Components of attack response inhibition in fencing: Components of attack response inhibition in fencing

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Abstract

Applying the Go/No-Go paradigm to fencing, we investigated the relationship between the moment at which the No-Go signal appeared after a movement had been initiated and the time required by fencers to suppress the motor execution of a step-lunge. Secondarily, we determined a time threshold from which movement inhibition results in an error. The No-Go stimulus was represented by a real attack movement. 18 elite fencers and a fencing master were included in the study. Four force plates measured the horizontal components of the fencer's and master's reaction forces, which were used to calculate the time components of the attack and the response inhibition process. Also, the velocity and displacement of the master's and fencer's respective centres of mass were estimated using inverse dynamics. In all cases, cognitive inhibition processes were completed after the onset of movement. Movement time was calculated using four time components (muscle activation, muscle deactivation, transition and braking time). The results obtained revealed that cognitive processes were not significantly affected by the timing of the appearance of the No-Go signal. In contrast, movement time and its time components tended to decrease when the time delay between the No-Go stimulus and the onset of the fencer's movement increased. In conclusion, any attempt to withhold an attack movement when it has already started leads to an error that increases the risk of being hit by the opponent, especially when attack is inhibited within 150 ms after the movement has started.

Keywords: *Biomechanics, motor control, attention, perception of movement*

Highlights

- A novel biomechanics methodology has been used to determine the components of inhibition.
- Further studies that analyze reaction response to continous stimuli should be considered in testing reaction time.
- Trying to inhibit the attack, the risk of being hit increases within 150 ms after the movement has started.

Introduction

In most interactive sports, environmental changes force players to quickly switch from an intended action to a new action, which involves a reprogramming process that is generally time-dependent. Reprogramming processes involve a number of cognitive and motor processing stages such as quick detection and discrimination of environmental changes, strong inhibition of the incorrect response and adaptation to the changed environment (Nakamoto & Mori, 2012; Verburgh, Scherder, van Lange, & Oosterlaan, 2014). Furthermore, following Bianco, Di Russo, Perri, & Berchicci, 2017; Zhang, Ding, Wang, Qi, & Luo, 2015, using electrophysiological measures with high temporal resolution, during laboratory cognitive tasks, it is possible to draw conclusions about brain activity that might account for the behavioural performance. Accordingly, the expert fencers might develop a preparatory strategy, which involves high effort on both motor and cognitive preparation in order to maintain both efficient reactivity and accuracy during choice reaction tasks.

Thus, in changing environments, inhibition processes are essential to flexibility in response actions involving precise movements (Muggleton, Chen,

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Tzeng, Hung, & Juan, 2010; Texeira, Dos Santos, & Marília, 2005). Fencing is a good example of the crucial role that these cognitive processes have, since fencers have to switch from an intended action to a new one in response in extremely short times due to unexpected actions or feints from their opponent; thus the fencer is forced to correct his/her response through an intense process of inhibition (Borysiuk & Waskiewicz, 2008; Chan, Wong, Liu, Yu, & Yan, 2011; Di Russo, Taddei, Apnile, & Spinelli, 2006).

Despite extensive research, no conclusive evidence has been obtained demonstrating that world-class experts have better reaction times than novice players (Gutiérrez-Dávila, Rojas, Antonio, & Navarro, 2013b; Harmenberg, Ceci, Barvestad, Hjerpe, & Nyström, 1991; Mouelhi Guizani et al., 2006). However, it has been proven that expert fencers have better inhibition response rates than novice players (Chan et al., 2011; Di Russo et al., 2006). These results suggest that inhibition processes may play an important role in response inhibition in environments requiring a quick movement that generally results in an error. Thus, fencers' ability to react to their opponents' actions in real competition seems to be more closely related to inhibition processes than to response processing speed. Czajkowski (1998) hypothesized that many world-class fencers stand out for their precision rather than for the speed of their movements.

