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Research report

Stop or move: Defensive strategies in humans

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HIGHLIGHTS

- Somatic and autonomic measures were used to study defensive strategies in humans.
- Gun pictures simulated realistic attack with more or less possibility of escape.
- Exposure to gun directed-away from the observer led to increased body sway.
- Exposure to facing guns led to reduced back-and-forth sway and heart deceleration.
- Under attack, humans present basic defensive reactions—flight or immobility.

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ABSTRACT

Threatening cues and surrounding contexts trigger specific defensive response patterns. Potential threat evokes attentive immobility; attack evokes flight when escape is available and immobility when escape is blocked. Tonic immobility installs when threat is overwhelming and life-risky. In humans, reduced body sway characterizes attentive and tonic immobility, the former with bradycardia, and the later with expressive tachycardia. Here, we investigate human defensive strategies in the presence or absence of an escape route. We employed pictures depicting a man carrying a gun and worked with participants exposed to urban violence. In pictures simulating more possibility of escape, the gun was directed away from the observer; in those simulating higher risk and less chance of escape, the gun was directed toward the observer. Matched control pictures depicted similar layouts, but a non-lethal object substituted the gun. Posturographic and electrocardiographic recordings were collected. Amplitude of sway and heart rate were higher for gun directed-away and lower for gun direct-toward. Compared to their respective matched controls, there was a general increase in the amplitude of sway for the gun directed-away pictures; and a reduction in back-and-forth sway and in heart rate for gun directed-toward pictures. Taken together, those measures suggest that, when exposed to threat invading their margin of safety in a context indicating possible escape route, humans, as non-human species, engage in active escape, resembling the flight stage of the defensive cascade. When facing threat indicating less possibility of escape, humans present an immobile response with bradycardia.

1. Introduction

In animals, threatening confrontations with predators or conspecifics cause defensive neural circuits to be activated, which prepare the organism for adaptive behaviors and improve its chance of survival [1,2].

Researchers have proposed that particular features of threatening cues and surrounding contexts trigger specific response patterns (defense cascade) that change systematically with the proximity and probability of an encounter. When an animal detects a potential threat, but has not been seen by the predator, "attentive immobility" is a common adaptive defensive behavior; being motionless increases the chances to go unnoticed by a predator [3,4]. If an attack starts and escape is available, "flight" is the dominant defensive reaction [5]. When survival is extremely threatened, "tonic immobility" is the last antipredator resort; cessation of

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struggling prevents or at least reduces the likelihood of continued attacks [3,4].

Working with rodents, Blanchard et al. [5] showed that active avoidance was the usual reaction to attack when the situation allowed the animal to move out of sight. Interestingly, Blanchard et al. [6] devised a paradigm in which avoidance or escape was not possible. In that study, the rat was trapped by a door at the end of straight alley while the experimenter approached from the other end. When at a distance of between 1 and 2 meters, immobility was consistently observed, but at closer distances, defensive attacks became more predominant.

Searching for parallel defensive patterns in humans, Blanchard et al. [7], Perkins and Corr [8] and Shuhama et al. [9] employed 12 written scenarios consisting of short texts describing daily life situations involving conspecific threat. The scenarios varied as widely as possible in conditions such as the magnitude of the threat, the escapability from the situation, the ambiguity of the threatening stimulus, the distance between the threat and the participant, and the presence of a hiding place. The evaluation consisted in selecting a first choice behavior from a list of 10 possible defensive behaviors, including: attack, escape, freeze, risk assessment and hide. The relationships observed between the chosen behavior and the features of the scenarios, suggested congruence between human and non-human defensive systems. For example, the answer “escape” was chosen as the most likely response to scenarios evaluated as unambiguous and highly threatening, when an escape route was available. Further, “become immobilized” was chosen in an inescapable threatening situation [7–9].

It is important to highlight that immobility can occur in three completely different contexts (i) when a potential threat is detected, but the predator has not perceived the prey (attentive immobility); (ii) when an attack has begun, but the escape route is not available; and (iii) when the prey is subdued and there is a risk to life (tonic immobility).

Biological evidence has provided significant insights into the immobility responses in humans. Our group first investigated attentive immobility prompted by aversive pictures (mutilated bodies), which was characterized by a significant reduction in the amplitude of body sway and increased body rigidity, along with heart rate deceleration [10,11]. Other studies using a similar paradigm corroborate these findings [12]. More recently, we conducted a pioneer study of tonic immobility, evaluating posturographic and electrocardiographic measures in trauma-exposed participants after listening to the script of their autobiographical trauma. Results showed that tonic immobility was characterized by reduced amplitude of body sway along with robust heart rate acceleration [13].

