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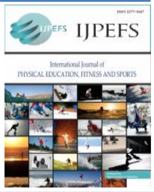

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# Can startle response magnitudes be used as a tool to predict sportive capacities? A comparative study between healthy young adults and athletes

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**Abstract:** The acoustic startle reflex (ASR) is an intense reaction that involves the contraction of muscle groups in response to an unexpected stimulus. We proposed that an ASR measurement may be used to select physical characteristics among healthy people, including athletes. To find the relationship between the ASR and physical conditioning level, we designed a study to perform ASR measurements, anthropometric measurements, neuromuscular conjugation exercises, strength test, and flexibility test. We studied young adults into 4 groups: male-control, male-athlete, female-control, and female-athlete. Our results showed how the startle amplitude was decreased in athletes compared with controls. In most of the anthropometric parameters, there were differences attending to gender in control groups, but these differences diminished in athletes. In addition, some fitness values were correlated with the latency of the muscle response and with the prepulse inhibition. This study demonstrates that regular practice of a sport, aside from causing changes in common fitness variables, also promotes changes in ASR parameters. In some way, the intense body training stimulates the brain reorganization to enhance some responses related to adapt the ASR. With this study, we are opening a field for those interested in finding out new instruments to discriminate athletes.

***Key Words:*** Prepulse Inhibition, Anthropometric Measurement, Bosco Tests, Neuromuscular Exercises, Biological Adaptations.

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i. Exercise, oxidative stress and risk of cardiovascular disease in the elderly. Protective role of antioxidant functional food.

ii. Role of S-adenosylmethionine on the hepatobiliary homeostasis of glutathione during cyclosporine a treatment.

iii. Increases in lipid peroxidation in rats chronically treated with cyclosporine A.

**Sebastian Hormigo,** gained his Ph.D. in Neuroscience at the University of Salamanca (Spain) in 2012. Shortly afterwards, he joined the Department of Neurobiology at Drexel University College of Medicine, in Philadelphia, where he has worked as a post-doctoral researcher first, and a research instructor currently. There, he

has been studying specific neural circuits and the generation of precise behavioral outcomes to help decipher how the brain operates under physiological conditions. He is participating in research projects granted by the National Institute of Neurological Disorders and Stroke, and the National Institute of Mental Health, and has authored several papers published in high-impact scientific journals.

## 1. Introduction

In sports science, there is a growing interest in the nature of the biological mechanisms that underlay the elite athlete. The nervous system provides specific signals, and the cellular machinery implements all of the genetic processes to generate permanent adaptive responses. Not only the type and the features of the training regulate these adaptations but also the individual characteristics. Age, sex, fitness level, and genetic predisposition determine the different individual responses among people facing the same training stimulus. The integration of multiple fields of science, in particular applied neurophysiology, will be required to elucidate the biological adaptation that occurs in response to a particular type of training. For this purpose, several tools are being developed based on neurophysiology findings to predict specific sports-related skills.

Reflexes are the first echelon of the movement. These actions are the simplest and are involuntary, and unchangeable when triggered; thus, they could be used as an internal standard to evaluate certain sports skills [1, 2]. Accordingly, reflex-based tools have been proposed as a cheap, easy, and efficient method to identify athletes.

In contrast, attention is a heterogeneous process that accompanies executive functions as well as selective attention, alertness, and vigilance [3]. Warning and surveillance are aspects of behavior and cognition that do not require any pre-selection or prioritization of stimuli [4], and they are considered non-selective attention and integrate concepts such as a state of alertness and arousal [4]. The startle reaction to a loud auditory stimulus is an example of non-selective attention phenomena [5] and thus is a good candidate for evaluation in athletes.

Specifically, the acoustic startle reflex (ASR) is a short and intense motor reaction that involves the contraction of a large number of muscle groups throughout the body in response to a loud and unexpected acoustic stimulus. In addition, the ASR has a vegetative component mediated by the autonomic nervous system, as is evident from the increase in blood pressure and heart rate [6, 7]. The ASR is a defensive reflex triggered by the brainstem against possible aggression or as an alert against unexpected events [8]; this reflex occurs in many species of mammals, including human beings. Measurement of the ASR and its various modulations is a tool increasingly used for its reliability, simplicity, and economy in the diagnosis of diseases, the control of their progression or the evaluation of the effectiveness of the treatments used [9].

One of the most interesting modifications of the ASR is prepulse inhibition (PPI). When the sound or noise that normally triggers the ASR is preceded (between 30 and 500 ms) by another sensory stimulus (visual, sound or touch), the response is less pronounced or even abolished (Figure 1.A) [10]. The PPI is directly related to sensory gating. This is a well-known process by which the brain adjusts its response to stimuli and is largely automatic. When one stimulus occurs, there is a response, but when it is followed by a second stimulus soon after, the response to the second stimulus is blunted [10]. This is an adaptive mechanism to prevent overstimulation, helping the brain to focus on a stimulus among a host of other distracters. The mechanism of sensory gating involves feed-forward and feed-back inhibition of the stimulus perceived. It requires GABA-ergic and -mediated inhibition of the pyramidal neurons in the CA3 region of the hippocampus [11, 12]. Sensory gating is thought to be disturbed in some psychiatric disorders such as schizophrenia [13], and its clinical evaluation to compare the evolution in pathology is currently increasing. As in patients, PPI should be evaluated in ordinary people not only for its simplicity to select skills but also for noting the neurophysiologic adaptations of the athlete to training.