Response inhibition is a cognitive process that is occasionally evidenced by visible changes in motor execution. Response inhibition depends on Stimulus Onset Asynchrony (SOA), in other words, the delay from the onset of a planned movement to the beginning of the inhibition process. It has been proven that increased SOA reduces the probability of inhibiting a response action successfully before the movement begins (Ilmane & LaRue, 2011; Marinovic, Plooy, & Tresilian, 2009; Osman, Kornblum, & Meyer, 1986). Previous studies suggest that the time required to reprogramme a movement is equivalent to the visual reaction time (Boulinguez & Nougier, 1999; McLeod, 1987; Texeira et al., 2005). This was confirmed by Marinovic et al. (2009), who demonstrated that the minimum time required to inhibit an action aimed at hitting or catching a moving target must exceed 200 ms before the onset of the action.

This can be better understood using the time scheme shown in Figure 1: Two different SOA values were used in a Go/No-Go paradigm, where a fencer had to suppress an erroneous attack movement: *a*) low SOA values allowed the inhibition process ($RT_{NO\text{-}GO}$) to end before the movement started; and *b*) SOA values were too high and the directed action (RT_{GO}) started before the response inhibition process was completed. When SOA values exceed a threshold, the movement is executed as a result of muscle activation, and it is not withheld until the cognitive inhibition process concludes ($RT_{NO\text{-}GO}$); then, muscle deactivation begins in parallel with the activation of the antagonist muscles to withhold the movement. Considering that muscles cannot activate and deactivate simultaneously (Brown & Loeb, 2000; Neptune & Kautz, 2001), the time required to suppress a movement will be the result of adding the time needed to complete cognitive processes to the time required to deactivate the antagonist muscles, which depends on the tension reached at the moment at which inhibition processes finish. Further, completing the motor inhibition process requires stopping the movement executed during the period of muscle activation. Thus, after muscle activation, the muscles must be activated again to change the movement initiated.

It should be noted that the Go/No Go paradigm displayed in Figure 1 involves a range of sequential motor and cognitive stages, among others i.e. stimulus detection, processing and discrimination, selection of the appropriate response and response output or response inhibition (Di Russo et al., 2006; Rubia et al., 2001). In our study, with different methodology, we used this paradigm to determine the components of the inhibition process when an erroneous motor response has to be inhibited (see the experimental conditions shown in Figure 1b). Specifically, the goal of this study was to determine the effect that different SOA values have on the time required by elite fencers to withhold a step-lunge. The secondary goal was to investigate whether there is a time threshold above which fencer's attempt to halt an erroneous movement leads to an error. In contrast with previous studies using the Go/No Go paradigm in fencing (Di Russo et al., 2006; Rossi, Zani, Taddei, & Pesce, 1992), in our study we decided to create a situation similar to real competition where the No-Go signal was represented by an opponent's attack. Based on the facts exposed above, it was hypothesized that SOA values <200 ms would affect the motor execution of attack in fencing, thereby inducing the fencer to error.

Methods

Participants

18 elite fencers from the Spanish National Team of Sword Fencing, 9 men (age = 21.3 ± 2, years; height = 1.86 ± 0.05 m; mass = 82.3 ± 7.3 Kg) and 9 women (age = 21.3 ± 2.2, years; height = 1.73 ± 0.06 m; mass = 66.3 ± 9.6 Kg), and a professional fencing master. In accordance with the guidelines of the Ethics Committee of the University, informed consent was obtained from all participants.

