example, in case of the moderate difficulty mode, it can be observe how the initial velocity is similar to that of the free mode. Quickly, participants increase the velocity until they reach a level that allows them to win. Something similar can also be observed in high difficulty mode.

Observing Fig. 4 we can make a preliminary assessment of the differences in the intensity levels from the mean velocity evolution in each exercise. In free mode, velocity is fairly constant throughout the session. In case of the moderate difficulty mode, results suggest that mean velocity value increases slightly compared to free mode. We also note a rising trend at the beginning of the exercise. In fact, results shows a peak of velocity around target 6 (Fig. 4). This is because of the reaction of the participants due to the appearance of a competitor. Participants start with a velocity too low but motivation to win makes them adopt a higher velocity than necessary. In this game mode, competitor always reaches the target in the same period of time, due to this, they end up adjusting their velocity to a comfortable level. This evolution is also observed in a certain way in the high difficulty mode. However, in this mode the mean velocity vary considerably because it is harder to adapt.

On the other hand, in the competitive mode, velocity increases with the time, starting with a velocity similar to that of the moderate difficulty mode and ending with a velocity similar to that of the high difficulty mode. This effect could be due to the game mode. Both competitors are influencing each other in order to win, so they go faster and faster.

In Fig. 5 results of the study carried out for the evaluation of the intensity levels are shown.

As previously mentioned, the intensity level is estimated mainly through the root mean square velocity value. Firstly, we observe that modes in which an intensity level has been established by setting the difficulty level, which are the moderate and high difficulty mode, are significantly different. This means that difficulty levels are well defined, as they make the intensity level of each other different enough to be statistically different. Regarding free mode, although we do not obtain a statistically

significant difference, results show that the intensity level is the lowest. On the other hand, for the competitive mode, the statistical study suggest that intensity level is broadly similar to that of the high difficulty mode. However, we observe that in high difficulty mode the maximum speed reaches significantly higher values than in the case of competitive mode. The increased in intensity level due to competition have already been widely demonstrated [4, 32], also in related fields [31], so this finding was expected.

In Fig. 4, we also observe that the exercise development is different. In case of the high difficulty mode, the initial reaction from the participants is to adopt an insufficient velocity to beat the competitor (the bird). At that moment, their reaction is to quickly increase the velocity to the point that results show a peak of mean velocity value that then drops a little bit to stabilize in a certain way. This suggest that the reaction makes them to adopt a higher velocity than necessary, but since the competitor always reaches the target in the same period of time, the participants tend to adopt a more or less constant mean velocity value. This is also seen in the fact that the maximum velocity value in high difficulty mode is significantly higher than in competitive mode. By comparison, in competitive mode, results suggests that mean velocity value tends to increase throughout the exercise. A likely explanation of this effect is the influence of one participant on the other. They are increasing the velocity in order to beat the opponent, the fact that cause the intensity level increasingly higher. Based on this results, if participants had performed more repetitions, they would possibly reach a somewhat higher intensity level than high difficulty mode.

Another parameter directly related to the intensity level is the reaction time. In Fig. 5 we can see how this parameter decrease as intensity level increase.

Comparing the high difficulty mode and the competitive mode, although we do not obtain a statistically significant difference, despite both modes have an equal intensity level, results suggests that the reaction time is longer in the competitive mode. However, this effect is not due to a different intensity level, but rather by the game mode. We have observed that the fact that they are able to see each other inside the game, influences in some way how they react when a target appears. In single-player modes, where the competitor is virtual, participants learn when the apple will appear, so they react faster. In competitive mode, the target appears in the same period of time as in single-player modes, so prior learning should make them react at least as fast as in high difficulty mode. However, the fact of being able to see the opponent within the game, makes the participants look at his reaction, which makes them to react slower.

Evaluation of task performance

In Fig. 6a results of the scores in each of the game modes are shown. Participants results were divided into two groups, the winners and the losers of the competitive mode. In free mode the maximum score is obviously achieved, since there is no competitor. At the moderate difficulty mode there is a competitor, but the results indicate that all participants also achieve to reach all the targets. However, at the high difficulty mode participants are no longer able to reach all the targets. On the other hand, in the competitive mode the participants' score is around 50 percent,

which means that couples are well defined since there is not much difference between winners and losers, so it was a close game. In view of the results, in a single player game mode with a virtual competitor, in order to obtain a level of competitiveness with the virtual competitor similar to that of the competitive mode, the difficulty level would have to be increased. However, although the score is high in the high difficulty mode, users reported that the intensity level was very high, so increasing the difficulty even more to achieve this, would result in a considerable increase in the stress level.

In Fig. 6b results of the Interest/Enjoy parameter from the Intrinsic Motivation Inventory are shown. In the light of the results, participants prefer a challenging game since the highest score of this parameter is in the high difficulty mode and competitive mode. These are the game modes in which they are not able to reach all the targets.

So next we'll be looking at differences in each condition among those who won and lost in the competitive mode (Fig. 6a). We notice that winners of the competitive mode achieve higher scores in the high difficulty mode. To study the reason behind this difference, parameters used to estimate the intensity for these two groups were checked (Fig. 8).

In case of the high difficulty mode, we observe the greatest difference between both groups for the intensity level estimation parameters. Based on the above data (5), the high difficulty mode requires participants to achieve the shortest reaction times and the highest velocities to be able to reach the targets, that is, this game mode requires a high skill level. With this in mind, and noting that winners also achieve higher velocities and shorter reaction times in the other game modes, data suggest that winners of the competitive mode are more skilled. Therefore, this difference does not mean that they experience a higher intensity levels.

Figure 8 Differences in the parameters related to the intensity level between winners and losers of the competitive mode.

Differences in stress level

Results of the Galvanic Skin Response (GSR) are shown in Fig. 7a. Data suggests that in case of single player modes, the stress level increases in accordance with intensity level. Regarding the competitive mode, a stress level similar to that of the high difficulty mode would be expected since the intensity level is practically the same, however, although there is not a statistically significant difference, we notice that stress level in competitive mode is lower. In fact, result is more like the one obtained in the moderate difficulty mode. Therefore, GSR results suggest that highest stress levels occur in high difficulty mode.

Heart Rate results (HR, Fig. 7a) behave more like GSR results. In single player modes, heart rate also increases in accordance with intensity level. Regarding the competitive mode, once again we obtain a lower stress level than in the high difficulty mode. However, in this case the stress level in the competitive mode is between moderate and high difficulty mode, being almost significantly higher than moderate difficulty mode but lower than in high difficulty mode. In the statistical study

we obtain a significant difference just in case of the free mode with respect to the high difficulty mode. Therefore, once again it seems that the highest stress level is reached in high difficulty mode.

Regarding HRV, Time-domain indices extracted are usually generate for 24h session, but it is also being studied in short-term ($\sim$ 5 min) and ultra-short-term ($<$ 5 min) sessions [25]. In our case, each game mode has a different duration, but none of them are longer than two minutes. This means that each condition is an ultra-short-term session. This type of sessions are poor at identifying differences between similar conditions. This can be seen in Fig. 7b. As it can be seen, we do not observe significant differences in any case, but if we look at the median value of the RMSSD parameter, we can see how it slightly decreases with the increasing difficulty level in the case of single player modes. However, in the competitive mode the median value substantial increase, which indicates a lower stress level. This result is in line with the results obtained from the GSR and HR responses.

We believe that differences would be clearer, not only in case of HRV parameters, but also for the rest of the physiological signals by increasing the duration of each condition and the number of participants,

Results of the Intrinsic Motivation Inventory parameters related to the subjective assessment of the stress level are shown in Fig. 7c. Regarding the Effort/Importance parameter, which represents the participants perceived exertion, results suggest that the effort rises as intensity level increase. In addition, we notice that perceived effort level in the competitive mode is very similar to that perceived in the high difficulty mode.

Perceived exertion by participants, have a similar behavior as the intensity levels (Fig. 5), in fact, we notice that it is correlated to the root mean square velocity value and the reaction time. Furthermore, this parameter is also correlated to the physiological responses (GSR and HR), suggesting that an increase in the effort level leads to an increase in the stress level. This finding was expected. It means that the participants are aware of increase of the intensity level.

In the study of 2014 [5], where IMI is used to measure the stress of a competitive game among patients, a high stress level was measure in case of competitive mode. Therefore, this study and others [33] consider the possibility that competition is stressful and unpleasant. However, in the study of 2017 [4], where the same questionnaire was employed to estimate the stress level, it was concluded that competition between patients and their friends or relatives does not significantly affect the stress level compared to exercising alone. In this study, it was concluded that the difference in the stress level between both studies [5, 4] is because couples are not always friends or relatives. That is, the relationship influences the stress level.

In the results obtained in this study for the Pressure/Tension parameter of the IMI questionnaire (Fig. 7c), we observe that the stress perceived subjectively by participants increases with intensity. In competitive mode, we have similar results but slightly higher than high difficulty mode. As in the study [4], the results obtained suggest that the stress level perceived by the participants are very similar in the competitive mode and high difficulty mode. However, in this study physiological signals are employed as an objective measure of the stress level.

Overall, we observe that the subjective assessment of the Pressure/Tension parameter is correlated to the physiological responses (Fig. 7a). Regarding the competitive

mode, participants indicate that the Pressure/Tension is equal or somewhat greater than in high difficulty mode. As we have seen in the physiological signals results, everything suggests that this is not the case, in fact, it is somewhat lower. Therefore, data suggest that in the competitive mode participants think they experience a higher stress level than is reflected in their physiological response, which we could say is a objective measure of the actual stress response. A similar result has been observed in the results obtained from the IMI questionnaire in a more current study [31].

Intrinsic Motivation Inventory

We used IMI in this study since it is the most popular validated motivation questionnaire in rehabilitation field. However, we have detected that IMI is not good at observing differences between similar exercises, as it is the case of this study. This limitation was also detected in other studies [4, 5].

We have also noted that participants get confused when interpreting certain questions, especially negative items. In fact, in this study, the obtained Perceived Competence parameter results of the IMI are biased because of this. This suggests that this questionnaire would be very difficult to use with patients with neurological injuries, because they often experience comprehension difficulties. We think that in order to carry out a future study with patients, IMI questionnaire should be adapted to make it more suitable for patients with neurological injuries.

Study Limitations

While our results are promising, a few study limitations should be discussed.

Admittedly, our study involved only 10 unimpaired participants. Therefore, while we believe that our findings would generalize to some degree, results may not be generalised beyond the conditions of this study. Results should be investigated further. However, it is enough to carry out an exploratory statistical study like the one we have carried out. We are aware that these results will have to be validated in a more extensive study, but this study allows us to understand a little better the relationship between the parameters that we can be controlled during the exercise with the physiological response of the subjects.

Furthermore, it is interesting to compare these preliminary results with those obtained in future experimentation with patients, since we expect that the behavior and the correlation of the different parameters will show differences, especially in terms of stress.