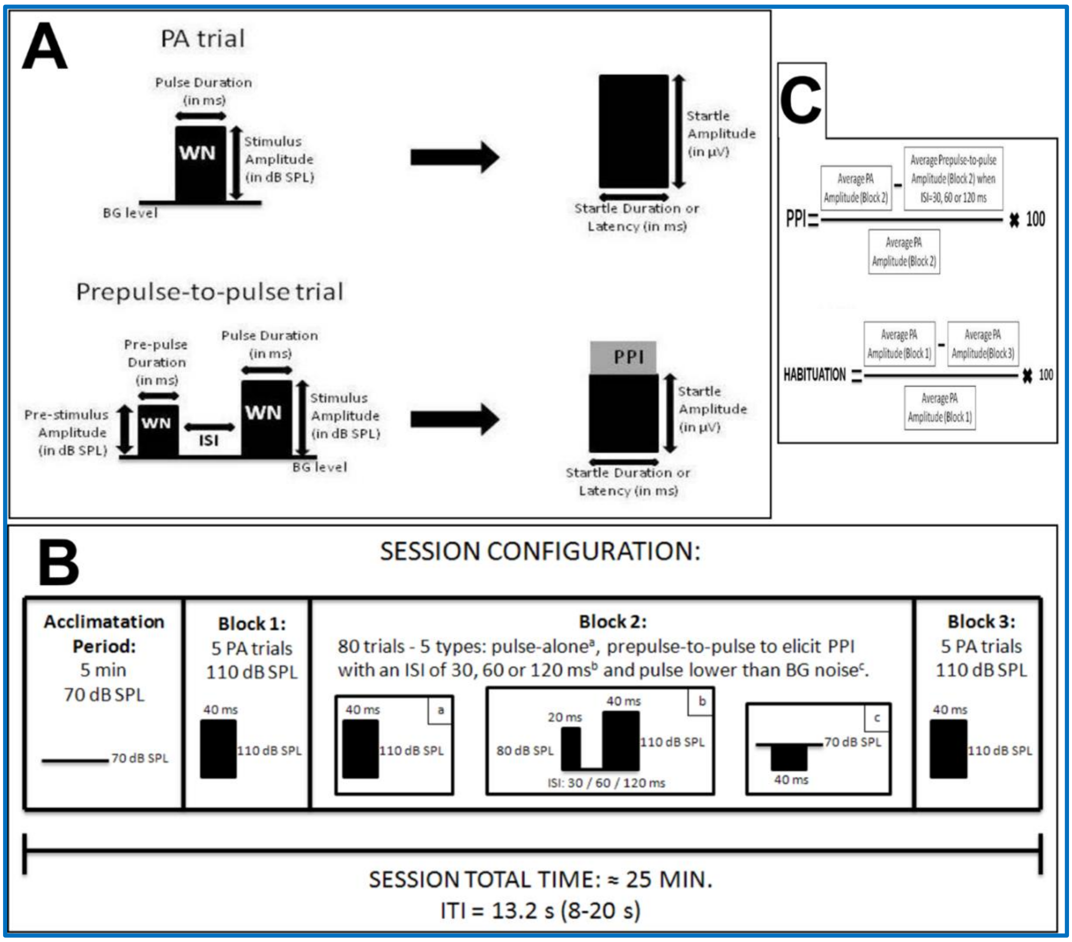


**Figure 1**. Startle reflex and prepulse inhibition: concepts and session. In A, representation of the responses when stimuli are presented to the subject. In B, startle measurement session configuration. In C, formula to reach the percentage of inhibition and formula to reach the percentage of habituation. Abbreviations: BG: background, constant during all session at 70 dB SPL. dB SPL: Decibel sound pressure level. ISI: inter-stimulus interval. ITI: inter-trial interval. ms: milliseconds. PA: pulse-alone. PPI: prepulse inhibition. WN: white noise. mV: millivolt.

Accordingly, we suggest the implementation of these tools (both the ASR and PPI) in selecting specific characteristics among healthy people, including athletes, to find any difference involving startle response magnitudes. Moreover, we will try to find correlations between physical characteristics and the ASR/PPI measurements to understand the mechanisms underlying the possible differences between groups, if any exist. To test this hypothesis, we designed a study in which human volunteers are tested for various physiological parameters: anthropometric measurements, neuromuscular conjugation exercises, strength test, flexibility test, and the startle reflex measurement. Using standard equipment, we will try to detect significant changes to develop a powerful tool that could be applied for selecting sportive capacities among young people.

## 2. Methods

### 2.1 Participants

We studied 34 young adults with a male / female ratio of 18/16, with mean ages of 22.8/20.6 years. We divided all of the human volunteers into 4 study groups: M-C (male-control group), M-A (male-athlete group), F-C (female-control group), and F-A (female-athlete group).

The general inclusion criteria were the age, and the absence of the following clinical manifestations during the latest year: loss of consciousness, lightheadedness, dizziness, insomnia, nervousness, paresthesia, weight loss, headaches, seizures, hyper / hypotension, arrhythmias, depression, stress, anxiety, neuropsychiatric disorders, ear infections, hearing loss, joint problems, chronic muscle pain, important strains, fractures, and no harmful habits -smoking, drug abuse, medication intake, and abuse of coffee or tea. In addition, all of the women were tested in the luteal phase of the menstrual cycle (data collected based on their last menstruation, its duration, and its periodicity) since hormonal changes during the cycle may give variations in the results of the startle tests.