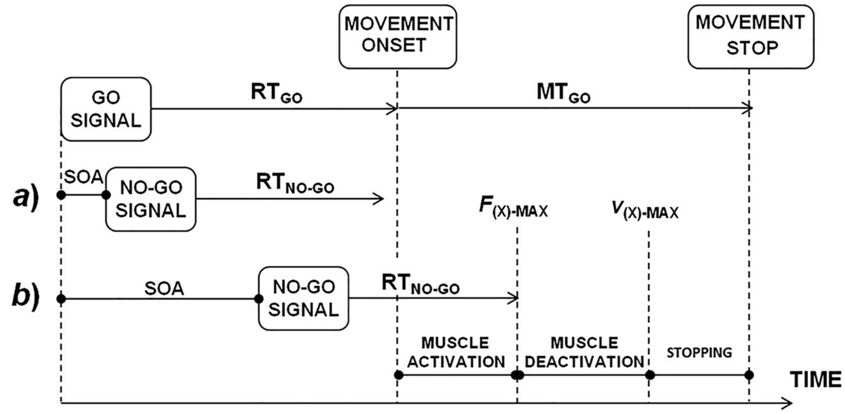

Figure 1. Figure of the countermand paradigm (Go/No-Go), with two different SOA values: *a*) when the inhibition process ($RT_{NO\text{-}GO}$) concludes before movement starts and *b*) when movement begins before the response inhibition process is completed.

Equipment and materials

The equipment included four Dinascan/IBV 0.6 × 0.37 m force plates (Instituto Biomecánica Valencia, Spain) adapted to a scaffold that served as the fencing piste. Two plates were placed under the fencer's feet in *en garde* position (A and B), whereas the other two plates were placed under the master's feet (C and D). The master was standing opposite to the fencer in en garde position with the first toe of the rear foot at a distance of 1.5 times his height from the geometric centre of the fencer's platform. The two 500 Hz-plates under each opponent's feet measured the horizontal components of the reaction force (F_{AX} y F_{BX} y F_{CX} y F_{DX}, respectively).

A Casio EX-FH20 video camera recorded the sagittal plane of motion at a 210 Hz frequency. The four plates were synchronized by an electronic signal that activated them simultaneously. At the same time, the electronic signal turned on a LED light which helped synchronize it with the plates. A LED light that was only visible for the opponent was installed at the mask lame bib of the fencer and the master. LED lights were turned on using an electronic system.

Experimental design of a countermanding paradigm

The Countermanding Paradigm is as follows: two conflicting signals (Go/No-Go) appear alternatively in what is known as Stimulus Onset Asynchrony (SOA). When the Go signal appears, the fencer has to perform an action as quickly as possible. When the No-Go signal is presented, the fencer has to change the action as fast as possible. The Go signal was represented by the LED light on the master's lame bib. When this light flashed, the fencer had to perform a direct attack and try to hit the master's plastron as fast as possible. The No-Go signal was represented by the onset of a step lunge by the master, defined as the point at which the net force of the horizontal component reached a value ≥ 1% of the master's body weight, as appropriate.

For the purposes of this study, we used different SOA values to determine their effect on the time required by the fencer to withhold a motor movement. SOA values were high enough for the lunge to start before cognitive inhibition processes were completed. Experimental control posed three problems: a) The change signal (No-Go) was represented by the onset of master's lunge, which was preceded by a variable reaction time (RT_{MASTER}); b) the fencer needed some time to reach the differential threshold or, in other words, to detect the just-noticeable difference (JND) of the attack movement (JND), which could also be variable; and c) the onset of the fencer's attack movement was preceded by a variable reaction time (RT_{GO}) too. Such variability (conscious or not) could allow that cognitive inhibition processes reached their target before or after the movement started.

To solve these problems, we used a repeated measures design, with the time interval between the onset of the master's movement (No-Go signal) and the onset of the fencer's movement (OM) as the independent variable. This time interval was defined as the interval between movement stimuli (ISM). To determine the OM, we used the moment at which the net force of the horizontal component (F_{AX} + F_{BX}) reached a value ≥ 1% of the fencer's body weight. Based on the Go/No-Go paradigm previously described, Figure 2 displays a ISM value calculated from the net force values of the horizontal component of the fencer ($F_{(X)\text{-FENCER}}$) and the master ($F_{(X)\text{-MASTER}}$), as measured in one of the trials. Considering the contributions by Marinovic et al. (2009) on the minimum time required to refrain a movement, ISM should be <200 ms to ensure that cognitive