A recent review pointed out the need to explore the role of various context variables on immobility defensive behavior [14]. To the best of our knowledge, no study has addressed posturographic correlates in humans of defensive immobility in the context of threat when an escape route is not available. Here, we attempted to fill this gap in the knowledge about the human defense cascade, by devising an experimental paradigm which aims to reproduce in a laboratory setting the presence or absence of an escape route in face of realistic attack-like conditions, and record somatic and autonomic responses.

To simulate these realistic attack-like conditions, we chose visual stimuli depicting scenes associated with violent crime and studied a sample with a high index of exposure to urban violence [15]. Interpersonal violence involving guns has increased across the world [16] affecting populations living in large urban centers [15,17], turning weapons into a pervasive threatening stimuli. We exposed participants to pictures in which a male was carrying a gun. The direction of the gun in relation to the observer modulated the availability of escape. For the pictures which simulate attack with more possibility of escape, the gun was directed away from the observer; whereas in those simulating less chance of escape, the gun was directed toward the observer.

Our prediction was that the sample would be very susceptible to gun exposure which would trigger distinct reactions suitable for somatic and autonomic measurements. We hypothesize that exposure to a gun directed away from the observer will prompt escape-like reaction, and that exposure to a gun directed toward the observer will prompt immobility-like reaction.

2. Materials and methods

2.1. Participants

One hundred eleven volunteers participated in the study. All participants were graduate or undergraduate students at the Federal University of Rio de Janeiro who reported no history of neurological, psychiatric or orthopedic disorders and were not taking any medications with central nervous system effect. The Ethics Review Board of the Federal University of Rio de Janeiro approved the study, and participants provided informed consent before assessment.

2.1.1. Characteristics of the sample

2.1.1.1. Trauma history. The participants were asked to complete the Trauma History Questionnaire translated and adapted to Portuguese [18] from the original [19]. The Trauma History Questionnaire is a self-report questionnaire which examines exposure to traumatic events. At the end of this questionnaire, participants had to indicate the event that he/she considered the most traumatic in his/her life. Given the characteristics of the present paradigm, we had a special focus on exposure to violent crime. The items related to “violent crime” were selected according to the trauma categorization of Luz et al. [20] which included any type of direct or indirect exposure to crime or act of violence.

2.1.1.2. Posttraumatic stress symptoms. Posttraumatic stress symptoms were assessed using the Posttraumatic Stress Disorder Checklist—Civilian Version [21], translated and adapted to Portuguese by Berger et al. [22]. The Posttraumatic Stress Disorder Checklist is a 17-item self-report measure of the severity of symptoms in response to a traumatic experience. A cut-off score of 44 [23] was used to exclude participants with symptoms compatible with Posttraumatic Stress Disorder. Previous studies showed different reactivity to threatening contexts in clinical and subclinical Posttraumatic Stress Disorder [13,24,25].

2.1.1.3. Violent video game play. Participants were asked to report how often they played violent video games with the choices: “never”, “sometimes”, “often”, “very often”.

2.2. Visual stimuli

Visual stimuli consisted of sixty four color pictures obtained from three sources, the Gettyimages© web catalog of pictures (www.gettyimages.com), the International Affective Pictures System [26] and pictures taken by a professional photographer in a studio. Care was taken to select realistic pictures according to the participants’ ethnographic context. All the pictures depicted a male subject carrying an object in his hands which was either a gun (“threat”) or a non-lethal item (“control”). Threat and control pictures were displayed in two different blocks, “directed-toward” and “directed-away”. In the “directed-toward” block, the carried object was directed toward the observer and two sets of pictures were tested (i) “threat directed-toward” and (ii) “control directed-toward”; while in the “directed-away” block, the carried object was