Secondly, based on participant feedback, we think the difficulty level set in single player modes might not be high enough to put a lot of stress on unimpaired participants. However, doing this we would expect a higher stress level in moderate and high difficulty modes. Therefore, this would increase the difference in the stress level between the high difficulty mode and the competitive mode.

Next steps

In robot-assisted therapy, it is very difficult to find a general relationship between physiological response, robot and game parameters because they are highly variable, since they depend on the game design, topology of the robot and the variability between people.

With this preliminary study, we have an idea of the relationships between parameters employed to adjust the intensity level and those used to measure the performance and the stress level of the user in the conditions of this study. However, the next step is to check these results with patients, since we expect there will be differences, and it is interesting to study them, because as it is already known, games for patients with neurological injuries should be designed accordingly.

In addition, based on the results of this study, we want to develop a difficulty adaptation algorithm that avoids an excessive stress level within a competitive game and also allows two patients with different levels of disability to compete.

We are also working on studying the effect of a competitive therapy with this type of difficulty adaptation algorithm for longer periods of time. Typical rehabilitation protocols consist of several sessions of 30 to 60 minutes of exercise [34, 35].

Conclusion

Results show that, comparing competitive game with the single-player high-difficulty game, a similar intensity level is remarkable. However, the competitive game increase the stress level to a lesser extent. This advantage, would allow us to reach higher levels of intensity than in single-player modes without stressing the patient in a counter productive way.

We also notice that GSR and HR responses show differences between intensity levels. They also have a good correlation with the parameters used to establish the difficulty level of the exercise.

It is interesting to note that according to the results obtained from the IMI questionnaire, despite having a higher stress level, participants find the more difficult game modes more fun. This suggests that it is necessary to keep a certain stress level to make the activity more challenging, and therefore be more engaging and rewarding.

Acknowledgments
The authors thank the subjects for their participation.

Funding
This work has been founded by the Conselleria d'Educacio, Cultura i Esport of Generalitat Valenciana, by the European Social Fund - Investing in your future, through the grant ACIF 2018/214 and by the spanish Ministry of Science and Innovation through the project PID2019-108310RB-I00.

Abbreviations
GSR: Galvanic Skin Response; SCR: frecuency range of the Skin Conductance Response; ECG: electrocardiogram; HR: Heart Rate; HRV: Heart Rate Variability; SDNN: Standard deviation of NN intervals; RMSSD: Root mean square of successive RR interval differences; IMI: Intrinsic Motivation Inventory

Availability of data and materials
Data and materials can be made available upon request to the corresponding author.

Ethics approval and consent to participate
Data recordings have been approved by the ethics committee of the Miguel Hernández University of Elche, Spain. All the subjects provided written informed consent.

Competing interests
The authors declare that they have no competing interests.

Consent for publication
Not applicable.

Author's contributions
JMC, AB and JAD conceived of and designed the experiments. JMC, JVG and DM worked on the construction of the experimental setup. JMC, AB and JAD performed the experiments. JMC analyzed the data. JMC drafted the paper. ABM deeply revised the manuscript. NGA contributed to the design of the study and deeply revised the manuscript. All the authors checked and approved the final submitted version of the manuscript.

Author details
Biomedical Neuroengineering Group, Miguel Hernández University, Avda. de la Universidad, 03202 Elche, Spain.

References

1. Stevens, E., Emmett, E., Wang, Y., C., M., C, W.: The burden of stroke in europe, report. Stroke Alliance for Europe (SAFE) (2007)
2. Grieve, R., Hutton, J., Bhalla, A., Rastenyte, D., Ryglewicz, D., Sarti, C., Lamassa, M., Giroud, M., Dundas, R., Wolfe, C.: A comparison of the costs and survival of hospital-admitted stroke patients across europe. Stroke **32**(7), 1684–1691 (2001)
3. Matchar, D.B., Bilger, M., Do, Y.K., Eom, K.: International comparison of poststroke resource use: A longitudinal analysis in europe. Journal of Stroke and Cerebrovascular Diseases **24**(10), 2256–2262 (2015)
4. Goršič, M., Cikajlo, I., Novak, D.: Competitive and cooperative arm rehabilitation games played by a patient and unimpaired person: effects on motivation and exercise intensity. Journal of NeuroEngineering and Rehabilitation **23**(14) (2017)
5. Novak, D., Nagle, A., Keller, U., Riener, R.: Increasing motivation in robot-aided arm rehabilitation with competitive and cooperative gameplay. Journal of NeuroEngineering and Rehabilitation **11** (2014)
6. Goršič, M., Cikajlo, I., Goljar, N., Novak, D.: A multisession evaluation of an adaptive competitive arm rehabilitation game. Journal of NeuroEngineering and Rehabilitation **14**(128) (2017)
7. Duarte, J.E., Baur, K., Riener, R.: Flowing to the optimal challenge: an adaptive challenge framework for multiplayer games. In Converging Clinical and Engineering Research on Neurorehabilitation II, 381–385 (2017)
8. Darzi, A., Novak, D.: Using physiological linkage for patient state assessment in a competitive rehabilitation game. In: 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR), pp. 1031–1036 (2019). IEEE
9. Darzi, A., Wondra, T., McCrea, S., Novak, D.: Classification of different cognitive and affective states in computer game players using physiology, performance and intrinsic factors. In: International Conference on Intelligent Human Systems Integration, pp. 23–29 (2019). Springer
10. Darzi, A., Goršič, M., Novak, D.: Difficulty adaptation in a competitive arm rehabilitation game using real-time control of arm electromyogram and respiration. In: In International Conference on Rehabilitation Robotics (ICORR), pp. 857–862 (2017). IEEE
11. Weibel, D., Wissmath, B., Habegger, S., Steiner, Y., Groner, R.: Playing online games against computer- vs. human-controlled opponents: Effects on presence, flow, and enjoyment. Computers in Human Behavior **24**(5), 2274–2291 (2008)
12. Wittchen, M., Krimmel, A., Kohler, M., Hertel, G.: The two sides of competition: Competition-induced effort and affect during intergroup versus interindividual competition. British Journal of Psychology **104**(5), 320–338 (2013)
13. Gajadhar, B.J., Nap, H.H., de Kort, Y.A., IJsselsteijn, W.A.: Out of sight, out of mind: co-player effects on seniors' player experience. In: 3rd International Conference on Fun and Games, pp. 74–83 (2010)
14. Díaz, I., Catalan, J.M., Badesa, F.J., Justo, X., Lledo, L.D., Ugartemendia, A., Gil, J.J., Díez, J., García-Aracil, N.: Development of a robotic device for post-stroke home tele-rehabilitation. Advances in Mechanical Engineering **10**(1) (2018)
15. Catalán, J.M., Garcia, J.V., Lopez, D., Ugartemendia, A., Diaz, I., Lledó, L.D., Blanco, A., Barios, J., Bertomeu, A., Garcia-Aracil, N.: Evaluation of an upper-limb rehabilitation robotic device for home use from patient perspective. In: International Conference on NeuroRehabilitation, pp. 449–453 (2018)
16. Goršič, M., Novak, D.: Design and pilot evaluation of competitive and cooperative exercise games for arm rehabilitation at home. In: Proceedings Annual International Conference IEEE EMBS, pp. 4690–4694 (2016). IEEE
17. van der Pas, S.C., Verbunt, J.A., Breukelaar, D.E., van Woerden, R., Seelen, H.A.: Assessment of arm activity using triaxial accelerometry in patients with a stroke. Archives of Physical Medicine and Rehabilitation **92**(9), 1437–1442 (2011)
18. Tsurumi, K., Itani, T., Tachi, N., Takanishi, T., Suzumura, H., Takeyama, H.: Estimation of energy expenditure during sedentary work with upper limb movement. Journal of occupational health **44**(6), 408–413 (2002)
19. Norouzi-Gheidari, N., Levin, M.F., Fung, J., Archambault, P.: Interactive virtual reality game-based rehabilitation for stroke patients. In: 2013 International Conference on Virtual Rehabilitation (ICVR), pp. 220–221 (2013). IEEE
20. Zimmerli, L., Jacky, M., Lünenburger, L., Riener, R., Bolliger, M.: Increasing patient engagement during virtual reality-based motor rehabilitation. Archives of physical medicine and rehabilitation **94**(9), 1737–1746 (2013)
21. Meshkati, N.: Heart rate variability and mental workload assessment. In: Hancock, P.A., Meshkati, N. (eds.) Human Mental Workload vol. 52, pp. 101–115. North-Holland, Elsevier (1988)
22. Boonnithi, S., Phongsuphap, S.: Comparison of heart rate variability measures for mental stress detection. In: 2011 Computing in Cardiology, pp. 85–88 (2011). IEEE
23. Kim, H.-G., Cheon, E.-J., Bai, D.-S., Lee, Y.H., Koo, B.-H.: Stress and heart rate variability: a meta-analysis and review of the literature. Psychiatry investigation **15**(3), 235 (2018)
24. Delliaux, S., Delaforge, A., Deharo, J.-C., Chaumet, G.: Mental workload alters heart rate variability, lowering non-linear dynamics. Frontiers in physiology **10**, 565 (2019)
25. Shaffer, F., Ginsberg, J.: An overview of heart rate variability metrics and norms. Frontiers in public health **5**, 258 (2017)
26. Nijenhuis, S., Prange, G., Amirabdollahian, F., Sale, P., Infarinato, F., Nasr, N., Mountain, G., Hermens, H., Stienen, A., Buurke, J., Rietman, J.: Feasibility study into self-administered training at home using an arm and hand device with motivational gaming environment in chronic stroke. Journal of NeuroEngineering and Rehabilitation **12**(89) (2015)
27. Colombo, R., Pisano, F., Mazzone, A., Delconte, C., Micera, S., Carrozza, M., Dario, P., Minuco, G.: Design strategies to improve patient motivation during robot-aided rehabilitation. Journal of NeuroEngineering and

Rehabilitation **4**(3) (2007)
28. Ballester, B.R., i Badia, S.B., Verschure, P.F.: Including social interaction in stroke vr-based motor rehabilitation enhances performance: a pilot study. Presence **21**(4), 490–501 (2012)
29. Mace, M., Rinne, P., Kinany, N., Bentley, P., Burdet, E.: Collaborative gaming to enhance patient performance during virtual therapy. In: Converging Clinical and Engineering Research on Neurorehabilitation II, pp. 375–379. Springer, Cham (2017)
30. McAuley, E., Duncan, T., Tammen, V.V.: Psychometric properties of the intrinsic motivation inventory in a competitive sport setting: A confirmatory factor analysis. Research quarterly for exercise and sport **60**(1), 48–58 (1989)
31. Goršič, M., Hlucny, S.D., Novak, D.: Effects of different opponent types on motivation and exercise intensity in a competitive arm exercise game. Games for Health Journal **9**(1), 31–36 (2020)
32. Marker, A.M., Staiano, A.E.: Better together: outcomes of cooperation versus competition in social exergaming. Games for health journal **4**(1), 25–30 (2015)
33. Alankus, G., Lazar, A., May, M., Kelleher, C.: Towards customizable games for stroke rehabilitation. In: Proceedings of the 28th International Conference on Human Factors in Computing Systems, pp. 2113–2122 (2010)
34. Lo, A.C., et al.: Robot-assisted therapy for long-term upper-limb impairment after stroke. New England Journal of Medicine **362**(19), 1772–1783 (2010)
35. Klamroth-Marganska, V., et al.: Three-dimensional, task-specific robot therapy of the arm after stroke: a multicentre, parallel-group randomised trial. The Lancet Neurology **13**(2), 159–166 (2014)

