Assessment of movement variability and time in a football reactive agility task depending on constraints

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Abstract

The aims of this study were to: (1) analyze time and movement variability in a football (soccer) agility task performed with or without ball, both in the following situations a) reacting to the movement of two players with a single exit gate (R1), b) reacting to the movement of one player with two possible exit gates (R2) and c) not reacting to a stimulus; and, (2) analyze the relationship between time and movement variability. Seventeen semi-professional female football players participated in the study. Acceleration was measured using an inertial measurement unit attached to each player through an elastic belt close to the sacrum. Entropy was calculated from the acceleration signal and time was extracted using a magnet-based timing system. Movement variability was reduced whereas time increased when adding the ball and/or the reaction, finding no differences between R1 and R2. A moderate negative correlation was found between time and movement variability ($r=-0.56$, $p<0.01$). Our findings demonstrate that increasing the difficulty and/or the amount of information from the environment, decreased movement variability and increased the time. The measurement of movement variability in addition to time in an agility task can be used to determine the mastery level of players.

Key words: "Change of direction", "skill acquisition", entropy, reaction, dribbling

Introduction

Football (soccer) is a team sport characterized by intermittent high-intensity actions, with a need to continuously adapt to an ever-changing environment. During training and competition, high-intensity actions such as: a change of direction maneuver to overcome an opponent, passing and shooting, a 1 vs. 1 dual, and a header to clear the ball, to name a few, are frequently performed (Bloomfield et al., 2007; Vescovi, 2012a, 2012b; Vescovi & Falenchuk, 2019). During a football match a player can make more than 1,000 changes in movement patterns, which means on average a change every 3-6 s (Datson et al., 2014), and these changes are underpinned by the constant need to adapt to the ever-evolving game situation. Noting that agility is defined as the ability to make a change of direction or speed in response to a stimulus (Sheppard & Young, 2006) and that it depends not only on physical and technical factors, but also on cognitive factors (Hojka et al., 2016), it is no surprise that this represents a critical capacity for optimizing performance in football.

In recent years, research relating to agility has grown exponentially. Some studies have found that more skilled players are able to exhibit superior agility performance compared to players of a lower skill level (Fiorilli, Mitrotasios, et al., 2017; Pojskic et al., 2018; Trecroci et al., 2018). Therefore, given the prevalence of agility actions and their ability to discriminate between players of differing skill levels, it stands to reason that this capacity is of great interest to practitioners and is likely to be a key factor in team sports performance.

Agility performance is multifactorial and depends on various factors including physical (e.g., strength and speed), physiological (e.g., metabolism and fiber type), cognitive (e.g., anticipation and reaction) and coordinative factors (e.g., technical factors associated to the execution of the action) (Paul et al., 2015). However, most of the studies conducted so far have only assessed conditional aspects of agility (i.e., total time to complete the task) and, to a lesser extent, the cognitive aspects, through assessing either the decision accuracy or the decision time between the appearance of the stimulus and the first movement in the desired direction (Morral et al., 2020). To the best of our knowledge, no study has assessed the coordinative aspects related to the execution of the action of an agility task.

In recent years, several studies have analysed the coordinative aspects of different motor actions by the assessment of movement variability (MV) understood as the fluctuations in different parameters, as the force, speed, trajectory or the body movement acceleration used in our study, through the use of non-linear measurements (Caballero Sánchez et al., 2014; Harbourne & Stergiou, 2009; Urbán Infantes et al., 2012) which provides qualitative information about movement, enabling the assessment of the regularity of a time series (Orellana & De La Cruz Torres, 2010). Entropy is one of the most popular methods to measure MV. It quantifies the amount of regularity versus unpredictability of point-to point fluctuations within large sets of time-series data (Richman & Moorman, 2000). The higher the entropy, the greater the irregularity of the signal and therefore the greater the MV. From the perspective of human movement, variability is described as the typical trial-to-trial irregularity occurring when executing multiple repetitions of the same task (Newell & James, 2008; Stergiou, 2016) or the within-trial irregularity in one repetition (Fernández-Valdés et al., 2022; Moras et al., 2018). In this sense, studies assessing MV have been conducted during different sporting actions such as: a free throw in basketball (Hamilton & Reinschmidt, 2010; Robins, 2006), tennis serve (Menayo et al., 2010, 2012; Mendes et al., 2013), kicking performance in soldiers (Vagner et al., 2022), with results suggesting that lower MV is often associated with greater performance precision in the task when aiming is required. Nevertheless, in open and multi-joint tasks greater variability is detected due to the need to adapt to changing conditions (Stergiou et al., 2006). Therefore, the nature of the task has an effect on MV which tends to reduce over time through learning or training associated with a higher amount of motor control (Fernández-Valdés et al., 2022; Guimarães et al., 2020).

Also, the influence of the inclusion of different constraints has been studied by analyzing the MV of the action compared to the other conditioned attempts of the task finding an increase (Moras et al., 2018) or decrease (Caballero et al., 2019; Robalo et al., 2020; Urbán et al., 2019), in the MV when including the constraints depending on the nature and difficulty of the task among others.

However, information about the influence of a ball dribbling inclusion or a reaction to a stimulus in MV measured through entropy, combined with the outcome measure of 'time' in an agility task is rare (Morral et al., 2020). This analysis would help to better understand the implications of the inclusion of different constraints on a change of direction drill, not only at a conditional (quantitative) level, but also at a coordinative (qualitative) level by analyzing the structure of the signal in the different situations.

Therefore, the aims of this study were to: (1) analyze the time and MV measured through the entropy of the body movement acceleration signal in a football agility task performed with or without ball, both in the following situations a) reacting to the movement of two players with a single exit gate (R1), b) reacting to the movement of one player with two possible exit gates (R2) and c) not reacting to a stimulus; and, (2) analyze the relationship between time and MV.

We hypothesized that: 1) the time will be longer and MV will be lower when performing the agility task with a ball compared to without a ball, reacting to a movement compared to not reacting , and in R2 compared to R1; 2) the agility task with ball and reacting to a stimulus will have the lowest MV compared to all other conditions; and 3) there will be a negative relationship between time and MV.

Materials and Methods

Subjects

Data were collected from 17 elite female football players (age: 19.65 [3.24] years; body mass: 57.49 [6.79] kg; height: 1.63 [0.06] m). All participants were players from a club participating in the second Spanish division ("Reto Iberdrola") with an average of 11.24 [3.67] years of football experience. Only players who were in team training dynamics and competition were included. The procedures complied with the Declaration of Helsinki (2013) and were approved by the local ethics committee (005/CEICEGC/2021). All subjects gave their written informed consent before participating in the study.