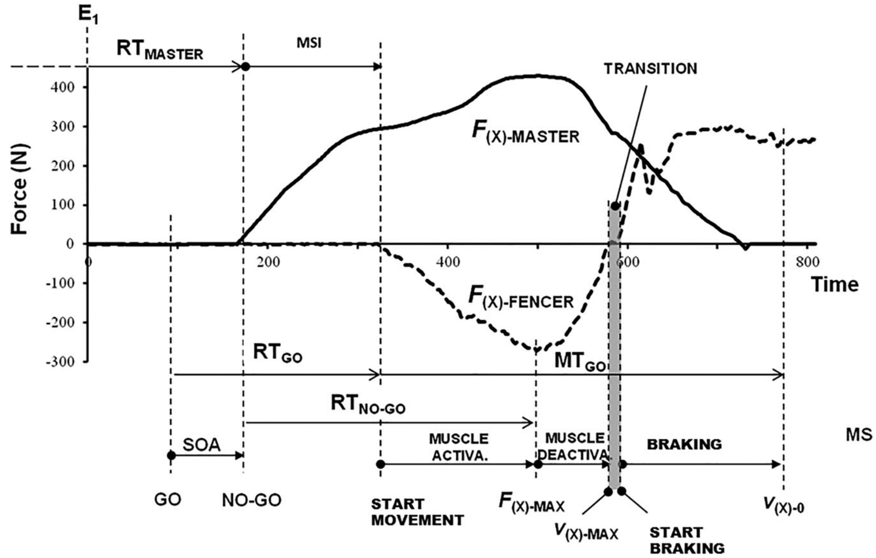

Figure 2. ISM value and horizontal component of the countermand process as calculated using the net force values of the horizontal component of the fencer ($F_{(X)\text{-}FENCER}$) and the master ($F_{(X)\text{-}MASTER}$), as measured in one of the trials.

inhibition processes ($RT_{NO\text{-}GO}$) are completed once a movement has started (OM). Thus, we established four intervals for the independent variable based on ISM values: A_1.–60 to 90 ms; A_2.–90 to 120 ms; A_3.–120 to 150 ms and A_4.–150 to 180 ms.

To determine the effect of changes in interval between movement stimuli (ISM) on reaction response time components, we measured the time required to complete the cognitive inhibition process ($RT_{NO\text{-}GO}$), defined as the time interval between the activation of the No-Go signal and the moment at which the net force of the horizontal component peaked ($F_{(X)\text{-}MAX}$). Fencer's movement time (MT_{GO}) was defined as the time interval between the onset of movement (OM) and the moment at which the velocity of the CM reaches the closest value to zero ($\boldsymbol{v}_{(X)\text{-}0}$). MT_{GO} was calculated by adding four time parameters: a) muscle activation time, (*Muscle activation*), the time interval between OM and $F_{(X)\text{-}MAX}$; b) Muscle deactivation time (*Muscle deactivation*), the time interval between $F_{(X)\text{-}MAX}$ and the moment at which the horizontal component of the CM speed peaked ($\boldsymbol{v}_{(X)\text{-}MAX}$); c) Movement inhibition time (*Braking*), the time interval between the moment at which the net force of the horizontal component is > 1% the fencer's weight (FW) and $\boldsymbol{v}_{(X)\text{-}0}$; d) A transition period generally occurs between ($v_{(X)\text{-}MAX}$) and FW (see Figure 2). As complementary data, we measured the time required by the fencer to raise his/her front foot from the floor (*Take-off time*).