Figures

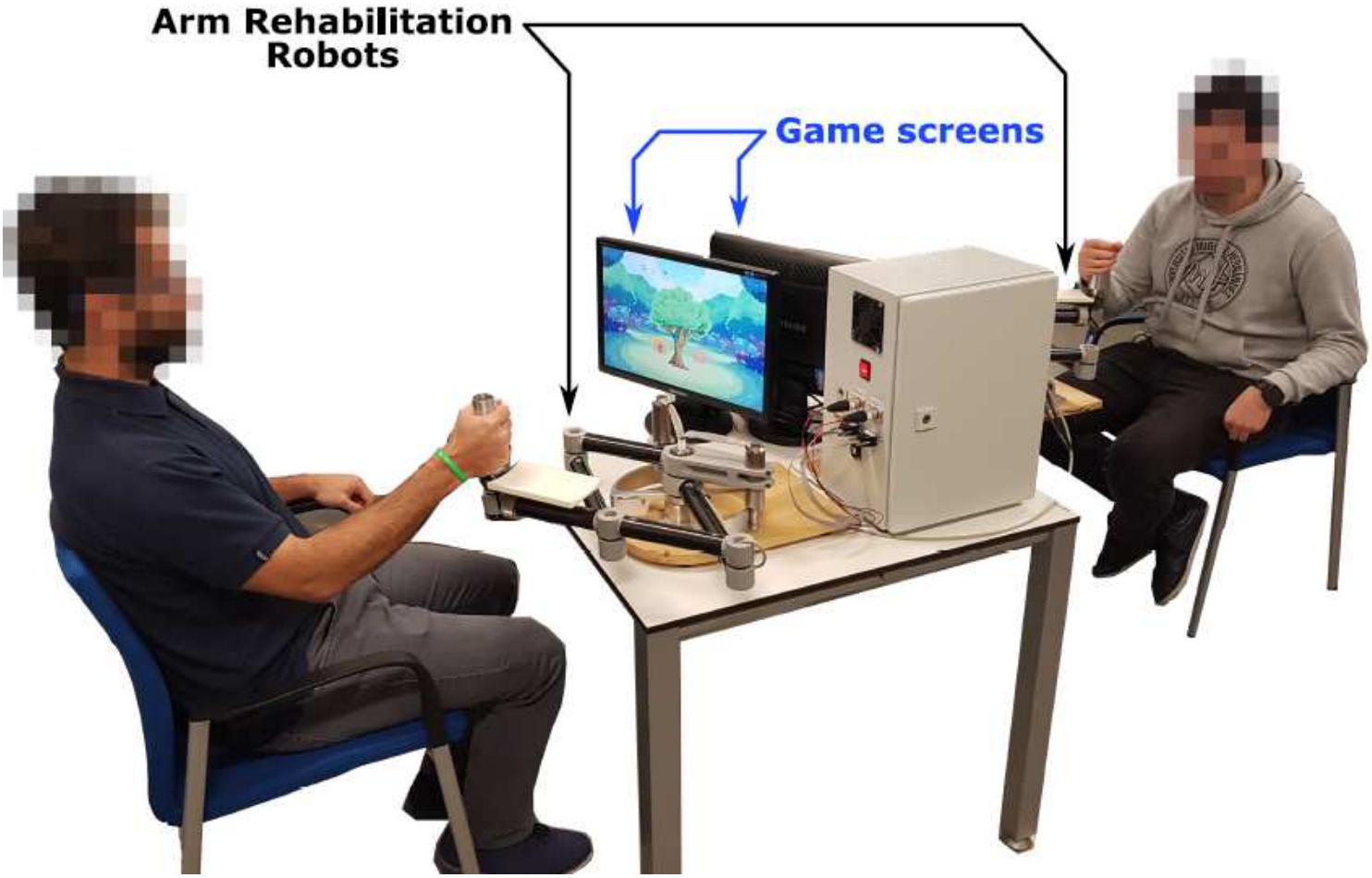


Figure 1

Overview of the experimental setup with two non-real participants.

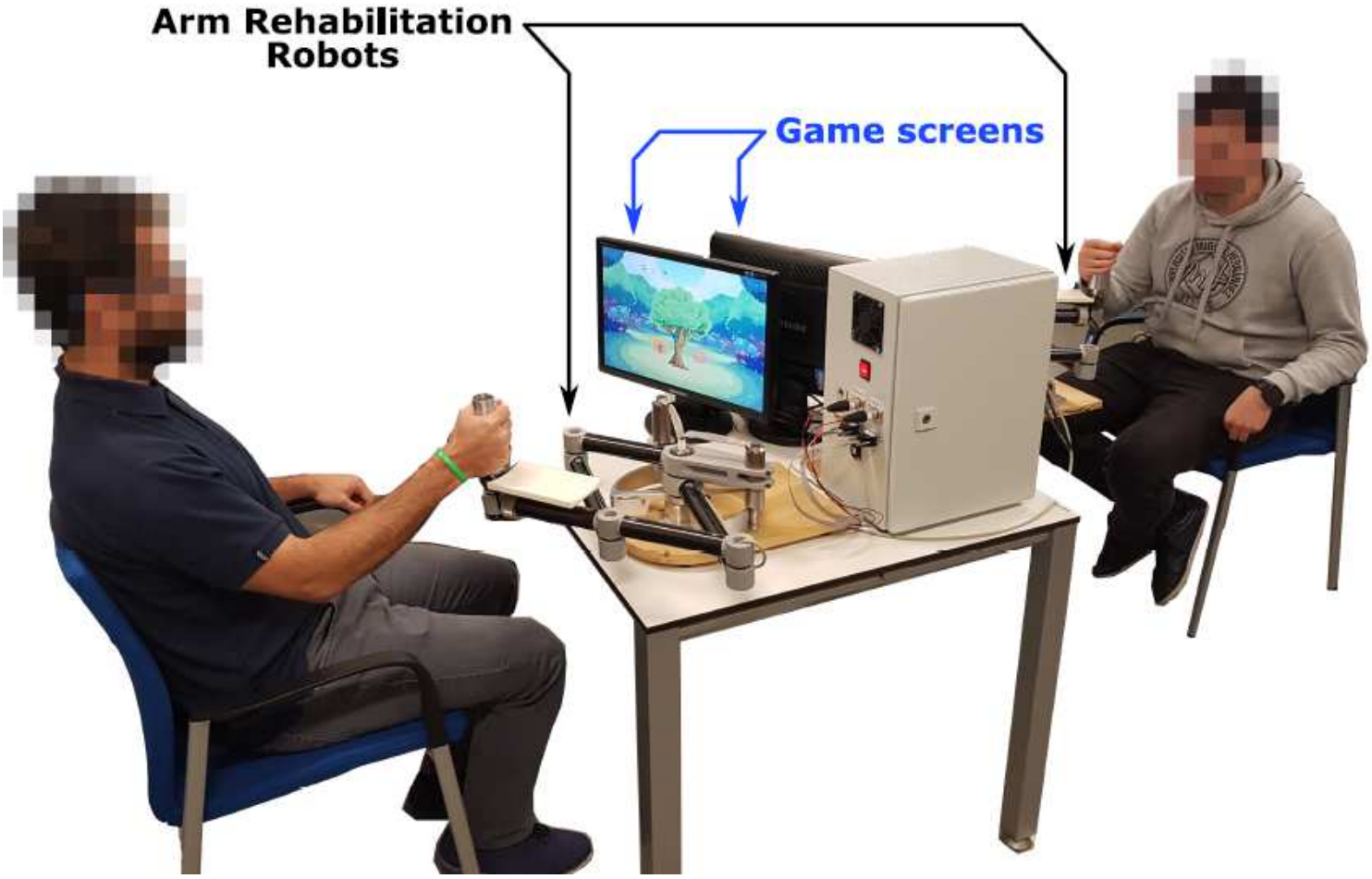


Figure 1

Overview of the experimental setup with two non-real participants.

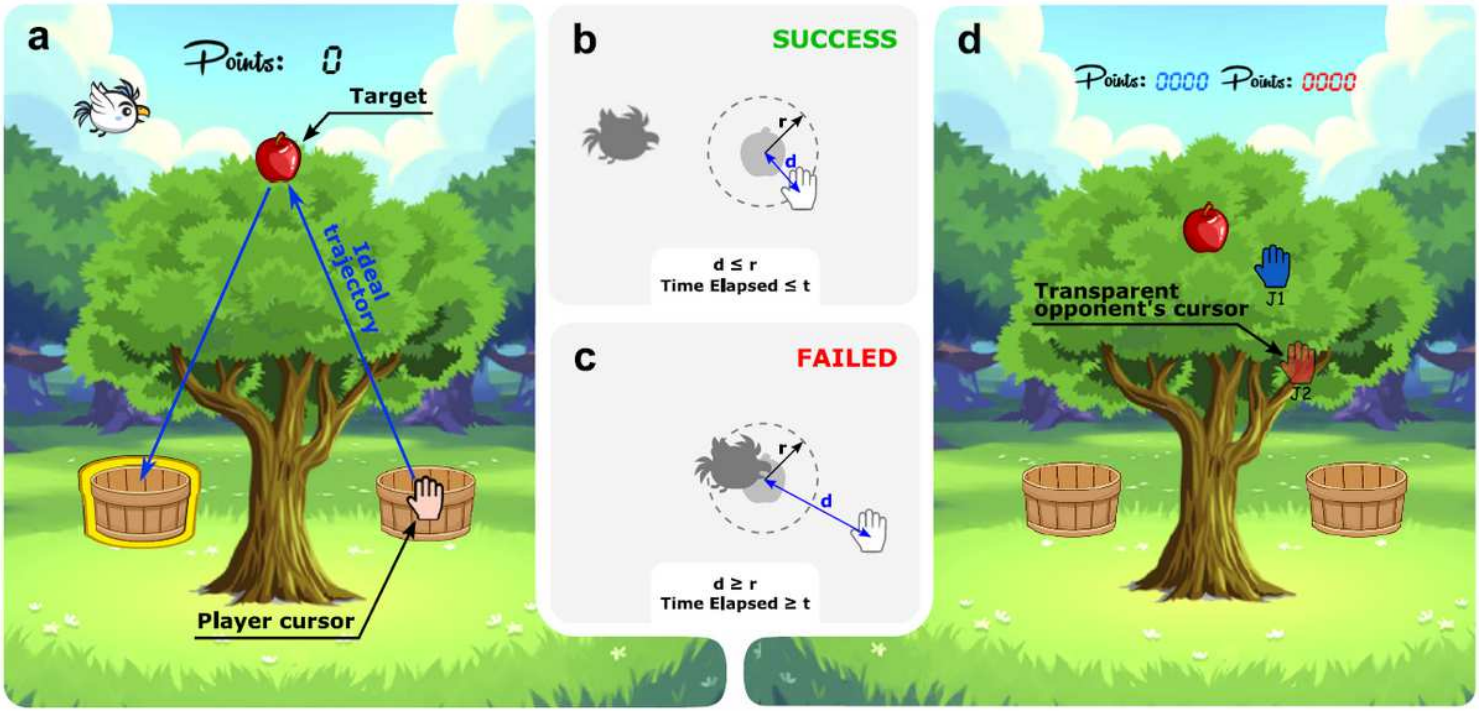


Figure 2

Overview of the game. a A screen shot of the single-player game mode. b Condition to successfully grasp the apple, where d is the distance of the user cursor to the target, r is the distance to successfully grasp the target and t is the set time to reach the target. c Condition to fail the grasp of the apple. d A screen shot from the competitive game mode.