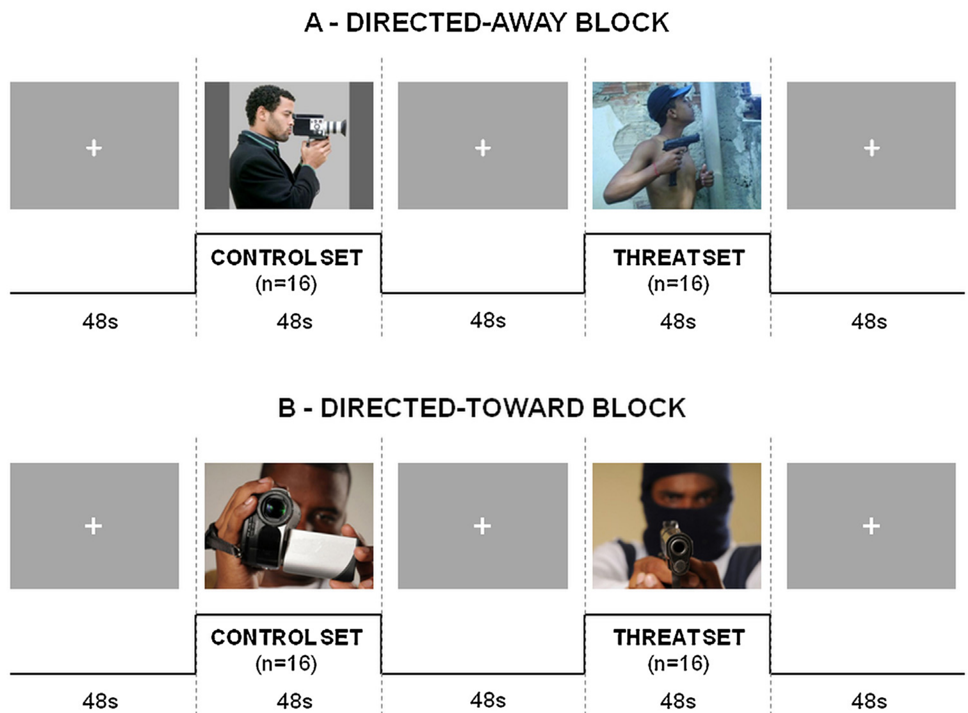

Fig. 1. Schematic representation of the experimental design. A—Directed-away block: control (non-lethal object) pictures followed by threat (gun) pictures. B—Directed-toward block: control (non-lethal object) pictures followed by threat (gun) pictures. Each block started with a gray screen which was presented again after the control set and after the threat set. A representative picture of each experimental set is depicted in this diagram.

directed away from the observer, and two other sets of pictures were tested (i) "threat directed-away" and (ii) "control directed-away". Each of the four sets had 16 pictures. Within each block, threat and control sets were matched in brightness, contrast and spatial frequency. All pictures had the same height; the width was adjusted by adding two gray borders at the lateral edges.

The stimuli were presented on a 37in LCD monitor.

2.3. Data collection

Two computers controlled picture presentation and data acquisition of the postural and electrocardiographic parameters, running Presentation (Neurobehavioral Systems), Balance Clinic (AMTI's AccSwayPLUS Balance Platform) and Acknowledge (BIOPAC Systems Inc.) software.

2.3.1. Posturography

Amplitude of body sway was estimated by measuring the displacement of the center of pressure using a force platform (AccuswayPLUS, AMTI, USA). The posturographic signals were sampled at 50 Hz and low-pass filtered with a cutoff frequency at 5 Hz. The area of postural sway was quantified by fitting the displacement of the center of pressure in the x–y plane into an ellipse that encloses approximately 85.35% of its trajectory. The standard deviation was also computed from the displacement of the center of pressure separately for the anterior–posterior and medial–lateral axes. The standard deviation provides a measure of the width of amplitude variability in each axis. We also measured the body weight of each participant using the same platform.

There were two orthogonal lines dividing the squared surface of the force platform. The platform was positioned so that these lines were aligned with the vertical and horizontal meridians of the monitor. The center of the platform distanced 80 cm from a vertical line passing through the center of the monitor and reaching the floor.

2.3.2. Electrocardiography

Participants had electrocardiogram electrodes attached according to the second cardiac derivation (right and left wrists and right ankle). Electrocardiographic recordings were collected at a sampling frequency of 240 Hz through an electrocardiograph ECG100C module coupled to the MP150 system (BIOPAC Systems Inc.). An off-line peak detection algorithm was used to estimate R-wave fiducial points, after which the series was screened by hand and corrected for artifacts. R-R intervals were averaged and converted to beats/minute to express heart rate [27].

2.4. Evaluative reports

Participants evaluated the emotional impact of each set of pictures. The evaluation consisted of eight questions, some of which were adapted from the ones used in the studies of Blanchard et al. [7] and Shuhama et al. [9]. The evaluative questionnaire was answered in a paper-and-pencil Likert-like scale of 9 points. Questions were related to threat (i) magnitude, (ii) proximity, (iii) inescapability, (iv) impossibility of hiding, (v) ambiguity, (vi) risk of death, (vii) immobilization and (viii) desire to escape.