Apart from the maximum force of the horizontal component ($F_{(X)\text{-}MAX}$), we also calculated the horizontal velocity and displacement of the fencer's center of mass (CM) using inverse dynamics. Thus, horizontal acceleration of the fencer's center of mass (CM) was calculated from the addition of the horizontal net forces measured by the two force plates ($F_{AX}+F_{BX}$) and from fencer's mass. Progressive horizontal velocities and displacements were calculated from the horizontal acceleration time values using trapezoidal integration. Based on this data, fencer's CM horizontal velocity and acceleration were calculated at the moment at which the horizontal force peaked ($\boldsymbol{v}_{(X)CM}\text{-}\boldsymbol{F}_{(X)\text{-}MAX}$ and $\boldsymbol{s}_{(X)CM}\text{-}\boldsymbol{F}_{(X)\text{-}MAX}$, respectively), and when the CM reached maximum velocity ($\boldsymbol{v}_{(X)CM\text{-}MAX}$ and $\boldsymbol{s}_{(X)CM\text{-}MAX}$, respectively).

Procedures

After a warm-up, the fencer and the master were asked to stand motionless in on guard position on the platform for a random time period until the LED on the fencer's mask lame bib flashed (E_1). Next, the master was instructed to execute a direct attack (straight thrust) to hit the fencer's chest as fast as possible. From E_1, the LED light on the master's lame bib flashed (Go signal) at five different time intervals (60, 90, 120, 150 and 180 ms); then, the fencer had to execute a direct attack to hit the fencer's chest as fast as possible. If the fencer perceived master's attack, s/he had to change his own attack as fast as possible to avoid being hit. Three trials were performed per interval; another five trials where the master did not execute any attack and the fencer completed his/her attack and hit the master's chest were performed. The time intervals at which LED lights flashed and the trials where the LED light on the fencer's mask lame bib did not flash were randomized. Before initiating measurements in each block of actions, the opponents performed several trials to become familiar with the experimental conditions.

The trial was considered non-valid: a) if the fencer's reaction time (RT_{GO}) was <100 ms; b) if the fencer did not start the movement, which was determined on the basis of the horizontal net force measured; c) if the fencer did not refrain the attack movement once s/he had started it; d)if the fencer placed his/her front foot out of the platform to execute the change. In all cases the trial was repeated in a randomized order. Finally, 32% of trials had to be repeated. In the situation where the master executed the attack (three per time interval), only 15 valid trials were performed by each fencer. Once the fencer had performed 15 valid trials, the onset time of master's and fencer's movements was determined (No-Go and OM, respectively) along with their respective time intervals (ISM). Finally, of all the trials performed by fencers in all experimental situations, we only considered the four trials where the ISM value obtained matched the median ISM for the intervals (60–90 ms; 90–120 ms; 120–150 ms and 150–180 ms).

Statistical analysis

Data are expressed as means (M) and standard deviation (SD) for each of the variables measured in the four experimental situations. Analysis of variance of repeated measured (ANOVA) was performed to determine whether there were statistically significant differences in the means obtained for the conditions taking into account the repetitions of each fencer. The level for acceptance of significance was set at 0.05. If a significant main effect was observed, least significant difference multiple-range tests determined where the differences occurred. Results were analysed using Statgraphics plus 5.1 software for Windows (STCS, Inc., Rockville, MD, USA).

Results

Table I displays a descriptive and inferential analysis of the time values obtained in the four experimental conditions (determined by the intervals of appearance of movement stimuli, (ISM). Clear differences were observed in the mean ISM values obtained for the four intervals. However, variations in ISM did no cause any statistically significant differences in cognitive process time parameters, which include fencer's reaction time (RT_{GO}) and the time required by the fencer to complete the inhibition process ($RT_{NO\text{-}GO}$). Conversely, statistically significant differences were found in mean movement time values; thus, when ISM was increased, fencer's attack movement time (MT_{GO}) tended to decline ($p < 0.001$). Multiple-range tests confirmed the existence of statistically significant differences between the four ISM intervals.