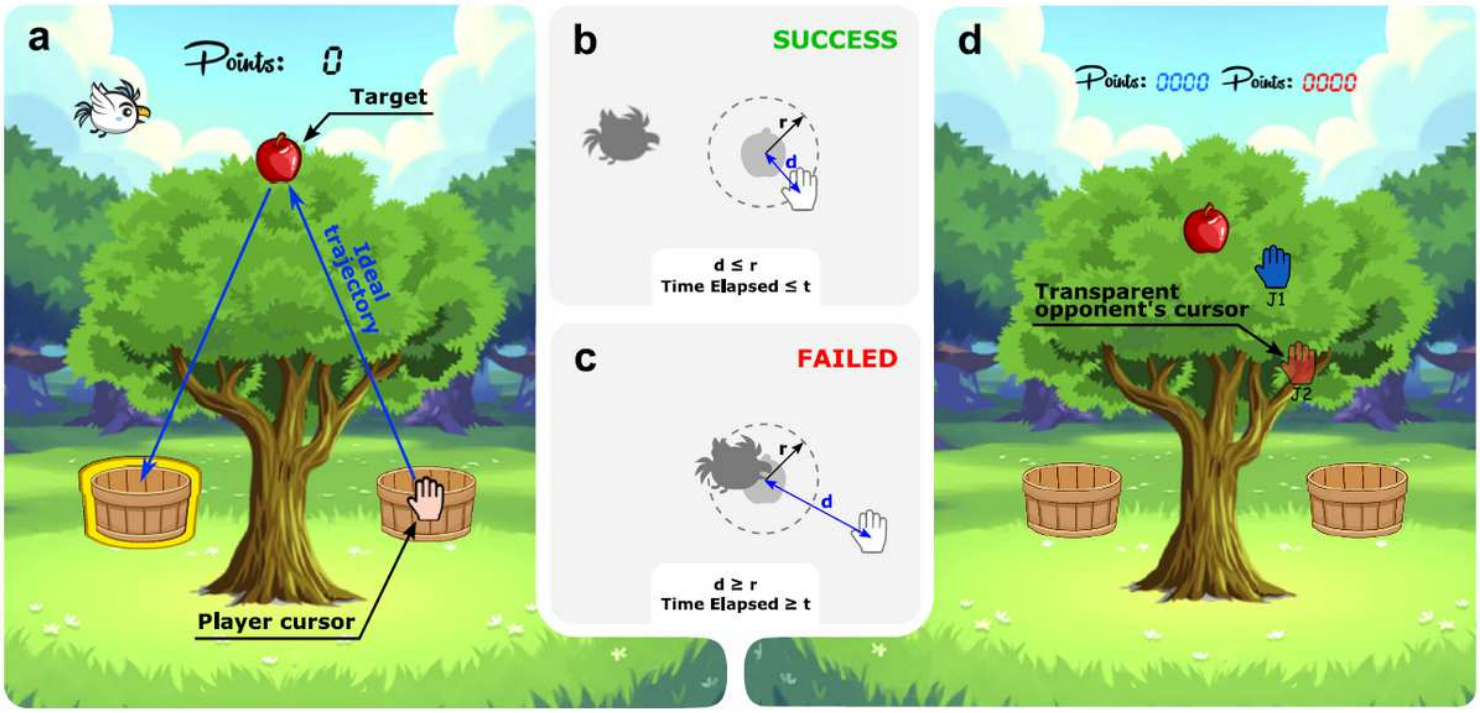


Figure 2

Overview of the game. a A screen shot of the single-player game mode. b Condition to successfully grasp the apple, where d is the distance of the user cursor to the target, r is the distance to successfully grasp the target and t is the set time to reach the target. c Condition to fail the grasp of the apple. d A screen shot from the competitive game mode.

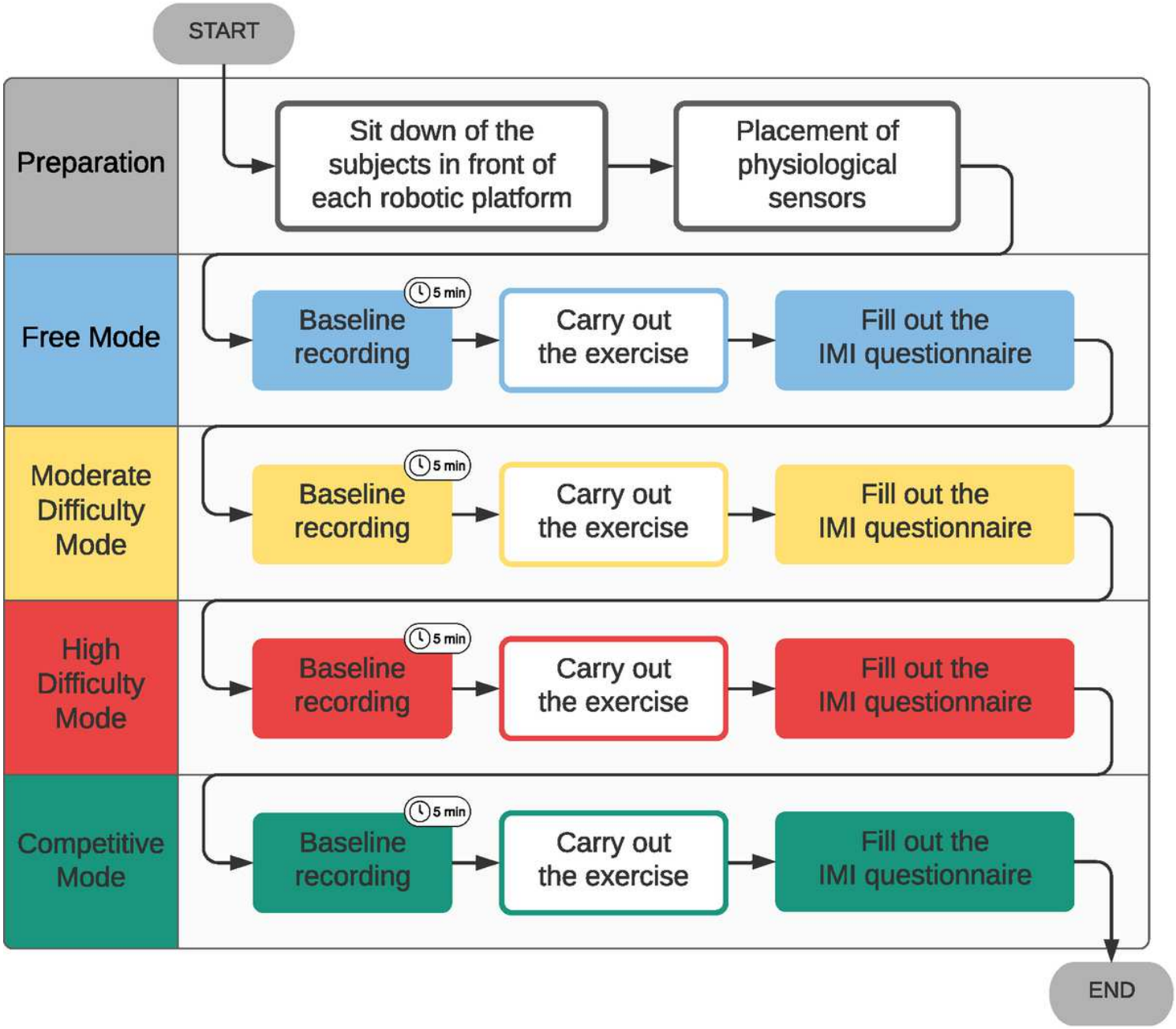


Figure 3

Study protocol. The conditions are carried out sequentially. Before each condition a baseline recording period of 5 minutes is carried out.