Procedures

The football agility task was designed based on the most typical agility test (Morral et al., 2020). It consisted of a Y-shaped course with 3 possible exit gates: middle, left and right. The total distance of the test was 10 m, consisting of a first section of 4 m to the midpoint of the test and a second section of 6 m to the final of each exit door at 45º to the right or to the left or straight ahead. At the midpoint of the agility task, a visible circle of 1 m in diameter was made to mark the point where the player must perform a change of direction to the final gate. When the player gets into the circle, the tester/s moved by covering the corresponding exits, according to a scripted sequence of imposed constraints. If the player did not perform the change of direction inside the circle, the trial was discarded and repeated later at random. Two magnets were placed as photocells at the starting gate and at each of the three possible exit gates of the task, for measuring the time of each run. This method has proven to be highly reliable in a previous study by Pérez-Chirinos et al., (2021). Beyond each final gate, two cones were placed two meters away to prevent players from slowing down before crossing the exit gate (Figure 1).

[Figure 1 near here]

Figure 1. Graphical description of the football agility task

The agility task was performed with or without ball and with or without reacting to a stimulus. The reaction was performed with two options: R1 and R2 (Figure 2). The combination of options resulted in 6 global categories: 1) without ball and pre-planned; 2) without ball and reacting to a stimulus with only one possible exit gate and 3) with two possible exit gates; 4) with ball dribbling and pre-planned; 5) with ball dribbling and reacting to a stimulus with only one possible exit gate; and 6) with two possible exit gates. These options resulted in a total of 20 different runs. Each player performed each run four times in a randomized order, performing a total of 80 runs.

[Figure 2 near here]

Figure 2. Graphical description of the reaction possibilities (R) of the agility task. To the movement of two testers with a single exit gate (R1) or to the movement of one tester with two possible exit gates (R2).

The protocol consisted of a standardized 10-minute warm-up consisting of running, dynamic joint mobility exercises and progressive runs. Afterwards, players were allowed to perform the task to familiarize with the different agility task options. They had a rest period of no less than 60 s after each run. After completing 10 runs, a rest of 10-15 min was taken before proceeding. The runs were assigned to each player on a random order. All trials were recorded by video.

Materials

Each player acceleration was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain), with a 3D accelerometer 100G, recording at 1000 Hz and a 3D magnetometer recording at 100 Hz. The use of a single inertial measurement unit during the performance of a brief task at the center of mass has been previously used and validated to capture motion (Fusca et al., 2018; Myklebust et al., 2015; Wilkinson & Lichtwark, 2021). The device was attached to the player using an elastic belt close to the sacrum with a hard fixation to avoid extraneous acceleration during running (Edwards et al., 2018).

Two magnets (D33 × 267 mm, ND35, A.C. magnets 98, Barcelona, Spain) were placed on each gate of the task following the magnet-based timing system methodology purposed by Pérez-Chirinos et al. (2021), to know the time of passage from the player through each gate. With this method, as the player cross the gate with the magnets, the magnetometer of the IMU increase the signal generating a detectable peak and allowing to cut the signal through these peaks to determine the time of each run (Figure 3).

[Figure 3 near here]

Figure 3. Graphical example of the analysis of the signal using the magnet-based timing system methodology.

A portable high-speed camera (Casio Exilim EX-ZR100) recording at 240 fps was placed perpendicular to the exit gates of the test to ensure that each run corresponds to the one marked on the note paper, and thus avoiding possible errors in the interpretation of the signal.

Data Analysis

Each time a football player passed near a bar magnet, a peak in the magnetometer time series was detected (Figure 3). SPRO software (Realtrack Systems, Almeria, Spain) was used to analyse the data recorded with the IMU to calculate the elapsed time between peaks (Figure 3). The magnetometer registered the peaks corresponding to the time of passage through the initial and final gate of the test, allowing us to cut the acceleration signal corresponding to each trial and obtain the time spent in each run (Pérez-Chirinos et al., 2021). The devices were calibrated prior to their placement. This was done with a self-calibration system that incorporates each device in the internal configuration of the boot. During self-calibration, three aspects were taken into account: (i) leaving the device immobile for 30 s; (ii) placing it in a flat area; and (iii) no magnetic devices around it (Bastida Castillo et al., 2017). This device have reported good results in accuracy and reliability of his different sensors in previous studies (Bastida Castillo et al., 2017; Gómez-Carmona et al., 2018, 2020; Pino-Ortega et al., 2019). The raw acceleration signal from each device (Figure 4) was extracted and processed using a summation of vectors (AcelT) in three axes, mediolateral (x), anteroposterior (y) and vertical (z) calculated according to Gómez-Carmona et al. (2018).

[Figure 4 near here]

Figure 4. Synchronization of the magnetometer signal with the acceleration (ACELT) signal of the WIMU.

Sample entropy (SampEn) for each accelerometery signal was calculated to determine the MV of the agility task. The total acceleration signal registered by the IMU at 1000Hz during the running time of the task was used to calculate the entropy, resulting in 1000 points of accelerometry for each second of task duration. Entropy calculation was done according to Goldberger et al. (2000), and through dedicated routines programmed in Matlab®(The MathWorks, Massachusetts, USA). We used the template length m of 2, and the tolerance criterion of 0.20 in the analyses.

Statistical Analysis

Statistical analysis was performed with SAS v9.3, SAS Institute Inc, Cary, NC, USA. The normality of time and entropy data was assessed using Shapiro-Wilk for the implementation of a mixed effects model.

A linear mixed model was used to analyze the response variables of time and entropy, with the player variable treated as the random factor. The covariance structure of the random effects used is "variance components" (VC) where it models a different variance component for each random effect. The degrees of freedom were corrected using the Kenward-Roger method. Three independent models were run for each response variable, taking the following explanatory factors: a) ball and run, b) ball and reaction, c) ball and type of reaction.

The general relationship between time and entropy was also analyzed using Pearson's correlation coefficient.

Statistical decisions have been made taking as the level of significance the value $p \leq 0.05$. In case of a significant result, a post-hoc 2 to 2 contrasts were performed to further investigate the differences between specific pair of variables analyzed allowing us to avoid potential Type I errors that may arise when conducting multiple comparisons. To correct for type I error in multiple testing, the *p* values obtained were corrected using Tukey's correction.