All of the measurements were conducted in the afternoon to minimize the effect of intra / inter subject circadian rhythms. Specifically, for inclusion in the M-A and F-A groups, each person was required to have performed a minimum of 10 hours of training a week for the last 2 years in a mixed sport (strength and endurance training), in this case, indoor running athletics.

The study meets the ethical standards laid down in the 1964 Declaration of Helsinki and it was approved by the University of Salamanca Ethics Committee. All of the participants gave written informed consent.

## 2.2 Startle Response Measurement

A commercial human startle response monitoring system (EMG Human Startle-SR Lab, San Diego, CA, USA) was used for the acoustic startle stimuli and for recording electromyographic (EMG) activity from the onset of the stimulus. The stimuli were presented to the participants binaurally through Sony MDR-V6 headphones (SONY Electronics Inc., San Diego, CA, USA) while they were sitting in a moderately lit soundproof room. The eye blink component of the startle response was indexed by recording the EMG activity of the orbicularis oculi muscle by positioning two miniature silver/silver chloride electrodes filled with electrolyte paste directly beneath the right eye. The ground electrode was attached to the mastoid muscle behind the right ear. The EMG signal amplification gain control was kept constant for all of the participants, and the recorded EMG activity was band-pass filtered to eliminate interference (50 Hz, as recommended by the SR Lab). The EMG data were scored off-line using the analytic program of this system for the response amplitude (mV), and for the latency (ms) of the response peak, which was determined as the point of maximal amplitude that occurred within 120 ms from the startling stimulus.

## 2.3 Experimental session

The pulse-alone stimulus was a 40 ms presentation of 110 decibels sound pressure level (dB SPL) white noise, and the prepulse stimulus was a 20 ms presentation of 85 dB SPL white noise. The session began with a 5 min acclimatization period consisting of 70 dB SPL continuous white noise, which was maintained along the session. Participants received 60 startle stimuli in three blocks: the initial pulse-alone trial block, the eliciting PPI trial block, and the final pulse-alone trial block. There was a range of prepulse to pulse intervals (prepulse onset to pulse onset), also known as the inter-stimulus interval (ISI), to elicit the PPI (30, 60, and 120 ms). This block consisted of 15 pulse-alone trials and 15 prepulse-to pulse trials; the intervals were presented to the participants in a pseudorandom order with a mean inter-trial interval (ITI) of 13.2 s (range: 8–20 s). The session lasted approximately 25 min. The participants were not given any specific instructions (Figure 1.B and C) [14].

## 2.4 Anthropometric Measurements

Using standard clinical equipment such as the weigh scale, the skinfold caliper (Holtain-Caliper, UK), short and long branch calipers (to measure distances), and skin pencils, and following the ISAK guidelines [15], we measured the following values: weight; height; skinfolds (tricipital, subscapular, pectoral, ileocrestal, supraspinal, abdominal, mid-thigh, and mid-leg); diameters (humeral biepicondylar, wrist bistyloid, and femoral bicondylar); and perimeters (arm in maximum contraction, waist, hip, mid-thigh, and mid-leg). With these values, we could determine body mass index (BMI), and somatotype (endomorphy, mesomorphy, and ectomorphy indexes).

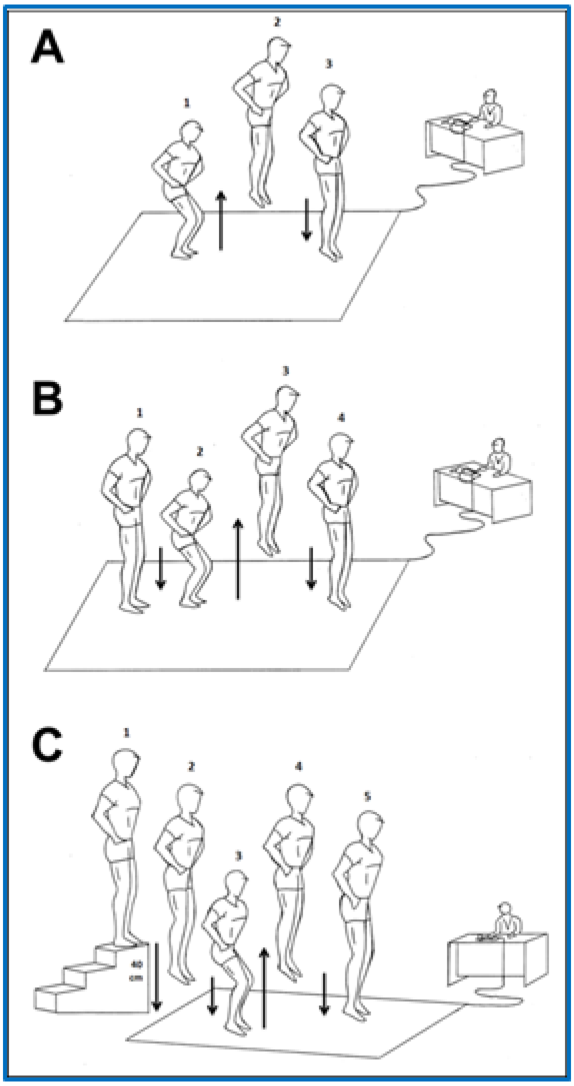


**Figure 2**. Bosco tests schematic drawings. In A, Squat Jump performed. In B, Counter Movement Jump performed. In C, Drop Jump performed.