2.5. Experimental design

The recording session comprised the "directed-away" and "directed-toward" blocks. The order of the blocks was counterbalanced across participants. Within a block, there were three gray screens with a central white fixation cross displayed for 48 s each; and two sets of pictures (control and threat), also displayed for 48 s each. Pictures were presented for 3 s each, with no interval between them. The sequence of the 16 pictures within a set was randomized for each participant. Each block began with the gray screen. Next, the control set of pictures was presented, followed by the gray screen. Then, the threat set of pictures was presented. Presentation of another gray screen ended the block. Each block lasted for

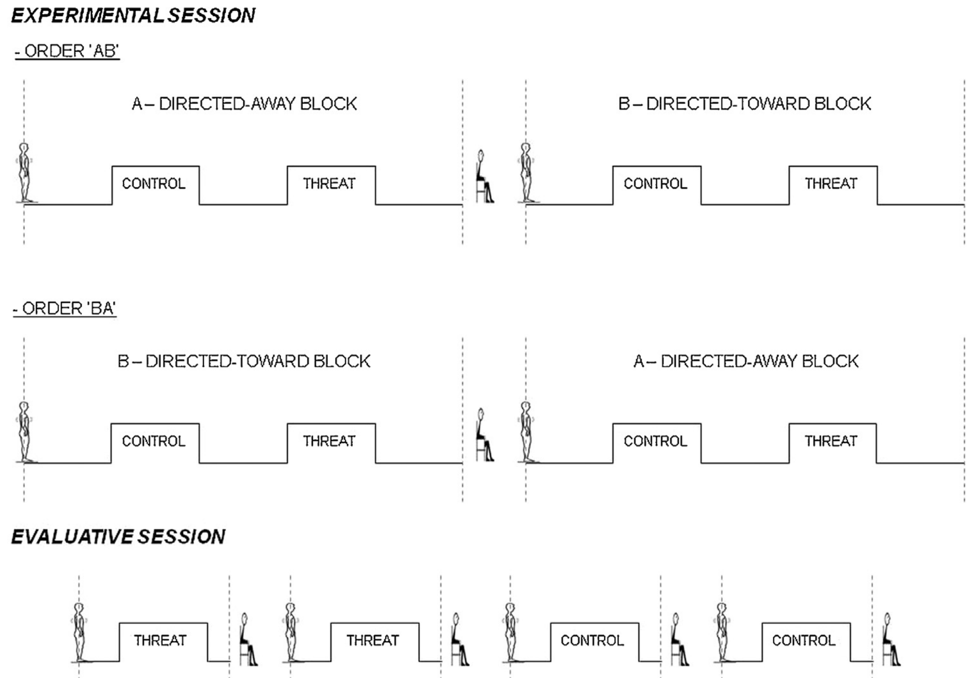

Fig. 2. Schematic representation of procedures for experimental session and for evaluative session. During the experimental session, each participant is exposed to two recording (posturography and electrocardiography) blocks, with a resting interval between them. Half the participants were presented to order 'AB', that is, "directed-away" block followed by "directed-toward" block, while the other half were presented to order 'BA', that is "directed-toward" block followed by "directed-away" block. In summary, sequences were either control A/threat A/interval/control B/threat B, or control B/threat B/interval/control A/threat A. For the evaluative session, participants stood on the force platform, viewed a set of pictures and sat to evaluate it. The two threat sets were evaluated first and then the two control ones. Sequences were either threat A/threat B/control A/control B, or threat B/threat A/control B/control A.

240 s. Within each block, the control set of pictures was always presented first and the threat set of pictures presented second. Fig. 1 illustrates block design.

The evaluative session consisted of the presentation of the same four sets of pictures to be evaluated by the participants. Each picture was again presented for 3 s but in a newly randomized sequence. Presentation of each set of pictures was followed by the respective ratings on the evaluative questionnaire. Evaluation relates to the whole set, i.e., pictures were not evaluated individually. Threat sets were always presented first followed by control sets. Orders of directed-away and directed-toward sets were random.

2.6. Procedure

The experimental sessions occurred in a sound-attenuated room under dim ambient light. The monitor was positioned on the center of one of the walls and the force platform was directly in front it. The white lateral walls were equidistant from the platform. First, the participant stood on the center of force platform with their feet together and at either side of the platform's midline, and at the mid anterior-posterior distance of its center. A laser level fixed on a tripod was placed next to the participant, and a red light was projected on the lateral of the participant's head, at eye level. Once this point was determined, the light was directed to the monitor. Then, the height of the monitor was adjusted so that its center (marked with a cross image) coincided with the projection of the laser, ensuring that the monitor center was aligned with the participant's center of gaze. To further adjust the distance from the participant's eyes to the monitor, we employed a digital laser measuring tape and asked the participant to move forward or backwards until the 80 cm distance was achieved. At this distance, the pictures had a $43.4^\circ \times 34.4^\circ$ visual angle. The outlines of the feet were drawn with a chalk for future repositioning.