Results

Based on the results of Shapiro-Wilk, the data for both time and entropy variables were found to be normally distributed ($p>0.05$). Results have been divided in two categories (time and MV). Each category has been also divided into two sections for a better understanding. The first section of each one corresponds to a univariate analysis comparing the global categories ball or no ball and reaction (R1 or R2) or no reaction, without considering the other. The second corresponds to a bivariate analysis where the influence and interaction between both categories is considered, differentiating between no reaction without ball, and with ball and with reaction without ball and with ball. Also, we added the relationships results between time and entropy.

Movement variability

Section 1

Figure 5A, shows significant differences between including the ball dribbling during the task (0.17 ± 0.02) and performing it without ball (0.21 ± 0.04), finding higher entropy without ball. In the same line, significant differences were found between performing the task in a pre-planned condition (0.20 ± 0.04) and reacting to a stimulus (0.18 ± 0.03), finding higher entropy when there is no stimulus to respond (Figure 5B). As we can see in Figure 5C, no differences were found between R1 and R2, finding very similar entropy values between both types of reactions.

[Figure 5 near here]

*Figure 5. A) Ball; B) Reaction C) Type of reaction. *p<0.01; **p>0.05.*

Section 2

Figure 6 shows significant differences between doing the task with (0.18 ± 0.03) or without ball dribbling (0.22 ± 0.04) in the pre-planned condition and with (0.161 ± 0.021), or without ball (0.20 ± 0.03) and reacting to a stimulus, always finding lower entropy in the runs performed with ball dribbling. There are also significant differences between performing the task pre-planned (0.18 ± 0.03) and reacting to a stimulus (0.16 ± 0.02) when dribbling the ball. In the same way, there are significant differences between not reacting (0.216 ± 0.040) and reacting to a stimulus (0.202 ± 0.033) without ball dribbling, always finding higher entropy in the runs performed pre-planned. As we can see in Figure 7, there are no differences between both types of reaction, neither in task performed with ball dribbling nor in task performed without the ball.

[Figure 6 near here]

*Figure 6. MV combining the inclusion or not of reaction with the inclusion or not of the ball; *p<0.01; **p<0.05.*

[Figure 7 near here]

*Figure 7. MV combining the inclusion or not of reaction with the inclusion or not of the ball differentiating between R1 and R2; *p<0.01; **p<0.05*

Time

Section 1

Figure 8A, shows significant differences between performing the task without the ball (1.84 ± 0.13) and with ball dribbling (2.16 ± 0.19), finding faster times in runs performed without the ball. In the same line, significant differences were found between not reacting to a stimulus (1.88 ± 0.20) and reacting to a stimulus (2.05 ± 0.22), finding lower times when the task is performed pre-planned (Figure 8B). As we can see in Figure 8C, no differences were found between both types of reaction.

[Figure 8 near here]

*Figure 8. A) Ball; B) Reaction C) Type of reaction. *p<0.01.*

Section 2

Figure 9 shows significant differences between times performed with (2.03 ± 0.17) and without ball (1.73 ± 0.07) in a pre-planned condition and with (2.22 ± 0.18) or without ball dribbling (1.89 ± 0.11) when reacting to a stimulus. In both cases, speed was lower when the agility task was performed with the ball. There are also significant differences between performing the task with ball and without reacting to a stimulus (2.03 ± 0.17), and reacting to stimulus (2.22 ± 0.18). In the same way, there are significant differences between performing the task without ball and reacting (1.89 ± 0.11) or not (1.73 ± 0.07) to a stimulus, always finding higher speed in the runs performed pre-planned. As we can see in Figure 10, there are no differences between R1 and R2, neither in with ball dribbling nor without ball.

[Figure 9 near here]

*Figure 9. Time combining the inclusion or not of reaction with the inclusion or not of the ball; *p<0.01; **p<0.05.*

[Figure 10 near here]

*Figure 10. Time combining the inclusion or not of reaction with the inclusion or not of the ball differentiating between R1 and R2; *p<0.01.*

Finally, we found a negative moderate correlation between time and entropy (r = -0.56, p < 0.01), finding a higher movement variability at higher speeds.

Discussion and Implications

In partial agreement with our hypothesis, we found slower time and lower MV with increasing difficulty and/or environmental information in a soccer agility task, but no differences were found between the complexity of the reaction (R1 vs R2). In addition, we found a moderate negative correlation between time and MV.

Increased difficulty or increased environmental information in the task leads to a reduction in the number of configurations available in the motor system, increasing movement regularity (i.e., decreasing MV) and decreasing performance (Couceiro et al., 2014). Furthermore, when the ball and the reaction to a stimulus participate together in the task, the MV is reduced and the speed becomes even slower, with the ball having the greatest influence on the reduction of MV and time. Consequently, the greater regularity of movement adopted by these players with the ball and reacting to a stimulus may imply the need to reduce the complexity of the action to cope with other variations in the environment.

We should highlight that the agility task performed in this study represents the execution of types of actions involved in football (i.e., change of direction, dribbling the ball, reaction to an opponent), that players have been repeating for more than 10 years in training. We can deduce a high mastery of the task associated to the low MV found in the results. In this sense, many studies have shown that experienced players show less variability associated with a higher motor control (Fernández-Valdés et al., 2020, 2022; Langdown et al., 2012; Menayo et al., 2012). In addition, it has been stated that with the training, learning and mastery of any given ability or task, as the control and accuracy of the skill increases, the MV of said action is reduced, which has the potential to result in plateaus in coordinative (qualitative) performance levels if no modifications are made to the task constraints (Fernández-Valdés et al., 2020, 2022).

The reduction in MV observed when including constraints are also in line with other studies that have assessed the influence of including different constraints to increase the difficulty of a given motor task (Caballero et al., 2019; Caballero Sánchez et al., 2016; Couceiro et al., 2014; Robalo et al., 2020; Urbán et al., 2019; Wolfgang & Fabian, 2019). It has been stated that the relationship between system complexity and performance depends on task constraints and their level of difficulty, finding lower complexity in the structure of the signal when tasks increase their level of difficulty by adding constraints (Caballero et al., 2019; Robalo et al., 2020; Urbán et al., 2019; Vaillancourt & Newell, 2002, 2003). The greater reduction found in MV with the inclusion of the ball dribbling and the reaction together, reinforce the fact that the inclusion of more constraints to a task causes a greater reduction in the degrees of freedom reducing the movement possibilities of the player. Thus, the requirements on a player are to become more stable in their action to reduce the complexity demanded by the context trying to adapt to the game situation

(Caballero Sánchez et al., 2016; Couceiro et al., 2014; Guimarães et al., 2020; Harbourne & Stergiou, 2009).