## *2.5 Bosco Tests*

A commercial jump tester (ERGO-JUMP Plus BOSCO SYSTEM® Byomedic, S.C.P., Barcelona, Spain) was used to assess the neuromuscular capacity of the participants. This system consists of several sensors fixed in a base on which jumps are performed. The data captured from taking off to landing are sent to a computer where different parameters will be processed. These parameters are the time of the flight, the height of the jump, and potency output. The types of jumps we used in the Bosco tests were the "squat jump" (it can evaluate the explosive power of lower limbs by recording the height achieved by the subject), the "counter movement jump" (it includes assessing the involvement of the elastic elements and the subsequent reuse of elastic energy required in the action), and the "drop jump" (the subject must perform a vertical jumping action after a fall from a 40 cm step; at the time of contact with the base ground, the subject must cushion the fall by an eccentric contraction in which elastic energy is stored and reused later in the following concentric contraction) (Figure 2) [16-18].

## *2.6 Strength and Flexibility tests*

We employed a calibrated manual dynamometer (Sammons Preston Rolyan, Bolingbrook, IL, USA) to test the grip strength of the hand during a maximum pressing that was maintained for 5 seconds. The participants performed the grip strength test first with the dominant hand, and later with the non-dominant hand. They repeated this test 3 times, and we calculated the mean value.

To measure the flexibility ("seat and reach test") of the posterior muscular chain, we used a special box whose horizontal upper side is calibrated in millimeters. The subject sat on the floor, supported the soles of the feet in the vertical part of the box, and maintained the knees blocked in extension with the popliteal cavity in contact with the floor. Then, the subject stretched the whole posterior chain and simultaneously moved both hands along a calibrated ruler on the side of the box. The participants repeated this test 3 times, and we calculated the mean value.

## *2.7 Statistical analysis*

The data are reported as the means ± SEM. Various experimental conditions were compared by a t-test and ANOVA (the Bonferroni test was used for post hoc comparisons). The Pearson test was utilized to find general correlations among independent variables. The statistical package we employed was PASW Statistics 18.0.0 (SPSS Inc., Chicago, IL, USA). Statistical significance was accepted at $p < 0.05$.

## 3. Results

We studied a total of 22 variables in each volunteer. From the anthropometric measurements, we calculated the following: body mass index (B.M.I.; kg/m$^2$), endomorphy index, mesomorphy index, and ectomorphy index. The flight time (ms) and the jump height (cm) were determined from the three Bosco tests. Moreover, we quantified the potency output (W/kg) of the drop jump test. Then, we measured strength (kg) and flexibility (cm). For the startle response measurement, we determined the following parameters: average of the startle amplitude (mV), latency (ms), and percentage of habituation. We also obtained the percentage of the prepulse inhibition (PPI) when ISI = 30 ms, 60 ms, and 120 ms, and their specific latencies.

### *3.1 Anthropometric Measurements*

The B.M.I. was 26.18 ± 1.65 for the M-C group, 22.52 ± 0.34 for the F-C group, 23.98 ± 0.27 for the M-A group, and 21.49 ± 0.86 for the F-A group. There was no significant difference related to whether the participants were athletes ($p = 0.150$), although there was a difference corresponding to gender: the men have a higher index ($p = 0.008$). The results found in the other indexes are shown in Figure 3.A. In summary, the endomorphy index was higher in the controls than in the athletes, with significant differences ($p = 0.003$). The men had a higher mesomorphy index than the women ($p < 0.001$) in both the control and the athlete groups. For the ectomorphy index, the women have a higher degree, and the athletes showed a higher index than the controls, but the differences were not significant.