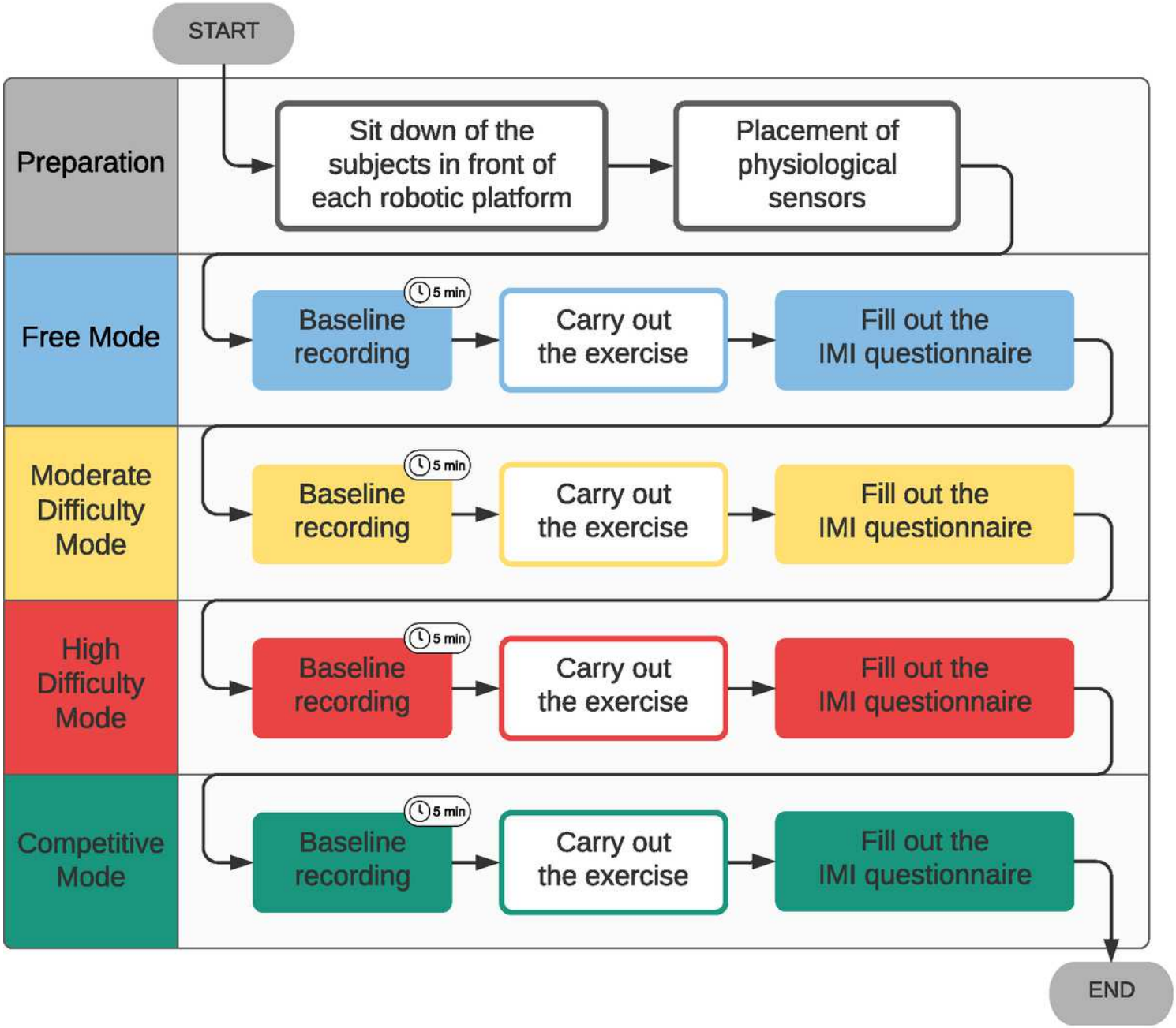


Figure 3

Study protocol. The conditions are carried out sequentially. Before each condition a baseline recording period of 5 minutes is carried out.

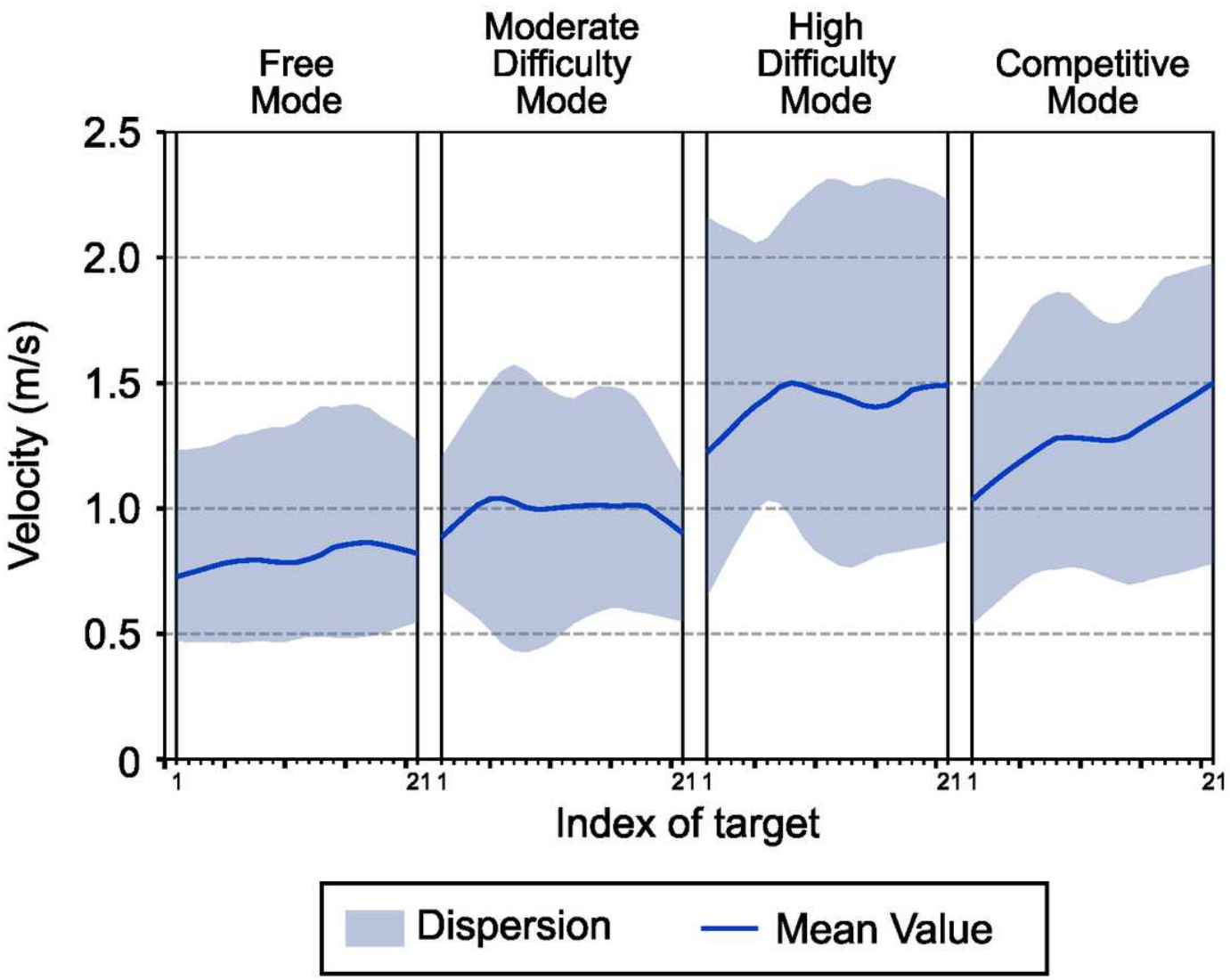


Figure 4

Evolution of mean velocity value during the activity in each mode represented consecutively. Shaded blue area contains the mean velocity values of all participants.

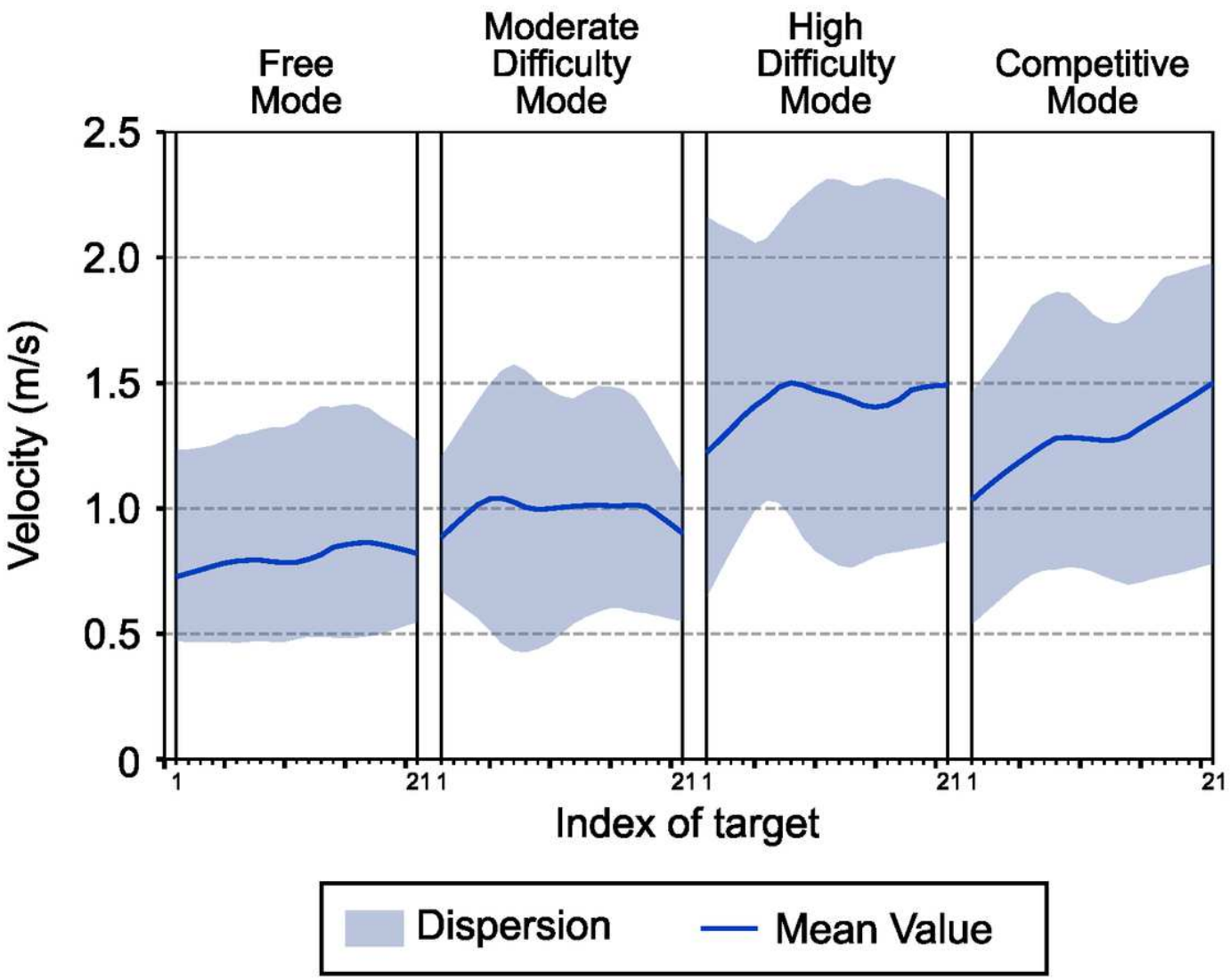


Figure 4

Evolution of mean velocity value during the activity in each mode represented consecutively. Shaded blue area contains the mean velocity values of all participants.