No differences were found according to the complexity of the reaction to the stimulus, finding very similar levels of MV in R1 and R2. This could be due to the low overall complexity the stimulus represented for the players, and because they tended to reduce the difficulty filtering some of the information from the environment. This may have been particularly evident in R2, where the players focused their attention on a single stimulus to discard some of the possibilities and find the solution faster.

In line with the results found in our research, other studies have also shown an increase in movement time in an agility task including the reaction to a stimulus compared to a pre-planned change of direction task (Andrašić et al., 2021; Fiorilli, Iuliano, et al., 2017; Pojskic et al., 2018). This behaviour has also been observed when including a ball in an agility task (Conte et al., 2020; Ramirez-Campillo et al., 2021; Scanlan et al., 2018). Specifically, smaller speed reductions were found between performing the pre-planned change of direction task compared to including the reaction to a stimulus at higher performance level athletes (Krolo et al., 2020; Pojskic et al., 2018; Zeljko et al., 2020), and when performing the change of direction including the ball compared to performing it without the ball (Bekris et al., 2018; Conte et al., 2020). Based on the current results, a higher skill at a coordinative and cognitive level is related to a smaller reduction in speed when including the constraints of ball dribbling and the reaction to a stimulus compared to the base category (pre-planned and without ball).

Reduced levels of MV combined with high speed in an agility task can mean a high mastery of the skill and the achievement of a final stage of learning (Guimarães et al., 2020). In this scenario, we could expect the player to have achieved a high level of performance in the specific task and, therefore, a low capacity to further improve coordinative performance through that task, suggesting the need for task modifications to trigger new adaptations. The measurement of MV during training, combined with the assessment of outcome measures such as time to completion during an agility drill, can help us to infer a higher or lower trainability of the task (Dhawale et al., 2017; Seifert et al., 2013; Sternad, 2018).

We found a moderate negative correlation (r = -0.56) between the MV and the time spent to perform the task. This behaviour can be explained if we consider that faster movements require larger motor unit recruitment than slower movements. As a consequence, the measurement of faster movement patterns may have more "noise" and thus, more within-trial acceleration signal variability (Sutter et al., 2021; Wang et al., 2021).

Practical implications

In order to train the speed in change of direction tasks, it is often recommended to perform them without external constraints (i.e. pre-planned change of direction tasks) as it allows maximum speed to be achieved. However maximum speed training in these kind of agility tasks is unspecific and in turn insufficient to guarantee performance improvements when performing changes of direction specific to the target sport (i.e. with ball and reacting to a stimulus). For this reason, it is advisable to perform agility tasks with and without constraints during physical training.

The incorporation of constraints in the task decreases conditional performance and movement variability in different proportions depending on the athlete. Therefore, physical coaches should prioritize training with or without constraints depending on the needs of the athlete.

Physical coaches should aim to improve speed when using task constraints while maintaining or decreasing MV to achieve a higher level of performance in the agility action.

The reaction to the movement of other players in an agility task could be used as a cognitive constraint. In this case, the MV will be similar as there will be one or two response options available, so they can be used interchangeably.

The measurement of time and MV when performing the agility task can allow coaches to know the level of performance not only from the conditional side, but also from the perspective of motor control.

Limitations

A potential limitation of the study is that the MV was measured using the acceleration signal extracted from a single IMU placed at the center of mass. It is important to acknowledge that our understanding is that greater variability/irregularity in the acceleration signal taken at the subject's center of gravity with the IMU, may represent greater MV. In the future it would be interesting to expand the number of IMUs in different anatomical sites.”

Conclusions

Our findings demonstrate that increasing the difficulty of the agility task with the inclusion of the ball, and/or increasing the amount of information from the environment with the inclusion of a reaction to a stimulus, the subjects decreased MV and executed the response more slowly. Furthermore, the subjects employed similar MV and movement time in both, reacting to the movement of two testers with a single exit gate (R1) and reacting to the movement of one tester with two possible finishing gates (R2). Finally, there is a moderate negative relationship between movement time and entropy confirming that faster movements have more irregularity on the acceleration signal and thus more within-trial variability.

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Declaration of interest statement

The author report there are no competing interest to declare.

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Figure Captions

Figure 1. Graphical description of the football agility task.

Figure 2. Graphical description of the reaction possibilities (R) of the agility task. To the movement of two players with a single exit gate (R1) or to the movement of one player with two possible exit gates (R2).

Figure 3. Graphical example of the analysis of the signal using the magnet-based timing system methodology.

Figure 4. Synchronization of the magnetometer signal with the acceleration (ACELT) signal of the WIMU.

Figure 5. A) Ball; B) Reaction C) Type of reaction. *$p<0.01$; **$p>0.05$.

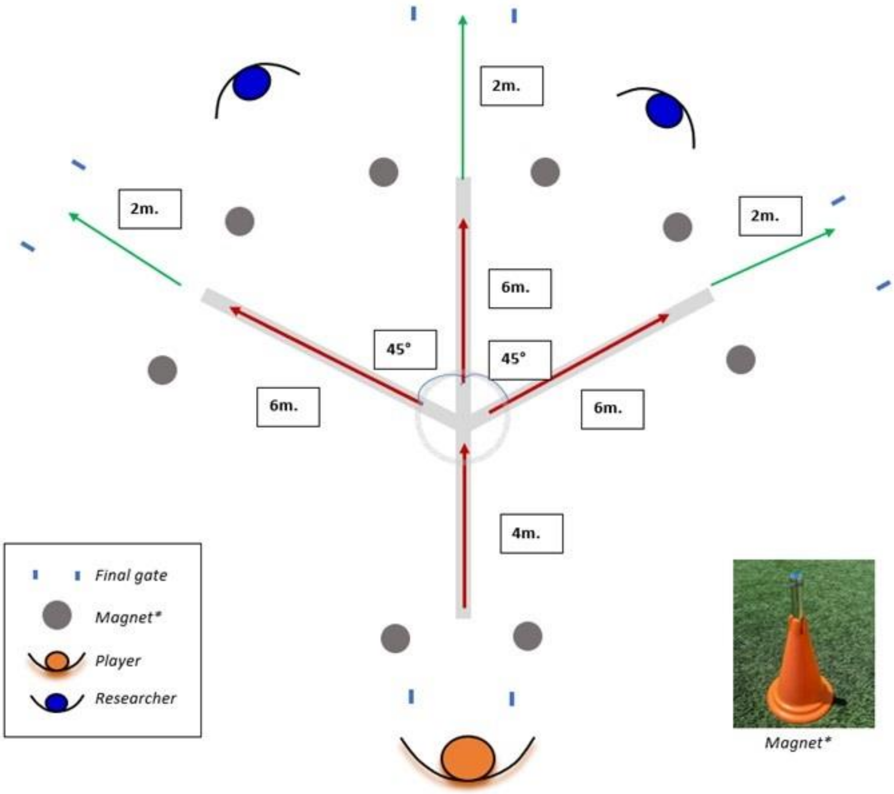
Figure 6. MV combining the inclusion or not of reaction with the inclusion or not of the ball; *$p<0.01$; **$p<0.05$.