The electrocardiogram electrodes were attached. To familiarize with the experimental set, the participant was asked to stand upright on the force platform for 60 s in the same traced feet position, with bare feet together, their arms relaxed along the trunk and to look at a gray screen with a central white fixation cross. Then, they sat, listened to the instructions and returned to the platform to start the recording session. Again, participants were instructed to stand upright on the force platform with bare feet together in the same traced position and arms relaxed along the trunk and to look at the monitor. At the completion of the first block, either the "directed-away" or the "directed-toward", the experimenters entered the room and instructed participants to leave the platform, sit and rest alone for two minutes to minimize fatigue effects. To start the second block, the experimenters entered the room to reposition the participants on the platform (Fig. 2).

After finishing the two-block recording session, the electrocardiogram electrodes were removed and the evaluative session began. Participants were instructed to stand upright on the force platform and to watch each of the four sets of pictures, first the two threats blocks and then the two controls ones (Fig. 2). In the intervals between each of them, participants sat and evaluated the respective set of pictures in a booklet. Re-exposure to the sets with the participants standing aimed to match as much as possible the recording context.

After the evaluative session, the participants completed the Trauma History Questionnaire, Posttraumatic Stress Disorder Checklist and the report of how often they play violent video games.

The experimenters tracked the whole experiment through a video camera installed in the experimental room. They assessed a clone screen from the monitor, an online statokinesigram screen and an online electrocardiogram recording screen.

2.7. Statistical analysis

2.7.1. Evaluative reports

The ratings for threat and matched control sets of pictures in the categories magnitude, risk of death, and desire to escape

Table 1
Traumatic events of violent crime[a].

Exposure to direct or indirect violence[b]:	
At least one	59 (86.8%)
None	9 (13.2%)
The most traumatic event experienced:	
Violent crime	22 (31.9%)
Other events	47 (68.1%)

[a] Two participants did not complete this questionnaire.
[b] One participant could not be classified.

were compared using Wilcoxon matched pairs test. The ratings for threat directed-toward and threat directed-away sets of pictures in the categories magnitude, proximity, inescapability, impossibility of hiding, ambiguity, risk of death, immobilization and desire to escape were compared using Wilcoxon matched pairs test.

2.7.2. Physiological recordings

A logarithmic transformation was applied to center of pressure summary measures to meet normal distribution requirements for statistical analyses.

2.7.2.1. Directed-away versus *directed-toward.* Student's *t*-tests for dependent samples were employed to compare exposure to "threat directed-away" *versus* "threat directed-toward". Comparisons of exposure to "control directed-away" *versus* "control directed-toward" were also performed through Student's *t*-tests for dependent samples. Dependent measures were area of sway, anterior–posterior standard deviation, medial–lateral standard deviation and heart rate.

2.7.2.2. Threat versus *control.* Each block (directed-away and directed-toward) was analyzed separately. In the analyses, threat and control (EMOTIONAL CONTENT) sets of pictures, were within-subject factors. ORDER OF BLOCKS ("directed-away" and "directed-toward") was between-group factor. We conducted mixed analyses of variance (ANOVAs) separately for area of sway, anterior–posterior standard deviation, medial–lateral standard deviation and heart rate and significant effects were followed-up with Fisher LSD test.

A control set of pictures was the first set seen by participants (directed-away for half participants and directed-toward for the other half). First time exposure to a novel context was shown to be associated with a tighter control of posture ("first trial effect") [28]. To investigate if "first seen" set of pictures impacted in postural and cardiac recordings, we employed Student's *t*-tests for dependent samples. We compared physiological recordings during exposure to control set of pictures presented in the first block *versus* the control set of pictures presented in the second block, separately for all parameters.

Using Spearman correlations, we investigated the relation between evaluative report of threat and physiological reactions to threat.

Student's *t*-test for independent samples was performed to assess body weight differences between men and women.

All analyses were performed with Statistica® software (v. 12.0) and a *p*-value under 0.05 was considered significant.

3. Results

Spontaneous random movements during the recording sessions led to exclusion of sixteen volunteers from further analyses. Six participants met exclusion criteria in relation to posttraumatic stress symptoms. Seventeen participants reported playing violent video games "often" or "very often" and one did not answer this question. These were not included in the present analyses and are described in a forthcoming study. There are reasons to suppose that expert players in violent video game might react differently to crime-related stimuli. Violent video games often include the presence of gun carriers in the scenes as well as first-person gun use. Thorough studies, including meta-analyses, have consistently found that greater short and long-term exposure to violent games increases aggressive behavior [29,30]. Also, individuals who evaluate violent videos as positive show distinct emotional modulation of brain areas when watching them, compared to individuals who evaluate them as negative [31].

The final sample consisted of seventy one participants (35 women). Mean age was 23.0 ± 4.13 years. Anthropometric factors, like weight, are reported to affect stabilometric parameters [32]. Mean weight of women was 55.7 ± 7.97 kg and men was 69.5 ± 10.77 kg, and this difference was significant ($t = -6.14$, $p < 0.001$). The majority of participants had been directly or indirectly exposed once or more to violent crime and one third reported violent crime as the most traumatic among other trauma events. Table 1 summarizes the exposure to violent crime, according to the Trauma History Questionnaire.