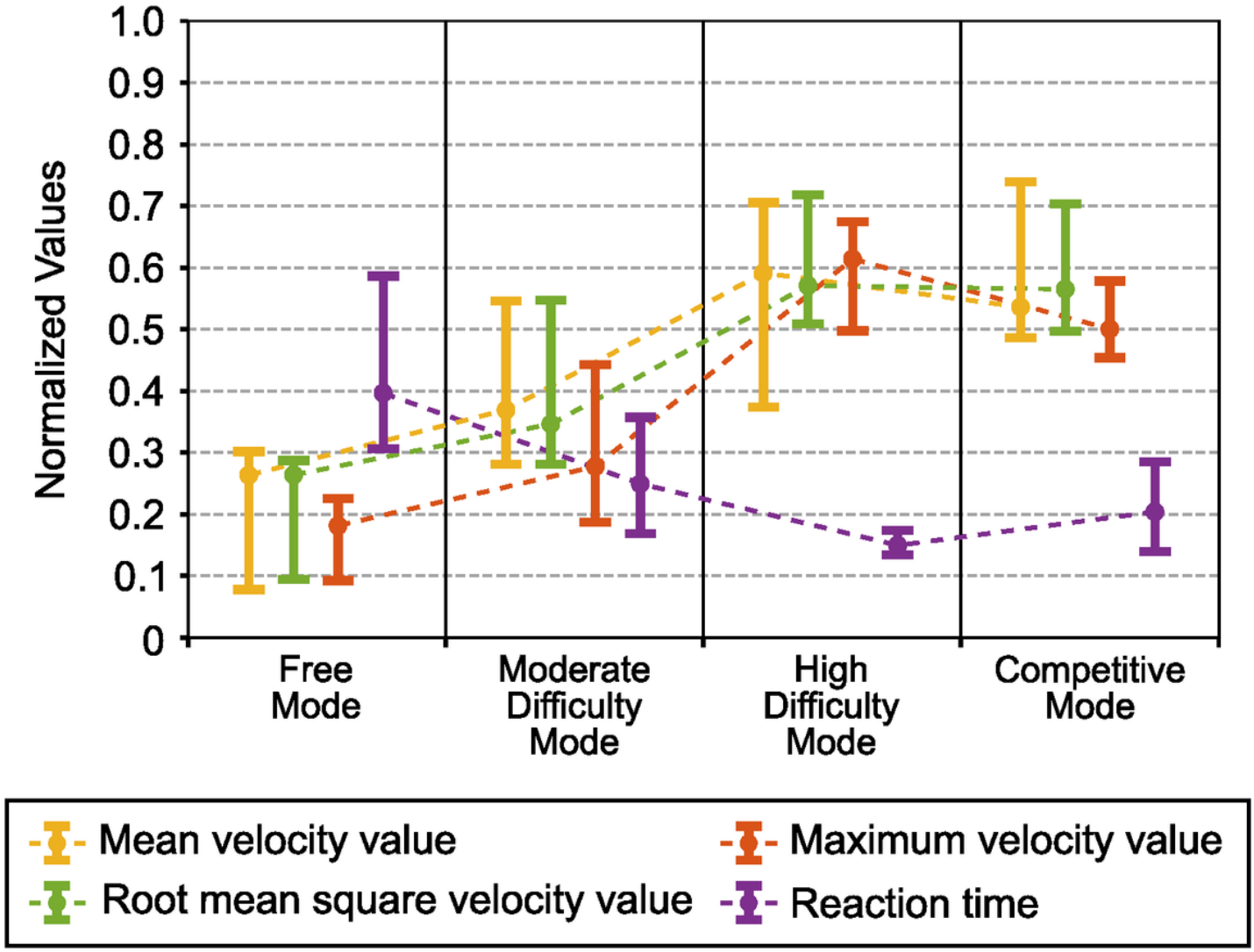


Figure 5

Exercise intensity related parameters. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles.

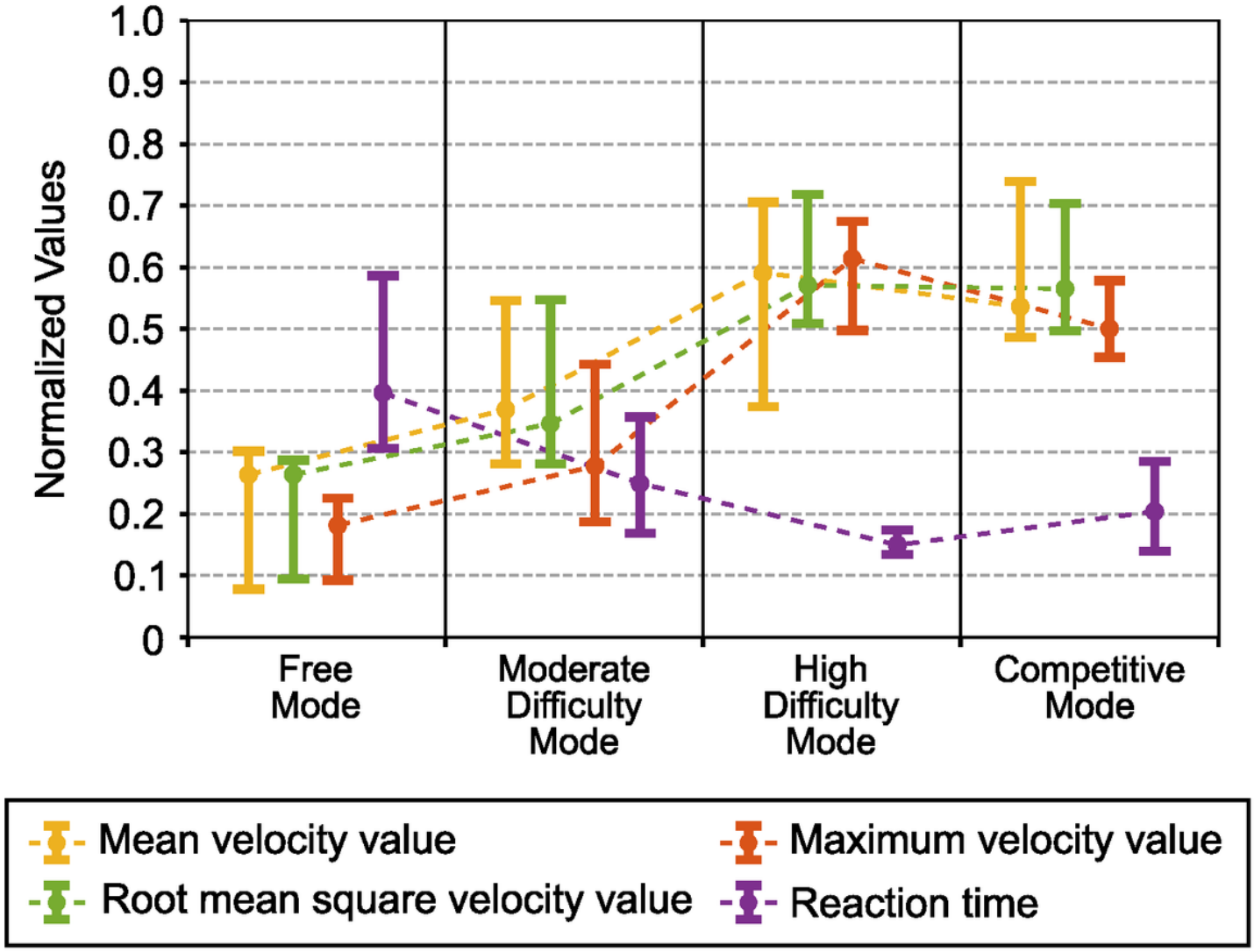
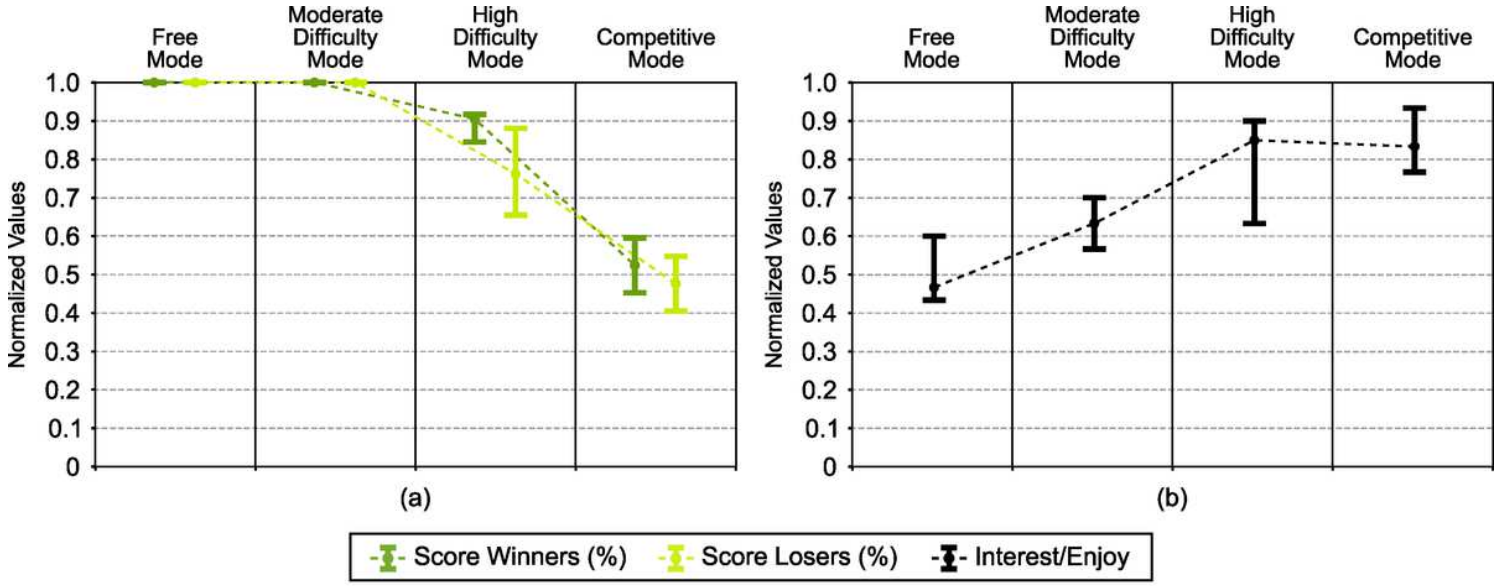