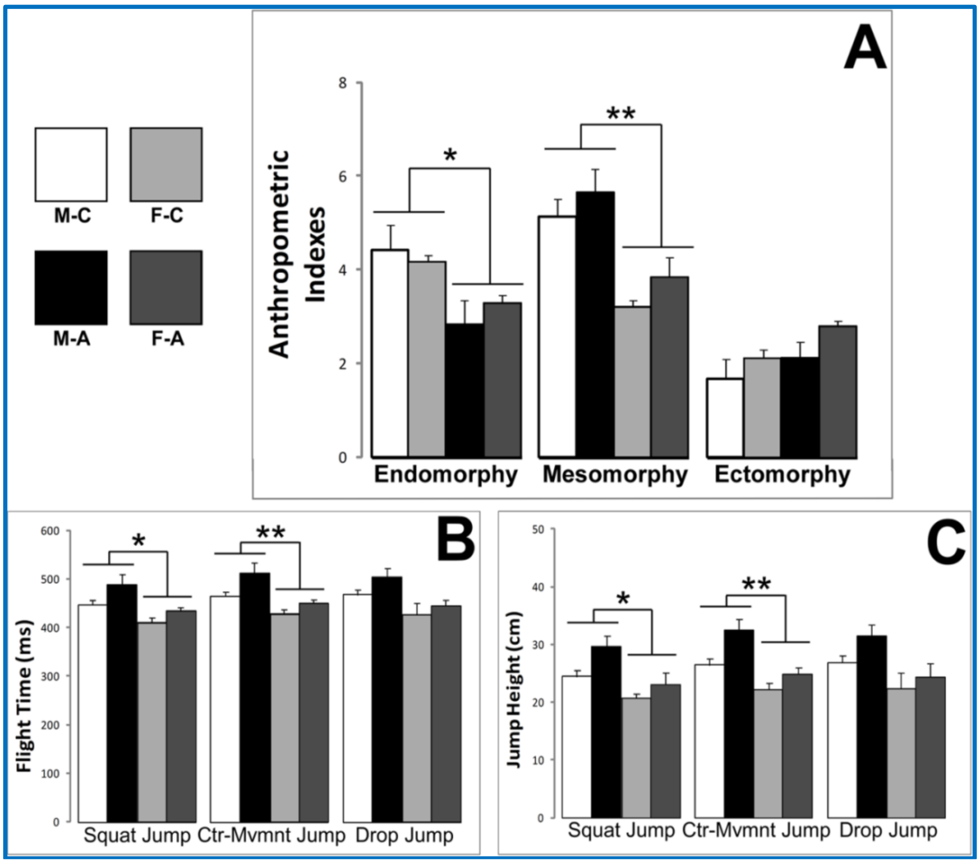


**Figure 3.** Physical conditioning measurements. In A, anthropometric indexes with non-dimensional units. Controls exhibited higher endomorphy index compared to athletes (*$p = 0.003$); and females showed lower mesomorphy index compared to males (**$p < 0.001$). In B, a representation of the flight time of the three tests used. There are statistical differences with athletes exhibiting results greater than controls (*$p = 0.036$; **$p = 0.040$). In C, a representation of the jump height of the three tests used. There are statistical differences with athletes exhibiting results greater than controls (*$p = 0.035$; **$p = 0.028$). Abbreviations: Ctr-Mvmnt: counter-movement jump. M-C: male-control group. F-C: female-control group. M-A: male-athlete group. F-A: female athlete group. Bars represent means ± SEM.

**Table 1**. Strength and Flexibility measurements for the 4 different groups.

| | Strength test | Flexibility test |
|---|---|---|
| M-C | 41.44 ± 2.77 | 11.75 ± 2.09 |
| F-C | 26.31 ± 1.34 | 15.87 ± 2.84 |
| M-A | 45.92 ± 1.55 | 18.85 ± 4.15 |
| F-A | 32.94 ± 0.89 | 19.56 ± 4.95 |

Footnote: Values are means ± SEM. See METHODS for calculations. The difference between athletes and controls is consistent in both tests. M-C: male-control group. F-C: female-control group. M-A: male-athlete group. F-A: female athlete group.

### 3.2 Bosco Tests

In the results from the squat jump, we found significant differences in both the flight time and jump height measurements between the athlete group compared with the control group ($p = 0.036$ and $p = 0.035$, respectively) (Figure 3.B and C). In the results from the counter movement jump, we found significant differences in both the flight time and the jump height measurements; the athlete groups and the men had increased values ($p = 0.040$ and $p = 0.005$, respectively, for the flight time, and $p = 0.028$ and $p = 0.004$, respectively, for the jump height) (Figure 3.B and C). In the results from the drop jump, we found significant differences corresponding to gender; the men had higher values in general in the flight time ($p = 0.006$), and in the jump height ($p = 0.006$) (Figure 3.B and C). For the potency output, we found differences related to gender; the men had higher values in general ($p = 0.003$). For the potency output, the athletes have increased values as well ($p = 0.034$).

### 3.3 Strength and Flexibility tests

The results from the grip strength of the hand showed significant differences related to gender; the men have more strength ($p < 0.001$). The athletes have more grip strength than the control volunteers ($p = 0.011$) (Table 1).

In the results from the flexibility of the posterior muscular chain test, we did not find any significant difference. This lack of difference in flexibility is most likely caused by the insufficient number of cases studied because there are some statistical tendencies (Table 1).

### 3.4 Startle Response Measurement

The startle amplitude was significantly lower in the athletes than in the control volunteers ($p = 0.026$). However, we did not find any significant difference corresponding to gender ($p = 0.631$); the women and the men had similar startle amplitudes (Figure 4.A). The latency of the startle response was also lower in the athletes, but we only found a statistical significance between the male-athlete group compared with the male-control group ($p = 0.033$) (Figure 4.B). For the habituation of the startle reflex, the men had a higher habituation than the women in the control groups, with significant differences ($p = 0.015$). Moreover, the athletes had the same degree of habituation, without gender differences. In addition, there was a significant interaction ($p = 0.015$): the control groups had significant differences between the women and the men ($p = 0.001$), which did not occur in the groups of athletes ($p = 0.963$), and while there was no difference between the control women vs. the female athletes, there was a difference in the men ($p = 0.038$). Among the men, there was a "reduction" in the habituation of the athlete group compared to the controls, but this effect did not exist among the women in the same way ($p = 0.126$). Therefore, the habituation was seen in men but not in women (Figure 4.C).