3.1. Evaluative reports

3.1.1. Threat versus *control*

Wilcoxon matched pairs test revealed that threat sets of pictures surpass their matched control sets in reports of magnitude, risk of death and desire to escape (Table 2).

3.1.2. Threat directed-toward versus *threat directed-away*

Compared to the set of pictures in which a person was pointing a gun away from the observer (threat directed-away), ratings for the set of pictures in which a person was pointing a gun toward the observer (threat directed-toward) were higher in magnitude, proximity, inescapability, impossibility of hiding, risk of death, immobilization and desire to escape. The threat directed-toward set was rated as less ambiguous than threat directed-away. These results are summarized in Table 3.

In summary, the analyses of evaluative reports showed that, as intended, both threat directed-away and threat directed-toward sets of pictures were perceived as very threatening and evoked the desire to escape. Threat directed-toward was even more threatening. Inescapability, as an absence of escape route, was a significant feature of the threat directed-toward set.

Table 2
Evaluative reports of threat *versus* matched control.

	Threat *versus* Control (Directed-away)		Threat *versus* Control (Directed-toward)	
	Z-score	*p*-value	*Z*-score	*p*-value
Magnitude	6.62	<0.001	6.91	<0.001
Risk of death	4.37	<0.001	5.15	<0.001
Desire to escape	4.18	<0.001	4.44	<0.001

Note: "Threat" presented higher scores than "control" in all analyses.

Table 3
Evaluative reports of "threat directed-toward" *versus* "threat directed-away".

	Z-score	*p*-value
Magnitude	4.65	<0.001
Proximity	4.92	<0.001
Inescapability	4.34	<0.001
Impossibility of hiding	4.69	<0.001
Ambiguity	3.50	<0.001
Risk of death	3.43	<0.001
Immobilization	4.96	<0.001
Desire to escape	3.29	0.001

Note: "Threat directed-toward" presented higher scores than "threat directed-away" in all analyses, except ambiguity.

3.2. *Physiological recordings*

3.2.1. *Directed-toward* versus *directed-away*

3.2.1.1. Threat. Analyses were performed comparing physiological parameters recorded during exposure to the set of pictures depicting guns directed-away from the observer *versus* the set of pictures depicting guns directed-toward the observer. The analyses of variance including SEX as between-group factor and DIRECTION as within-subject factor revealed significant main effects of SEX for all parameters. Women showed lower amplitudes of body sway, and greater heart rate than men. There was, though, no significant interaction between DIRECTION and SEX in any parameters, and so men and women were grouped together for further analyses.

Student's *t*-tests for dependent samples showed significant differences in the postural parameters area ($t = 3.38$, $p = 0.001$), medial–lateral standard deviation ($t = 3.68$, $p < 0.001$) and anterior–posterior standard deviation ($t = 2.38$, $p = 0.020$), with lower amplitude for gun directed-toward compared to gun directed-away pictures in all parameters. Fig. 3 illustrates a representative data from one participant depicting reduced amplitude of sway during viewing of threat (guns) directed-toward pictures compared to threat directed-away. For heart rate, there was also a significant difference ($t = 2.34$, $p = 0.022$), with lower heart rate for gun directed-toward compared to gun directed-away pictures. Fig. 4 illustrates postural and heart rate results.

3.2.1.2. Control. To investigate if "direction" of any object could *per se* influence the above results, we employed Student's *t*-tests for dependent samples to compare the control set of pictures depicting non-lethal objects directed-away the observer *versus* the control set of pictures depicting non-lethal objects directed-toward the observer. We found no significant differences in any of the analyzed postural parameters, nor in heart rate.

Means and standard-deviations of physiological parameters for threat and control sets are depicted in Table 4.

3.2.2. *Threat* versus *control*

We investigated the modulation of each threatening context, directed-away and directed-toward, relative to their matched respective control ones.

Initially, we investigated for the occurrence of "first trial effect". A control set was always the first presented in an experimental session (see Fig. 2), so we compared the exposure to the control set presented in the first block with the control set presented in the second block. Student's *t*-test for dependent samples revealed significant lower amplitude in postural parameters and lower heart rate for the control set presented in the first block compared to the one presented in the second block (Table 5).

Further analyses included ORDER OF BLOCKS as between-group factor.

Table 4
Mean and standard-deviations of physiological parameters for threat and control sets.