Figure 7. MV combining the inclusion or not of reaction with the inclusion or not of the ball differentiating between R1 and R2; *$p<0.01$; **$p<0.05$

Figure 8. A) Ball; B) Reaction C) Type of reaction. *$p<0.01$.

Figure 9. Time combining the inclusion or not of reaction with the inclusion or not of the ball; *$p<0.01$; **$p<0.05$.

Figure 10. Time combining the inclusion or not of reaction with the inclusion or not of the ball differentiating between R1 and R2; *$p<0.01$.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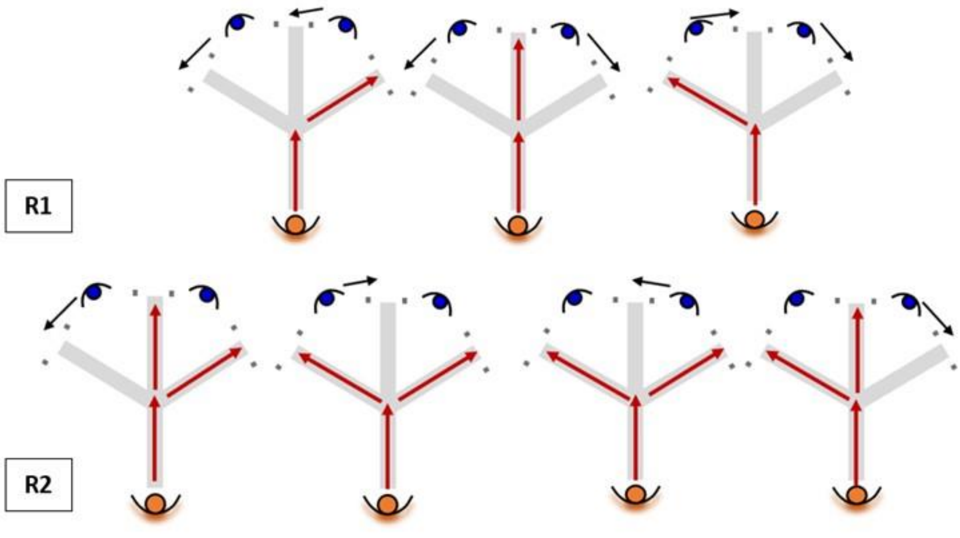
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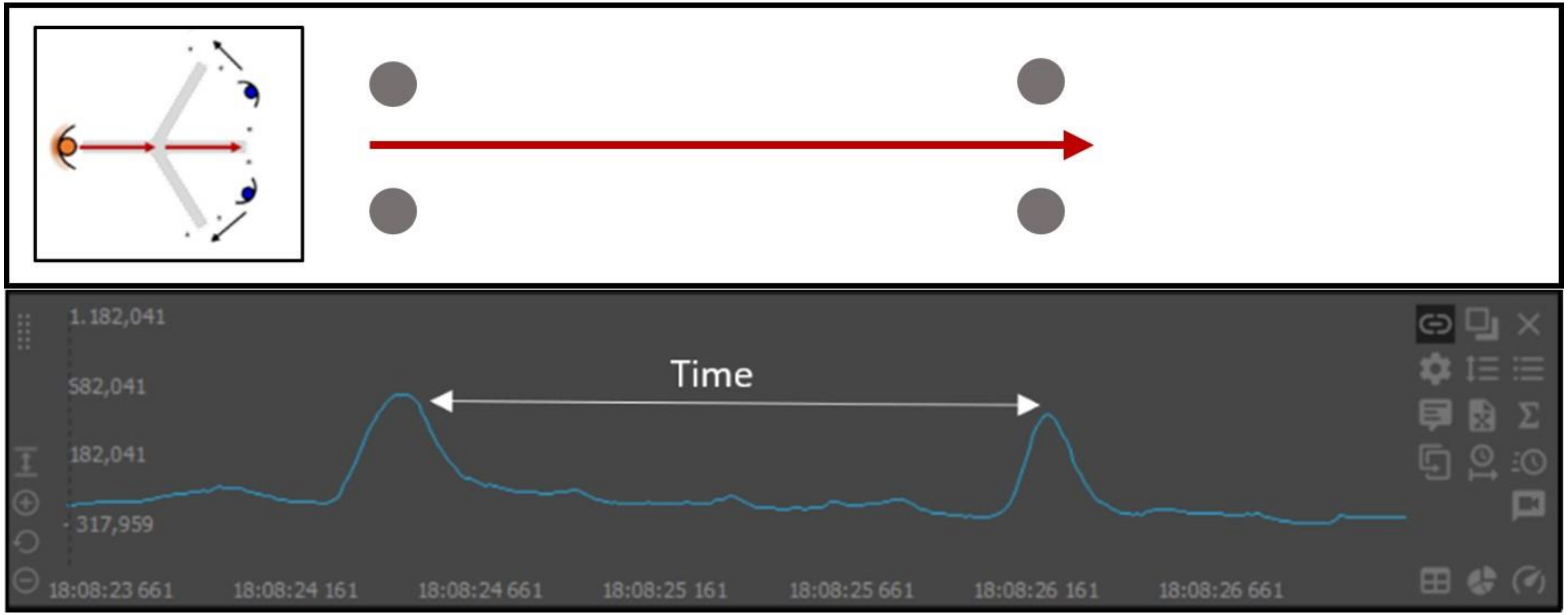
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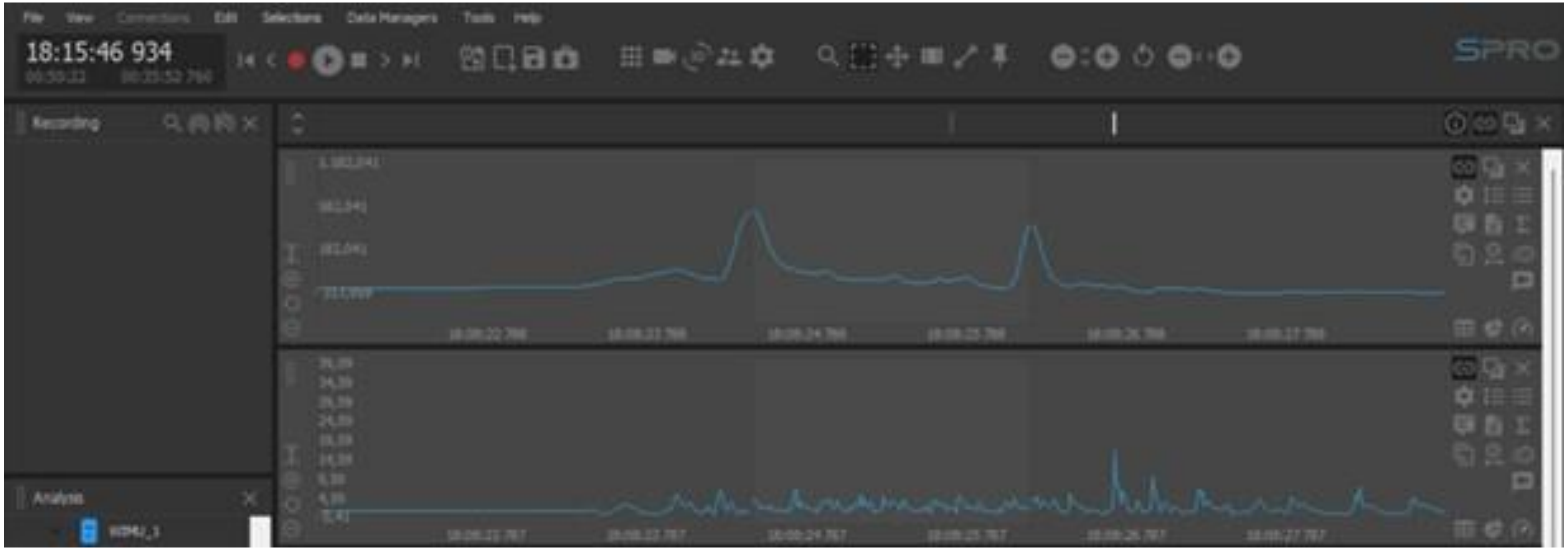