As in MT_{GO}, we observed that the means for Muscle activation time, Muscle deactivation time, transition time and braking time decreased significantly when ISM was increased ($p < 0.001$). Such correlation was confirmed by statistical hypothesis testing of muscle activation time, which included pairwise comparison of the three highest muscle activation intervals. In contrast, no statistically significant differences were observed between the intervals with two lowest ISM (60–90/90–120 ms). Pairwise comparison revealed statistically significant differences in muscle deactivation time (*Muscle deactivation*) among all ISM intervals, except when 90–120 and 120–150 ms were compared. The time required to withhold a movement *(Braking Time)* shows a similar tendency to that observed in muscle deactivation time *(Muscle deactivation)*. The short time interval between completion of muscle deactivation and the onset of movement inhibition (*Time transition*) shows the same general tendency, although no statistically significant differences were found on pairwise comparison of the lowest ISM intervals. Finally, Table I displays the time required by the fencer to raise his/her front foot from the floor (*take-off time*). No significant differences were observed between mean values for the three lowest ISM intervals. The highest ISM interval (150–180) was not considered, as most fencers were not able to raise their foot during trials with this time interval.

Table II shows the magnitude of the maximum horizontal force ($\boldsymbol{F}_{(X)\text{-MAX}}$) for the four ISM intervals. As expected, $\boldsymbol{F}_{(X)\text{-MAX}}$ decreased when ISM increased ($p < 0.001$). Significant differences between the means for maximum horizontal force were only obtained on pairwise comparison of the ISM interval 150–180 ms with the other intervals, and of 120–150 with 60–80 ms. In Table II are also shown the fencer's horizontal velocity and displacement at the moment at which the maximum horizontal force peaked ($\boldsymbol{v}_{(X)CM}$-$F_{(X)\text{-MAX}}$ and $\boldsymbol{s}_{(X)CM}$-$F_{(X)\text{-MAX}}$, respectively). It was confirmed that these values decreased when ISM increased ($p < 0.001$). Significant differences between mean values were observed on pairwise comparison of all ISM intervals. A similar tendency was observed in these variables at the moment at which the maximum horizontal velocity of the centre of mass was attained ($\boldsymbol{v}_{(X)CM}$-TM y $\boldsymbol{s}_{(X)CM}$-TM, respectively). However, no significant differences were found on pairwise comparison of 90–120/120–150 ms de IMO at this time point.

Table I. Descriptive and inferential statistics of time variables for the four experimental situations or intervals between movement stimuli (ISM).

Variables	ISM (60–90 ms)	ISM (90–120 ms)	ISM (120–150 ms)	ISM (150–180 ms)	F
ISM (ms) (Cond.)	78 ± 9	107 ± 7	137 ± 9	172 ± 8	443.5***
RT_{GO} (ms)	200 ± 32	203 ± 27	217 ± 20	207 ± 26	1.7
$RT_{NO\text{-}GO}$ (ms)	243 ± 37	257 ± 26	259 ± 38	260 ± 33	1.4
MT_{GO} (ms)	467 ± 59	364 ± 42[1]	311 ± 62[1,2]	230 ± 74[1,2,3]	66.9***
Time muscle activation (ms)	166 ± 39	150 ± 25	122 ± 34[1,2]	89 ± 32[1,2,3]	25.7***
Time muscle deactivation (ms)	100 ± 22	83 ± 17[1]	82 ± 18[1]	61 ± 17[1,2,3]	14.2***
Time transition (ms)	22 ± 21	25 ± 20	12 ± 13[2,1]	4 ± 6[1,2,3]	13.2***
Time braking (ms)	182 ± 51	107 ± 31[1]	95 ± 31[1]	76 ± 35[1,2,3]	41.7***
Time take-off (ms)	132 ± 29	130 ± 28	120 ± 28	–	2.1

[1,2,3,4]Indicate significant differences between the groups ($p < 0.05$).
***$p < 0.001$.