Threat	Directed-away m ± SD	Directed-toward m ± SD	*t*	*p*-value
Area (log_mm^2)	2.30 ± 0.28	2.23 ± 0.27	3.38	0.001
M-L SD (log_mm)	0.64 ± 0.14	0.60 ± 0.14	3.68	<0.001
A-P SD (log_mm)	0.60 ± 0.19	0.56 ± 0.17	2.38	0.020
HR (bpm)	87.98 ± 12.84	87.0 ± 12.48	2.34	0.022
Control				
Area (log_mm^2)	2.24 ± 0.25	2.23 ± 0.30	0.28	0.780
M-L SD (log_mm)	0.61 ± 0.13	0.59 ± 0.14	1.58	0.119
A-P SD (log_mm)	0.56 ± 0.16	0.57 ± 0.19	−0.47	0.643
HR (bpm)	87.57 ± 12.44	87.40 ± 13.11	0.27	0.791

t-values indicate the results of Student's *t*-tests for dependent samples.
Abbreviations: M-L SD = medial–lateral standard deviation; A-P SD = anterior–posterior standard deviation; HR = heart rate.

3.2.2.1. Directed-away. In this block, participants viewed pictures of a man carrying an object that was pointed away from the observer. The first set presented non-lethal objects (control) and the second set presented guns (threat) (Fig. 1A). The analyses of variance showed main effects for EMOTIONAL CONTENT (threat *versus* control) in the postural parameters area ($F(1,69) = 8.70$, $p = 0.004$), medial–lateral standard deviation ($F(1,69) = 5.75$, $p = 0.019$) and anterior–posterior standard deviation ($F(1,69) = 4.37$, $p = 0.040$), with increases in amplitude for threat compared to the control set in all parameters (Fig. 5).

Larger sway for threat directed-away pictures relative to control pictures, i.e. threat *minus* control >0, was present in 65% of the sample, which suggests that these pictures were strong enough to trigger a transition into an active motoric state, possibly an escape-like defensive response in a large part of the sample. To examine whether the perceived threat relates to this active state, we conducted an analysis comparing the enhancement in amplitude of body sway (area) and evaluative report (magnitude of threat) within those participants and found a significant correlation (rho = 0.311, $p = 0.035$). In other words, participants who reported the set of gun pictures as more threatening also had higher increases of body sway.

For heart rate, there was no main effect for EMOTIONAL CONTENT. However, for the group of participants who had experienced violent crime as their most traumatic event (see Table 1), there was a positive correlation between reports of threat magnitude and heart rate modulation (threat *minus* control) (rho = 0.45, $p = 0.04$). In other words, heart rate was drifted toward acceleration for participants who perceived gun pictures as more threatening. For the group of participants who had experienced other events as their most traumatic, no significant correlation was observed.

Table 5
Means and standard-deviations of physiological parameters for control sets presented in the first and in the second blocks.

Control	First m ± SD	Second m ± SD	*t*	*p*-value
Area (log_mm^2)	2.18 ± 0.27	2.30 ± 0.26	−5.39	<0.001
M-L SD (log_mm)	0.59 ± 0.14	0.61 ± 0.13	−2.23	0.029
A-P SD (log_mm)	0.52 ± 0.16	0.61 ± 0.18	−5.34	<0.001
HR (bpm)	86.13 ± 12.48	88.84 ± 12.93	−4.95	<0.001

t-values indicate the results of Student's *t*-tests for dependent samples.
Abbreviations: M-L SD = medial–lateral standard deviation; A-P SD = anterior–posterior standard deviation; HR = heart rate

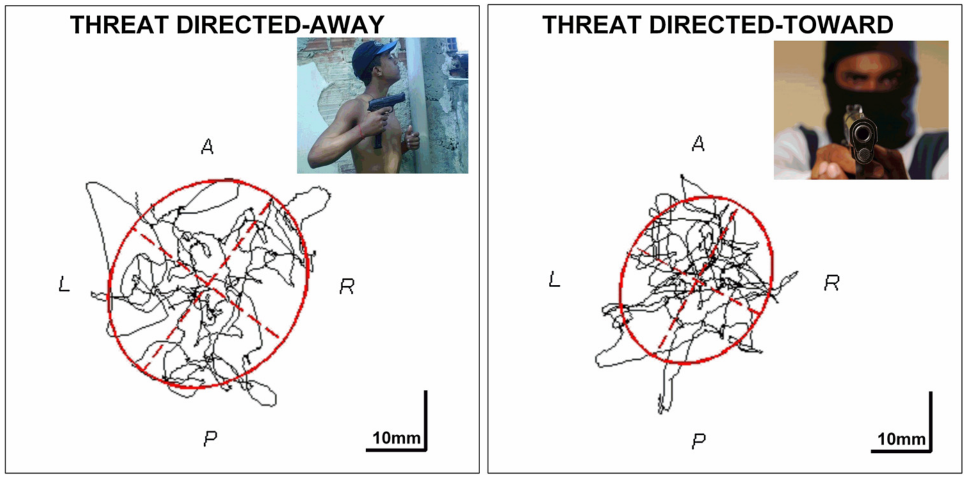

Fig. 3. Representative data from one participant depicting reduced amplitude of sway during viewing of threat (guns) directed-toward pictures compared to threat (guns) directed-away pictures.