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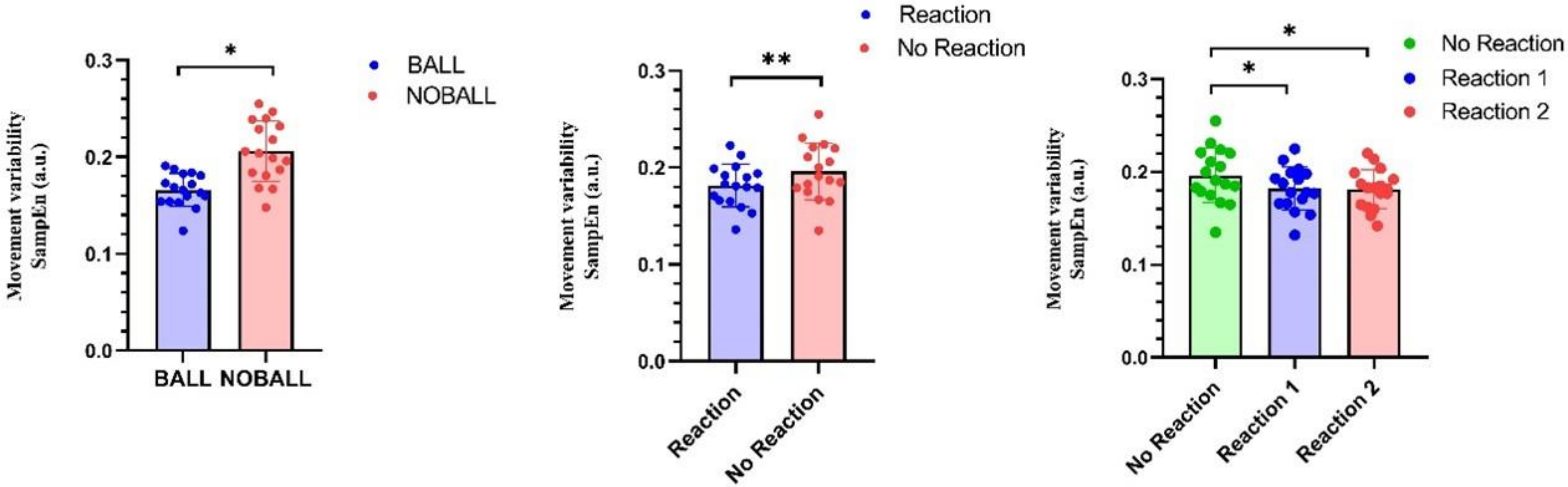