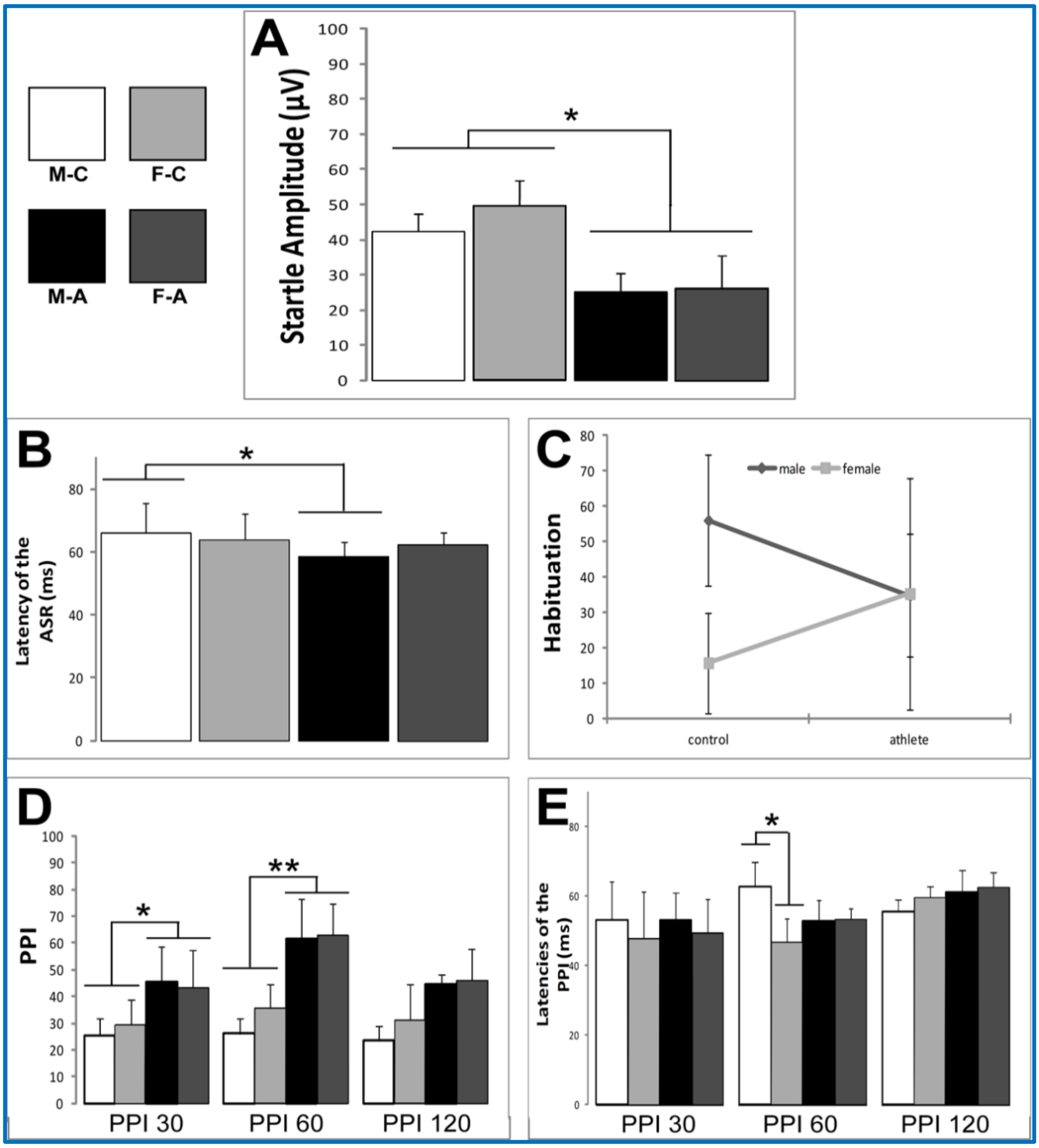


**Figure 4**. Startle reflex parameters. In A, mean values for the startle amplitude. Control groups have an increased response compared to athlete groups (*p = 0.026). In B, values for the latencies of the startle in all experimental groups. There is a statistical significance between the male athlete group vs. the male control group during the PA trials (*p = 0.033) with controls exhibiting longer response duration. In C, habituation responses. Notice how athlete groups tend to centralize vs. control. There is a statistical difference between the female control group and the male control group (p = 0.015). In D, prepulse inhibition. Percentage of inhibition of the startle attending to the three prepulse-to-pulse inter-stimulus interval performed. Notice how athlete groups have a greater inhibition comparing to the control groups, mainly when ISI was 30 ms (*p = 0.022) and 60 ms (**p < 0.001). PPI30: inhibition when ISI was 30 ms. PPI60: inhibition when ISI was 60 ms. PPI120: inhibition when ISI was 120 ms. In E, values for the latencies of the PPI in all experimental groups. There is a statistical significance between the male control group when ISI was 60 ms (**p = 0.030) with females presenting a shorter response latency. Abbreviations: M-C: male-control group. F-C: female-control group. M-A: male-athlete group. F-A: female athlete group. Bars represent means ± SEM.

### 3.5 Prepulse inhibition measurements

The PPI calculated for the three ISI studied (30, 60 and 120 ms) were higher for the athlete groups, with a maximum difference compared to the control groups when the ISI = 60 ms ($p < 0.001$). There was also a significant difference when the ISI = 30 ms ($p = 0.022$) (Figure 4.D). The latencies for the PPI only discriminate the control men from the women when the ISI = 60 ms; the women exhibited lower latency than the men ($p = 0.030$) (Figure 4.E).