Discussion

It seems reasonable to deduce that the countermanding paradigm implies some uncertainty that does not only affect cognitive processes, but also the subsequent motor execution. According to this paradigm, the inhibition process would be based on two related mechanisms: a) stimulus control, by which errors are avoided by inhibiting response choice activation at spinal level; and b) conflict resolution, where the fencer chooses between continuing or inhibiting the attack. This second inhibitory mechanism occurs at higher cortical levels, which causes response delay (Duque, Lew, Mazzocchio, Olivier, & Ivry, 2010; Ivanoff, Branning, & Marois, 2009). Considering that uncertainty was present in the four experimental situations, no statistically significant differences were expected to be found in mean reaction times (RT_{GO}), which were similar to those reported by Gutiérrez-Dávila, et al.(2013a) and Gutiérrez-Dávila, Zingsem, Gutiérrez-Cruz, Giles, and Rojas (2014) using similar methods for situations of uncertainty.

The data obtained evidence that an increase in the interval of appearance of movement stimuli (ISM) has no effects on the time required to complete the cognitive inhibition process ($RT_{NO\text{-}GO}$), which was higher than the reaction time (RT_{GO}) in all experimental situations. The increase in $RT_{NO\text{-}GO}$ with respect to RT_{GO} might be related to the different stimuli used for measuring these two parameters. Thus, RT_{GO} was measured using a discrete visual signal as stimulus (activation of a LED light), whereas $RT_{NO\text{-}GO}$ was measured using the onset of the master's attack movement, which requires extra time to perceive the differential threshold or just-noticeable difference (JND). Although there is no data available on JND in fencing, general theories on signal detection suggest that JND might be related to receptor's attention, experience and sensitivity (Green & Swets, 1966; Wolf, Algom, & Lewin, 1988). On the other hand, $RT_{NO\text{-}GO}$ involves a motor phase of muscle activation (*Muscle Activation Time*). Muscle activation time tends to decrease when ISM increases ($p < 0.001$, see figure 2 and table I). This inverse relationship suggests that movement does not affect cognitive inhibition processes, which apparently take place in parallel with controlled and ballistic response processes and during movement execution, according to the Race Model proposed by Osman, Kornblum, and Meyer (1986) and Osman (1990). The results obtained in this study are supported by previous studies, as the

Table II. Descriptive and inferential statistics of intervals between movement stimuli (ISM) in maximum horizontal force attained during the movement-time and kinematic values of the CM when the maximum force is reached and when the motion-time concludes.

Variables	ISM *(60–90 ms)*	ISM *(90–120 ms)*	ISM *(120–150 ms)*	ISM *(150–180 ms)*	F
$F_{(X)\text{-MAX}}$ *(N)*	341 ± 94	311 ± 77	277 ± 71[1]	198 ± 91[1,2,3]	18.7***
$v_{(X)CM}$-$F_{(X)\text{-MAX}}$ *(m/s)*	0.44 ± 0.14	0.36 ± 0.12[1]	0.27 ± 0.12[1,2]	0.15 ± 0.11[1,2,3]	23.3***
$s_{(X)CM}$-$F_{(X)\text{-MAX}}$ *(m)*	0.029 ± 0.013	0.021 ± 0.011[1]	0.013 ± 0.009[1,2]	0.006 ± 0.006[1,2,3]	20.0***
$v_{(X)CM\text{-MAX}}$ *(m/s)*	0.71 ± 0.21	0.55 ± 0.16[1]	0.46 ± 0.17[1]	0.27 ± 0.18[1,2,3]	25.8***
$s_{(X)CM\text{-MAX}}$ *(m)*	0.088 ± 0.034	0.060 ± 0.025[1]	0.048 ± 0.027[1]	0.022 ± 0.019[1,2,3]	23.8***

[1,2,3,4]Indicate significant differences between the groups ($p < 0.05$).
***$p < 0.001$.

evidence that uncertainty as a result of the appearance of target switch inhibitory stimuli in fencing do not affect movement coordination (Borysiuk & Waskiewicz, 2008; Gutiérrez-Davila, Rojas, Antonio, & Navarro, 2013a; Gutiérrez-Dávila et al., 2014; Gutiérrez-Cruz, Rojas, & Gutiérrez-Dávila, 2015).