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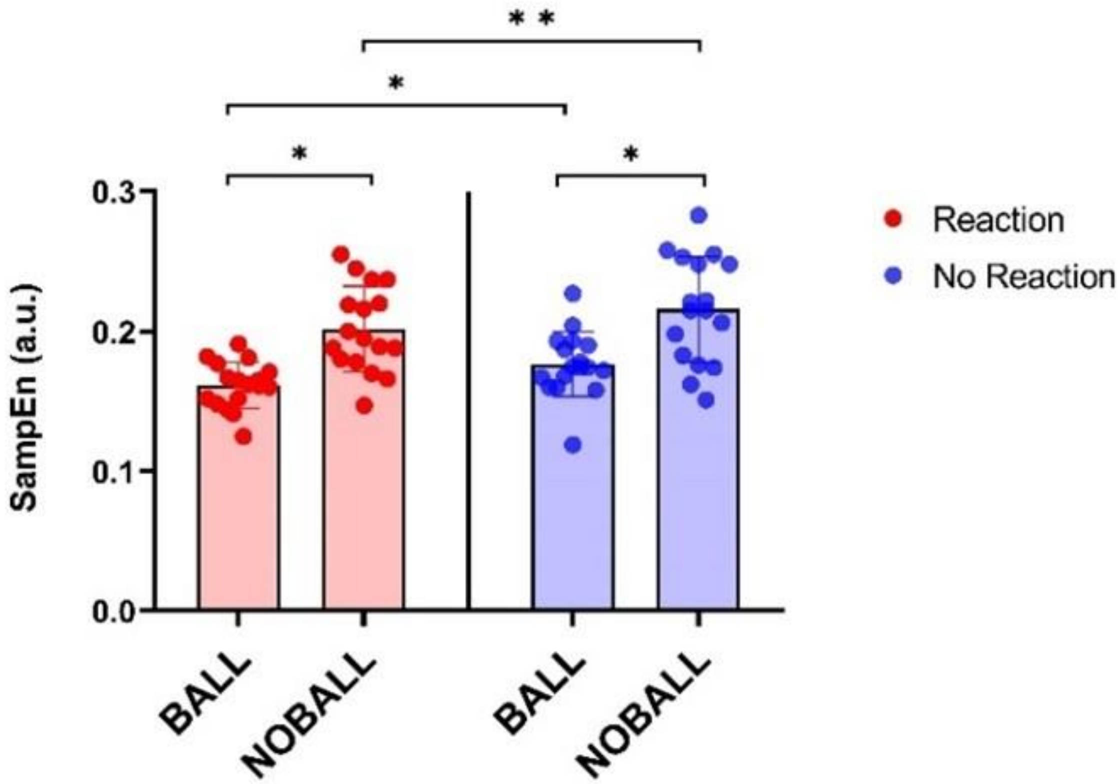
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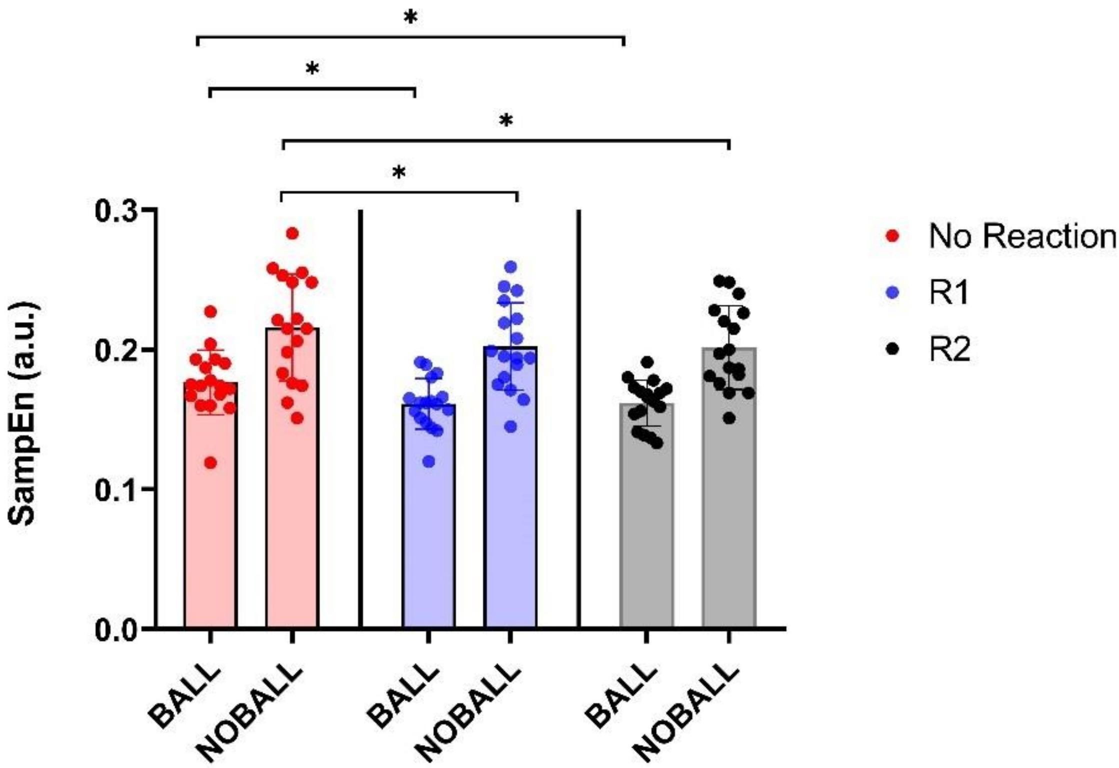

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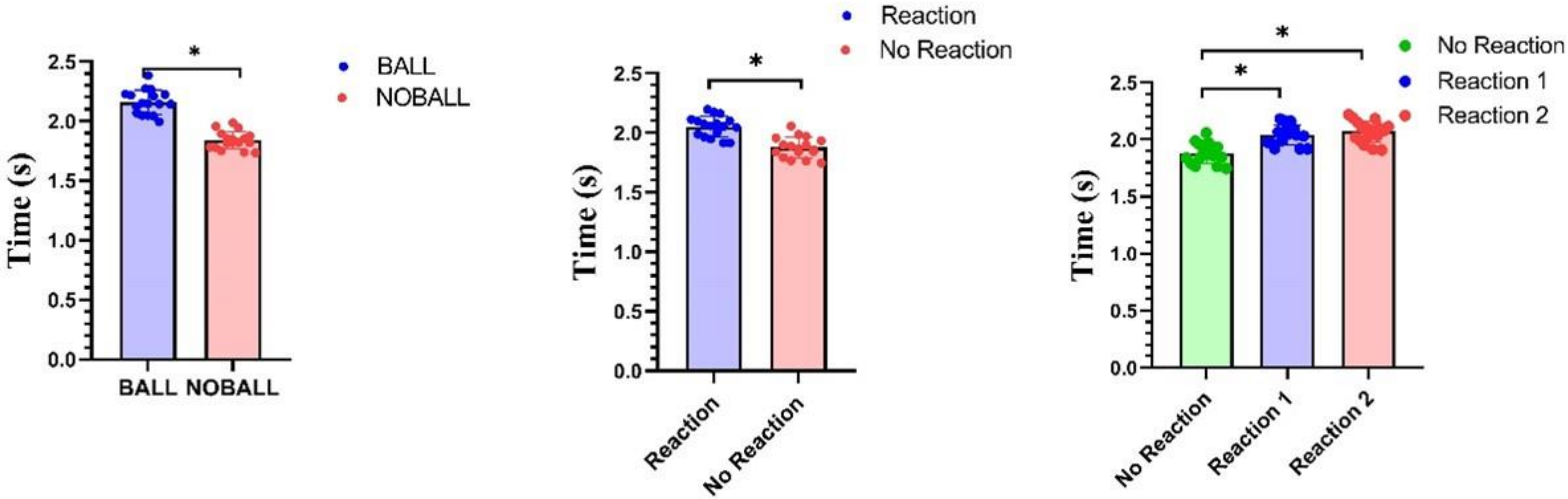