Eventually, we performed linear correlation tests involving all of the participants to detect any relationship between the independent variables. These tests were a method of screening to determine whether there were simple connections between the startle measurement and any of the other parameters measured. We discovered a statistical correlation with a negative slope between the startle amplitude and the ectomorphy index ($r = -0.391$; $p = 0.033$). Additionally, we discovered relations between the latency of the PPI 30 with the flight time of the counter movement jump ($r = 0.372$; $p = 0.047$), with the flight time of the drop jump ($r = 0.370$; $p = 0.048$), and with the jump height of the drop jump ($r = 0.371$; $p = 0.047$). There are also bidirectional relations between inhibition responses: the PPI 30 with the PPI 60 ($r = 0.644$; $p < 0.001$), with the PPI 120 ($r = 0.508$; $p = 0.005$), with the flight time of the squat jump ($r = 0.42$; $p = 0.023$), with the jump height of the squat jump ($r = 0.404$; $p = 0.030$), with the strength test ($r = 0.371$; $p = 0.047$), and finally, with the flexibility test ($r = 0.449$; $p = 0.015$). Moreover, there are statistical correlations of the PPI 60 with the PPI 120 ($r = 0.692$; $p < 0.001$), with the flight time of the squat jump ($r = 0.405$; $p = 0.029$), with the jump height of the squat jump ($r = 0.395$; $p = 0.034$), and with the flight time of the counter movement jump ($r = 0.373$; $p = 0.046$). Finally, we noticed a relation between the habituation response and the B.M.I. ($r = 0.411$; $p = 0.027$).

## 4. Discussion

Our study has shown that the startle amplitude is decreased in athletes when compared to controls. The fitness values were higher in the athlete groups compared to the controls. In addition, for most of the physical characteristics studied, there were differences between the men and women in the control group, but these gender differences tended to diminish in both male and female athletes, reaching almost the same values.

### 4.1 Methodological discussion

In humans, muscle activity has been studied to measure reflexes in different muscles all over the body. There are large variations in the response from one muscle to another, both in healthy individuals and those that have some type of pathology. A particular situation related to the startle response is the orbicularis oculi muscle, in which there are both the blink reflex (a brainstem reflex for eye protection that is not part of the startle reflex) and the ASR response. The electromyographic recording analysis of the activity in this muscle allows both reflexes to be discriminated. In the majority of the records there are two peaks of maximum amplitude after application of an acoustic stimulus: the first corresponds to the blink reflex itself, and the second corresponds to the palpebral component of the ASR [19]. Thus, an off-line analysis of the recording is necessary to prevent errors in the calculations of the startle parameters; therefore, this analysis makes the measurement very reliable.

The ASR is the measure most used to study the involuntary reaction to a stimulus. The modulation of the startle response represents a cross-species non-invasive psychophysiological model, which is widely applied to evaluate information processing and emotional deficits in a wide variety of human and animal populations [9, 20]. Variations in the startle measurement demonstrate forms of plasticity, including habituation, and pre-pulse inhibition [20]. Because the habituation is a form of non-associative learning [21], we chose to perform the measures to quantify the difference among athletes, who are supposed to be trained to focus on and perform a specific task, and non-athlete volunteers. The PPI is thought to reflect reduced processing of incoming information while processing of the initial stimulus is still ongoing [22]. Thus, we used this measurement to objectify the sensory filtering among the groups.

We chose to measure anthropometric variables, the Bosco test, the strength test, and the flexibility test because they are highly contrasted and validated tools. These measurements are used in a multitude of trials to evaluate different capabilities and physiological variables to characterize the athlete.

Within the classifications of the human being by the physical shape, the somatotype is the most descriptive evaluation tool. The somatotype is the morphological conformation related to three interrelated components. Endomorphy is the tendency for accumulating fat mass; mesomorphy is the degree of muscle-skeletal development associated with size; and ectomorphy is related to the linearity of the body [23]. Therefore, we can define the somatotype as the quantification of the three primary components of the human body that configure the morphology of the subject, expressed in three digits [24,25]. Thus, the evaluation of the somatotype provides a numerical measure of the physical conditioning level of the subject, and we can use these numbers to connect the morphological conformation with the startle parameters.

Furthermore, the data obtained from the measurement system for the vertical jumps or the Bosco tests are used as a very effective tool to determine the strength and the neuromuscular condition of each subject in an easy and simple method [16 - 18]. When this set of tests is performed, the strength and neuromuscular condition are calculated analytically and separate the various individual components that underlie the complex physiological phenomena involved in the adaptation process. The implementation is conceptually simple but scientifically defined [16, 26]. Thus, the Bosco tests are a good candidate for evaluation alongside the startle parameters for quantifying the modification of the standard reflexes by the regular practice of a sport.

Additionally, the central nervous system receives all information about the changes occurring real-time in the organism and its environment through the receptors located throughout the body. These receptors are known as the somatosensory system, or the proprioceptive system. The muscle spindles, the Golgi tendon organs, free nerve endings in the skin, and Pacini's corpuscles shape this system. Their main functions are to either build up the sensation of the body and its movements, weight, and position in the space or the position of the individual segments, among others. The somatosensory system is also involved in the control of balance, the coordination of both sides of the body, and the handling of objects. Thus, when there are problems in this system, motor dysfunction is clearly observed. Moreover, the somatosensory system is involved in the development of body image in the relation to space, and the planning of motor action. Thus, the person is provided with sufficient information on his/her own body, allowing full orderly mobility in the environment [27-31]. Therefore, further development of the proprioceptive system by training allows greater control over all of the muscles of our body. This control allows us to react differently to the various stimuli to which we are submitted [32]. For instance, we can modify our own reflexes by means of specific training, and thus modify the response to a stimulus triggered by a sound.

### *4.2 Functional discussion*

This study was designed to test the hypothesis that regular practice of a sport, aside from causing changes in common fitness variables, can also modify various parameters of the startle response. A reflex is an involuntary muscle reaction to certain types of stimulation; certain sensations or movements produce specific muscular responses. Reflexes can be learned and require many years of experience and practice to form part of the response repertoire of an athlete [2]. Practice sessions to improve the ability of the performer to develop a reflex behavior could be organized on a daily basis, even in the elderly [32].