Figure 5

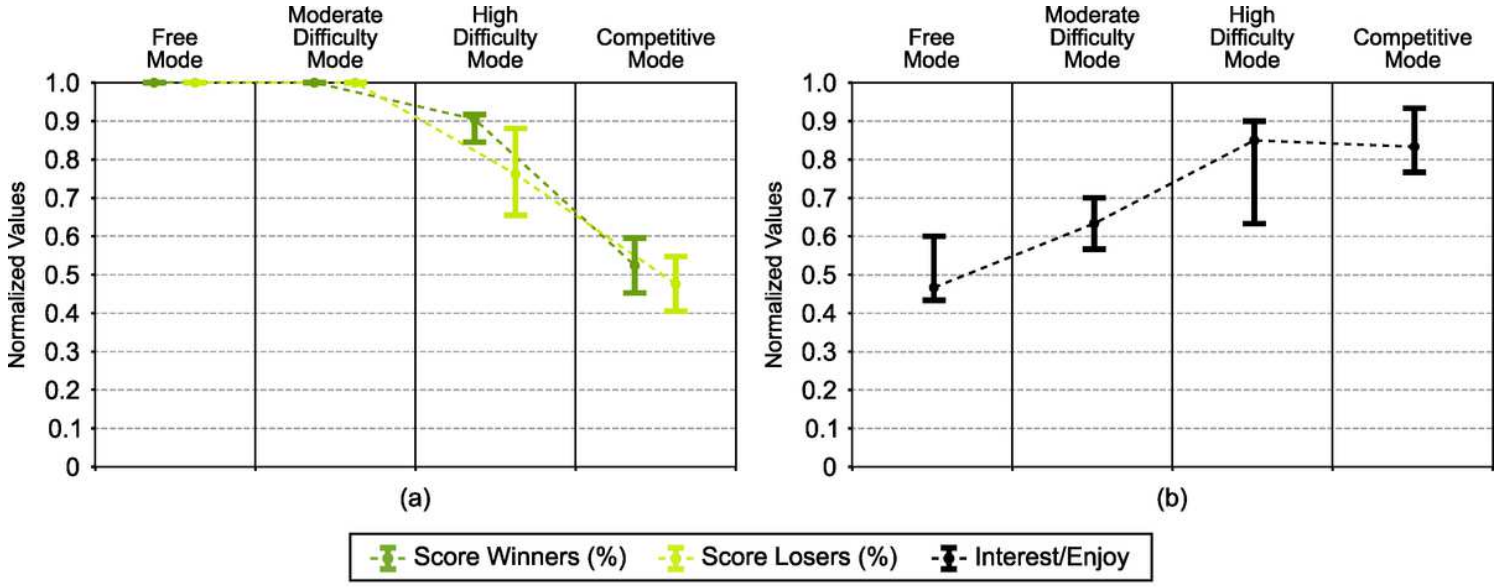
Exercise intensity related parameters. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles.



	Free Mode	Moderate Difficulty Mode	High Difficulty Mode	Competitive Mode
Score Winners	1(1, 1)	1(1, 1)	0.91(0.85, 0.92)	0.52(0.45, 0.60)
Score Losers	1(1, 1)	1(1, 1)	0.76(0.65, 0.88)	0.48(0.41, 0.55)
INT_ENJ	0.47(0.43, 0.6)	0.63(0.57, 0.7)	0.85(0.63, 0.9)	0.83(0.77, 0.93)

Figure 6

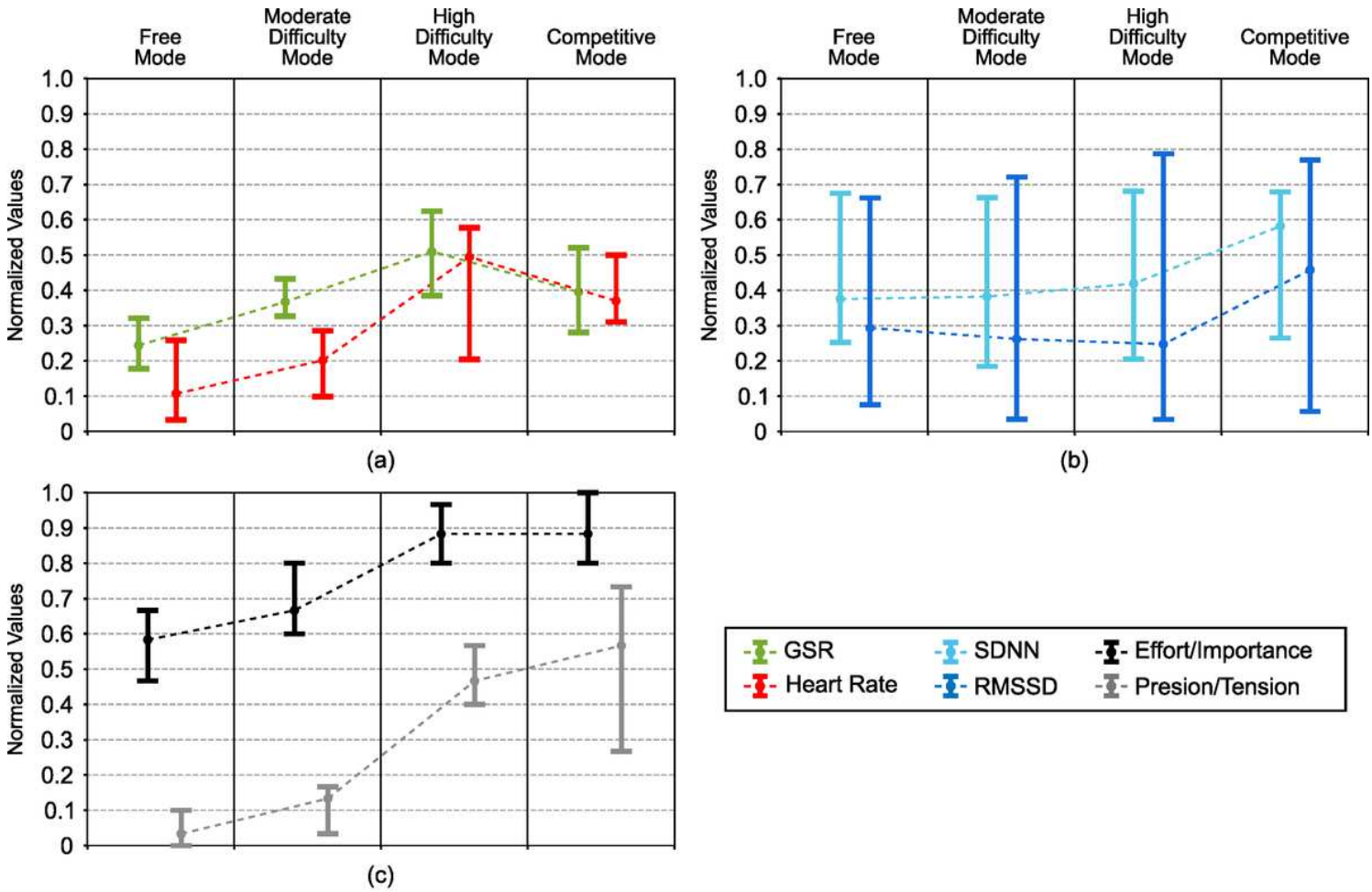
Representation of the parameters related with the exercise performance. (a) Graphical representation of the game score, separated between winners and losers of the competitive mode.(b) Graphical representation of the Interest/Enjoy parameter from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles. The table collects the non-normalized values of all parameters.



	Free Mode	Moderate Difficulty Mode	High Difficulty Mode	Competitive Mode
Score Winners	1(1, 1)	1(1, 1)	0.91(0.85, 0.92)	0.52(0.45, 0.60)
Score Losers	1(1, 1)	1(1, 1)	0.76(0.65, 0.88)	0.48(0.41, 0.55)
INT_ENJ	0.47(0.43, 0.6)	0.63(0.57, 0.7)	0.85(0.63, 0.9)	0.83(0.77, 0.93)

Figure 6

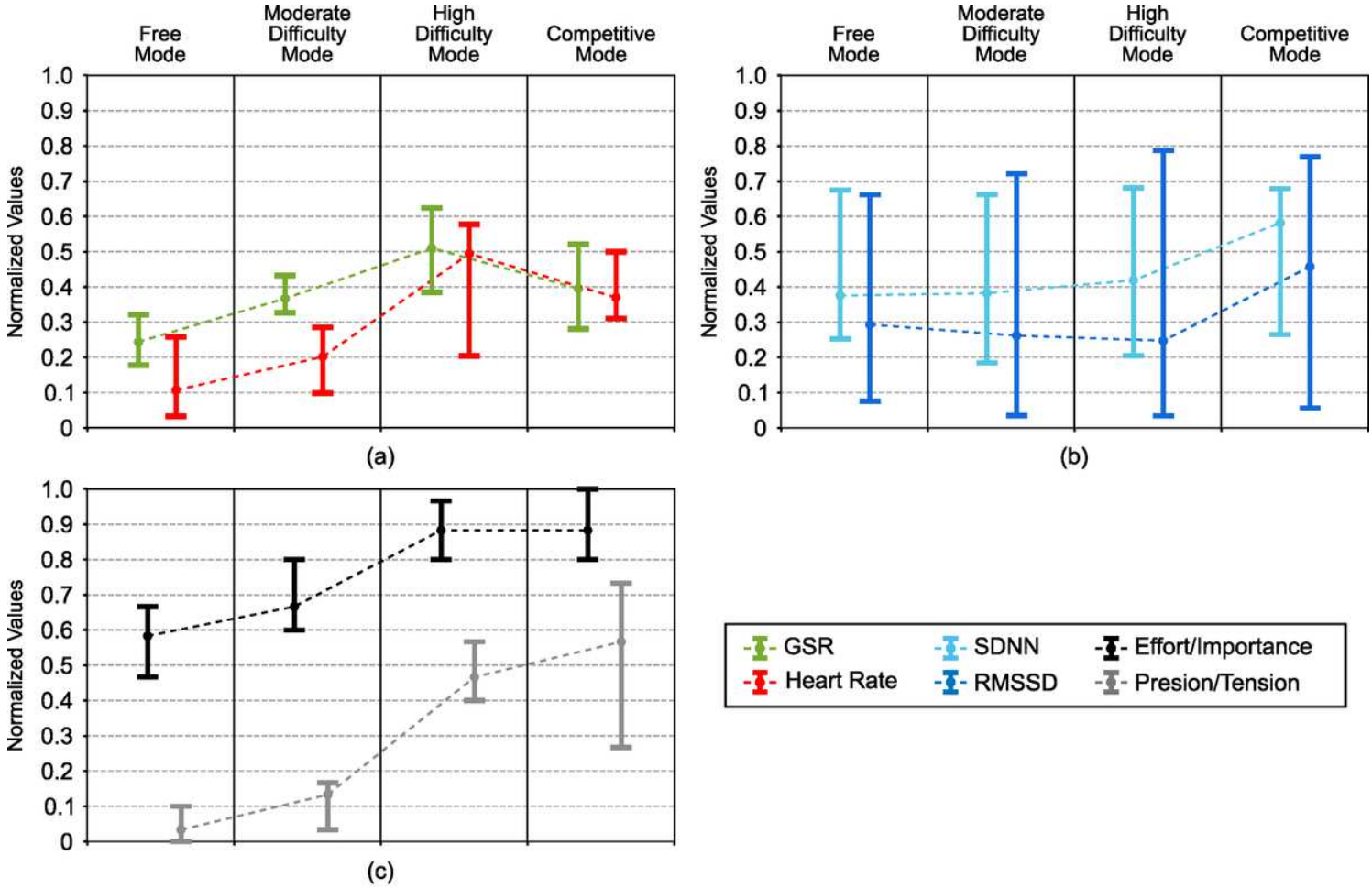
Representation of the parameters related with the exercise performance. (a) Graphical representation of the game score, separated between winners and losers of the competitive mode.(b) Graphical representation of the Interest/Enjoy parameter from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles. The table collects the non-normalized values of all parameters.