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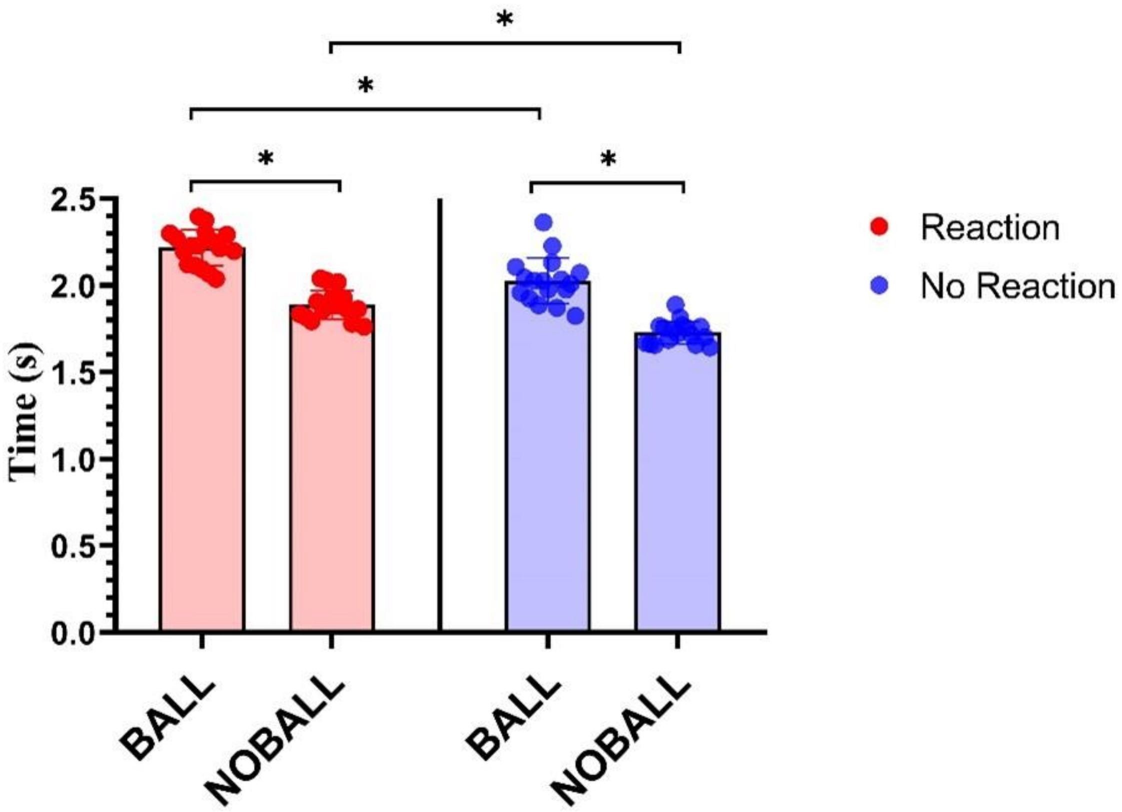

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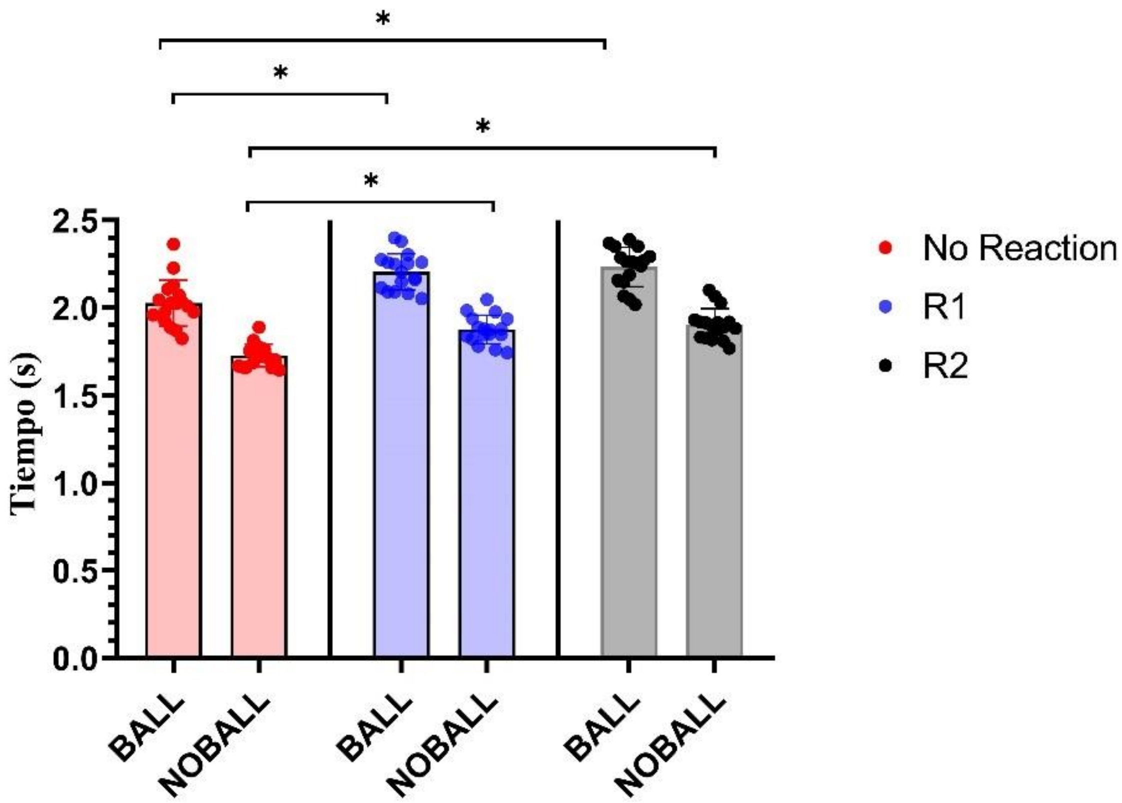

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