The startle reflex and PPI are being increasingly studied to understand the neurobiology of information processing in psychiatric patients compared with healthy human volunteers [33]. PPI has a strong genetic basis, which explains its heritability, stability, and reliability in humans; thus, PPI is increasingly being used as an endophenotype to identify vulnerability genes to detect brain disorders in early stages, including schizophrenia [34-36]. Nevertheless, there is sufficient evidence to believe that circuits mediating PPI lie entirely in the brainstem because this phenomenon is present in experimental animals previously decerebrated by surgical sectioning at the anterior pole of the superior colliculus [37, 38]. Structures involved in this process include the inferior and superior colliculus, the pedunculopontine tegmental and laterodorsal nuclei, the reticulated portion of the substantia nigra, and the caudal pontine reticular nucleus [39]. All of these data provide an anatomical reference in which plasticity and re-structuring mechanisms may take place, such as those permanent biological adaptations that occur during regular training [40 - 42].

The amazing ability of the injured and uninjured brain to reorganize, change and adapt is now a recognized process known as "plasticity". We now know that the brain is capable of "plastic change" and learning throughout life. This capability is also great news for athletes of all ages, insofar as improving your proprioception and agility (e.g., honing your tennis strokes and making changes to your golf swing or other sporting techniques) is possible whether you are 4 or 104 [43].

These motor skills are acquired through the formation of nerve circuits or "maps" in the brain, which in turn require certain growth factors, such as human growth hormone (HGH), to stimulate nerve growth (neurogenesis) and the "wiring" together of the nerve circuits that make up each brain map. HGH is abundant during our formative years, and until very recently, it was thought that the release of this supercharged growth hormone reduced dramatically once and individual passed his/her early 20s [45]. However, it has been recently discovered that HGH and other growth factors are stimulated in adults by specific modes of training.

An interesting point in the same line, related to our results from the startle reflex measurements, is that athletes exhibited both lower startle amplitude and greater inhibition when shortened inter-stimulus intervals were presented (30 and 60 ms). Thus, there could be some type of reorganization within the brainstem and the sensory gating circuits that is responsible for triggering the inhibition when several stimuli are presented to prevent the overstimulation of the brain. Accordingly, athletes in general, and the athletes in this study, are supposed to be isolated when performing their specific sport. Separating their internal environment from the external stimuli (distracters) is a crucial action to reach success. Thus, the attenuation of the startle reflex response may be a good candidate for screening the best athletes.

One of the fundamental aspects of information processing that serves to focus attention on relevant environmental cues is the ubiquitous process of habituation, the simplest form of learning [45]. We found that among the control groups, males displayed statistically greater habituation than females; however, in the athlete groups, these data tend to converge without any significant differences. In other words, the control males had lower responses at the end of the startle measurement session, whereas the control females tended to have the same amplitude in the beginning and at the end of the testing session. However, at the end of the session, both the sportsmen and the sportswomen groups responded with an intensity nearly half that of the response at the beginning of the startle measurement session. As in the previous example, neural plasticity could be causing these actions. We suspect that some circuits are restructured within the brain due to the practice of a sport that implements the plasticity mechanisms.

Furthermore, there are some correlations between different parameters that are quite remarkable, such as those occurring between different PPI. For all durations of the ISI, the percentage of inhibition correlates bidirectionally among the three inter-stimulus intervals, 30, 60, and 120 ms. This fact is consistent with the literature that shows that PPI is a constant and steady phenomenon [11, 34, 46]. There are some other noteworthy relations involving the startle magnitudes with the measured physical conditioning parameters, as shown in the results. There are positive relations between the latencies (the time necessary to trigger a muscle response, and the time the muscle response lasts), and both the flight time and the jump height in the Bosco tests. This correlation means that participants responding faster and longer to sound stimuli obtain better results in the neuromuscular conjugation exercises. Moreover, the participants exhibiting higher inhibition values have better results in the strength and flexibility tests. People in whom a short inter-stimulus interval (30 ms) between the pre-pulse and the pulse elicit a smaller startle can develop more strength and more flexibility in the tests they are submitted. All of these facts lead to the preliminary idea that using reflex measurements to infer some physical aptitudes may be valuable. Apart from that, "excitability" is most likely the concept that fits better with the definition of the role of neurophysiology in the study of brainstem functions and circuits. Neurophysiological techniques are likely the best suited of all paraclinical tests for documenting the eventual excitability changes that may occur in certain physiological states and in many neurological disorders [47].

## 5. Conclusions

The startle reflex measurement and its variables related to athletes is a relative unexplored field, and there are currently no studies in this area. It would be of interest to study whether habituation is disrupted in a selective attention test or during orienting responses to compare with the results we found between the controls and athletes. This work is a pilot study, and the continuation of this research line for the near future is essential. In addition, expanding the number of parameters measured and the number of human volunteers in each experimental group is needed to obtain stronger correlations and significances. Moreover, the measurement of the startle reflex may be an objective test to assess the most simple and primitive movements in an athlete's physiological profile. In the future, these tools may have a great potential because specific instruments could be developed to select athletes based on the evaluation of the startle response. The theoretical potential of these set of tools is enormous. With this study, we are opening a brand new field of research for those who are interested in finding new instruments to select characteristics from athletes in an early stage, and to develop new strategies in applied neurophysiology and in sports medicine.

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