The procedural goal of this study was to cause changes in fencer's movement time (MT_{GO}), thus forcing different time intervals between the onset of the master's and the fencer's movement (ISM). The data obtained confirm that MT_{GO} decreases significantly with increased ISM ($p < 0.001$). This tendency persists in all its time components. Thus, muscle activation and deactivation tend to decline when the interval between movement stimuli (ISM) increases. However, the mean muscle deactivation time was lower as compared to the muscle activation time in the four experimental conditions. The cause might be the decreased velocity of the CM due to uncertainty during muscle activation (Gutiérrez-Davila et al., 2013a; Gutiérrez-Dávila et al., 2014); however, such uncertainty is suppressed when cognitive inhibition processes are completed ($F_{(X)\text{-MAX}}$), when the muscle deactivation period begins.

As it was mentioned above, to refrain an attack action, it is necessary to exert forces in the opposite direction to that of CM displacement, which occurs subsequently to the muscle deactivation period (see Figure 2). Nevertheless, to exert such opposite forces, it is necessary that the fencer's front foot is touching the floor, which only occurred in some trials of the 150–180 ISM situation. Thus, according to the data shown in Table I, when the ISM is <150 ms the take-off time of the front foot is lower than the time interval between the onset of movement and the end of muscle deactivation, which requires that the foot hits the floor again after having taking off. However, the low mean values obtained for the transition period (*Transition Time*) suggest that the foot strikes the floor during the muscle deactivation period.

Horizontal velocity and displacement of the fencer's centre of mass ($\boldsymbol{v}_{(X)CM}$-$F_{(X)\text{-MAX}}$ and $\boldsymbol{s}_{(X)CM}$-$F_{(X)\text{-MAX}}$, respectively) evidence that these variables decrease with increased ISM. Also, apart from the differences in time values described above, significant changes were observed in the kynematics of the CM for each experimental situation. The same tendency as in CM kynematics was observed at the moment at which the CM reaches maximum horizontal velocity ($\boldsymbol{v}_{(X)\text{-MAX}}$). This proves that when ISM decreases, the fencer has to increase his/her braking impulse to withhold the attack movement, and his/her CM will be closer to the opponent.

On the basis of the analysis presented, when the time interval between the onset of the master's and the fencer's movement (ISM) is below 150 ms, the mean time required to complete the GO/NO-GO process is higher than 528 ± 60 ms (RT_{GO}+MT_{GO}). This value is slightly higher as compared to that required by elite fencers to hit a fixed target at a distance similar to that used in this study (Gutiérrez-Davila et al., 2013a). Thus, trying to inhibit an attack movement when the ISM is <50 ms could be considered an error, since the fencer who starts the attack would have to move his/her CM forward trying to hit the opponent and simultaneously dodge the opponent's hit. In real competition, where the GO stimulus is represented by the opponent's movement, the time required to complete the GO/NO-GO process would be even higher, due to the time needed to perceive the just-noticeable difference (JND).

Conclusions

Most visual stimuli in interactive sports such as fencing are represented by opponent's movements. Thus, to start a motor response the time needed for the reaction process has to be added to the time needed to perceive the just-noticeable difference, which depends on receptor's attention, experience and sensitivity. Accordingly, the need for further studies that analyze reaction response to continuous stimuli and the level of expertise of fencers should be considered in the tests assessing reaction time to visual stimuli. Based on the results from the current study, when a fencer tries to withhold an attack movement when it has already started, s/he runs the risk of being hit by the opponent, a risk that increases within 150 ms after the movement has started when the fencer tries to inhibit the attack action by raising the front foot. Thus, fencer should prevent errors using a tactical process that increases the probabilities of success, this could be a useful criterion of efficacy in fencing.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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