	Free Mode	Moderate Difficulty Mode	High Difficulty Mode	Competitive Mode
GSR	0.19(0.90, 0.32)	0.39(0.33, 0.49)	0.62(0.42, 0.80)	0.43(0.25, 0.63)
Heart Rate	0.02(-0.02, 0.09)	0.06(0.01, 0.10)	0.21(0.06, 0.25)	0.15(0.12, 0.21)
SDNN	0.095(0.073, 0.15)	0.097(0.061, 0.147)	0.103(0.065, 0.15)	0.132(0.076, 0.15)
RMSSD	0.115(0.045, 0.23)	0.104(0.03, 0.25)	0.1(0.03, 0.27)	0.167(0.04, 0.27)
EFF_IMP	0.58(0.47, 0.67)	0.67(0.6, 0.8)	0.88(0.8, 0.97)	0.88(0.8, 1)
PRE_TEN	0.03(0, 0.1)	0.13(0.03, 0.17)	0.47(0.4, 0.57)	0.57(0.27, 0.73)

Figure 7

Graphical representation of the parameters related to the stress level. (a) Results of the Galvanic Skin Response (GSR) and the Heart Rate (HR). (b) Results of the Heart Reat Variability time-domain measures. (c) Results of the Pressure/Tension and E□ort/Importance parameters from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles. The table collects the non-normalized values of all parameters.



	Free Mode	Moderate Difficulty Mode	High Difficulty Mode	Competitive Mode
GSR	0.19(0.90, 0.32)	0.39(0.33, 0.49)	0.62(0.42, 0.80)	0.43(0.25, 0.63)
Heart Rate	0.02(-0.02, 0.09)	0.06(0.01, 0.10)	0.21(0.06, 0.25)	0.15(0.12, 0.21)
SDNN	0.095(0.073, 0.15)	0.097(0.061, 0.147)	0.103(0.065, 0.15)	0.132(0.076, 0.15)
RMSSD	0.115(0.045, 0.23)	0.104(0.03, 0.25)	0.1(0.03, 0.27)	0.167(0.04, 0.27)
EFF_IMP	0.58(0.47, 0.67)	0.67(0.6, 0.8)	0.88(0.8, 0.97)	0.88(0.8, 1)
PRE_TEN	0.03(0, 0.1)	0.13(0.03, 0.17)	0.47(0.4, 0.57)	0.57(0.27, 0.73)

Figure 7

Graphical representation of the parameters related to the stress level. (a) Results of the Galvanic Skin Response (GSR) and the Heart Rate (HR). (b) Results of the Heart Reat Variability time-domain measures. (c) Results of the Pressure/Tension and E□ort/Importance parameters from Intrinsic Motivation Inventory. All parameters has been normalized by the min-max normalization method and are graphical represented in each game mode by the median value and an error bar representing the rst and third quartiles. The table collects the non-normalized values of all parameters.

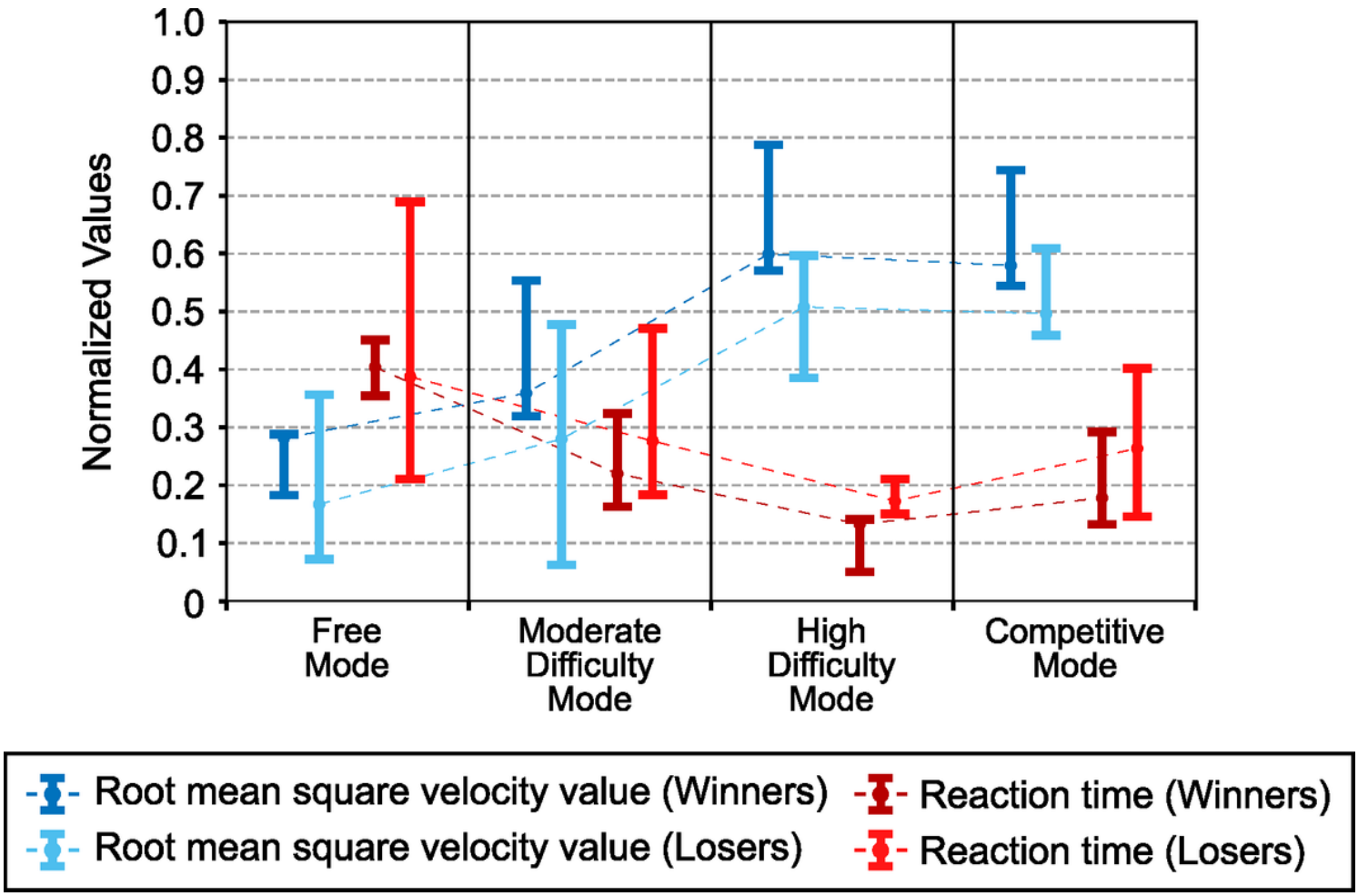


Figure 8

Di erences in the parameters related to the intensity level between winners and losers of the competitive mode.

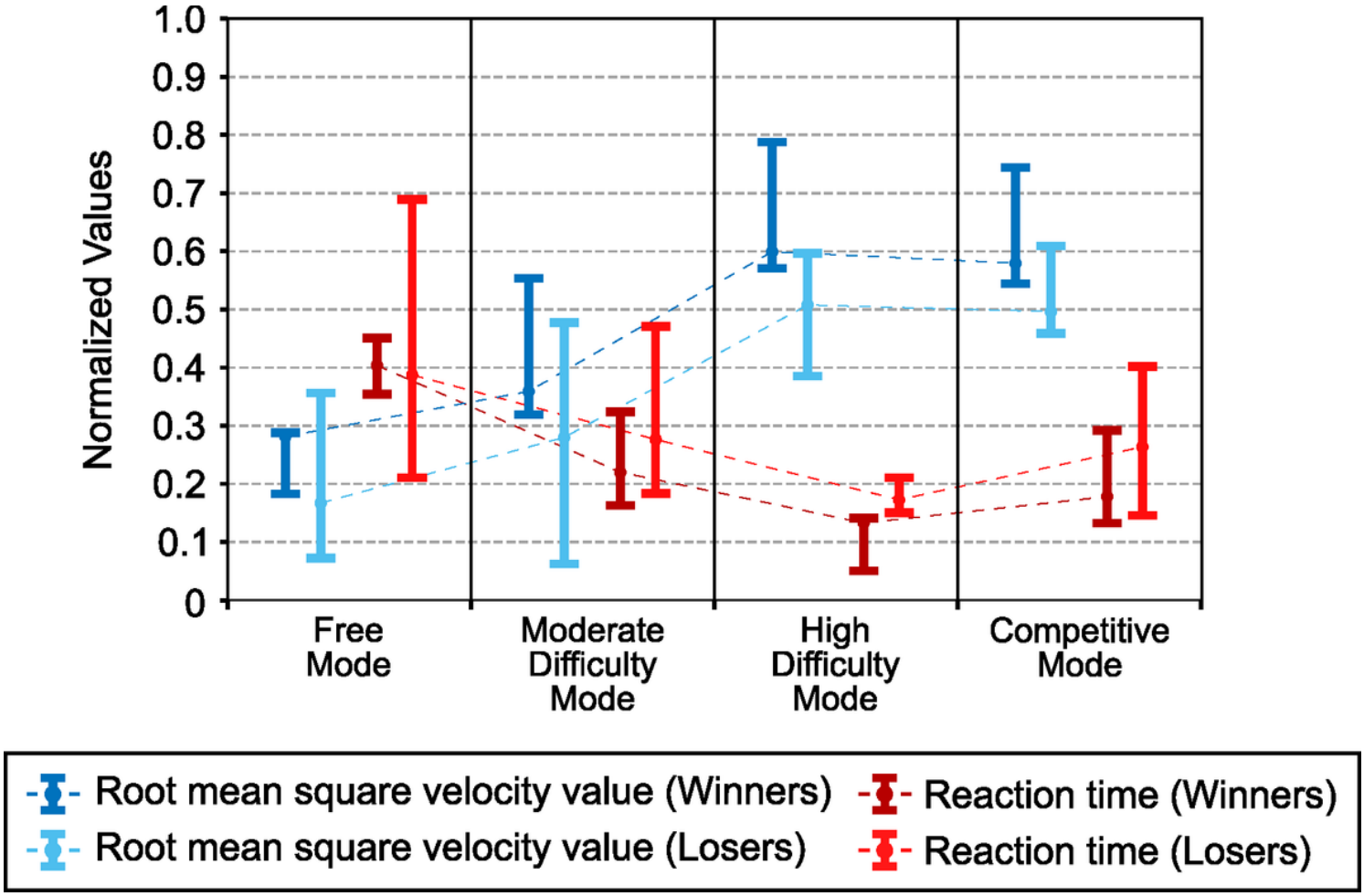


Figure 8

Di erences in the parameters related to the intensity level between winners and losers of the competitive mode.