Finally, the ORDER OF BLOCKS, that is, order 'AB' and order 'BA' (as in Fig. 2) did not interact significantly with EMOTIONAL CONTENT in any of the parameters.

3.2.2.2. Directed-toward. In this block, participants viewed pictures of a man carrying an object that was pointed toward the observer. The first set presented non-lethal objects (control) and the second set presented guns (threat) (Fig. 1B). The analyses of variance revealed no main effects for EMOTIONAL CONTENT in any parameter. There was, though, a significant interaction between EMOTIONAL CONTENT and ORDER OF BLOCKS in anterior–posterior standard deviation ($F(1,69) = 7.28$, $p = 0.009$) and in heart rate ($F(1,69) = 11.63$, $p = 0.001$). Post-hoc analyses showed that, for participants ($N = 35$) who viewed the directed-

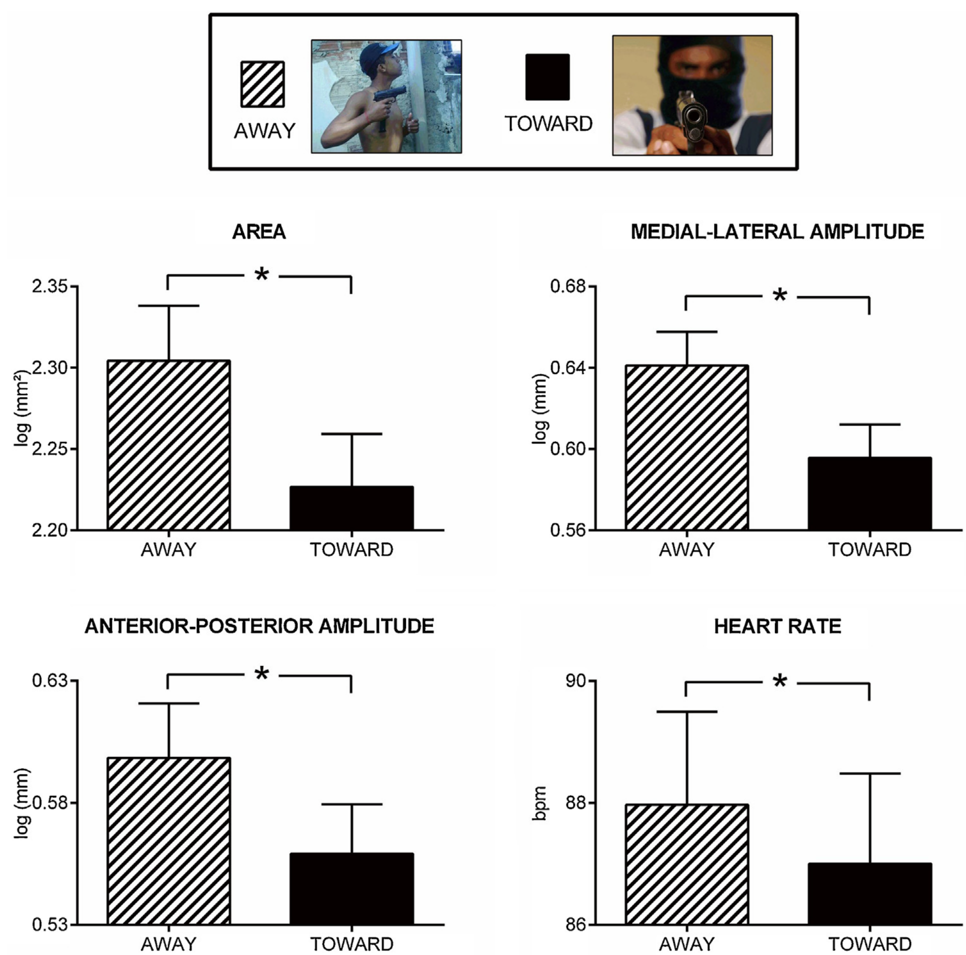

Fig. 4. Threat (gun) directed-toward *versus* directed-away. Amplitude of body sway: area, medial–lateral standard deviation, anterior–posterior standard deviation; heart rate. $N = 71$, data are expressed as mean ± SEM, $^{*}p < 0.05$.

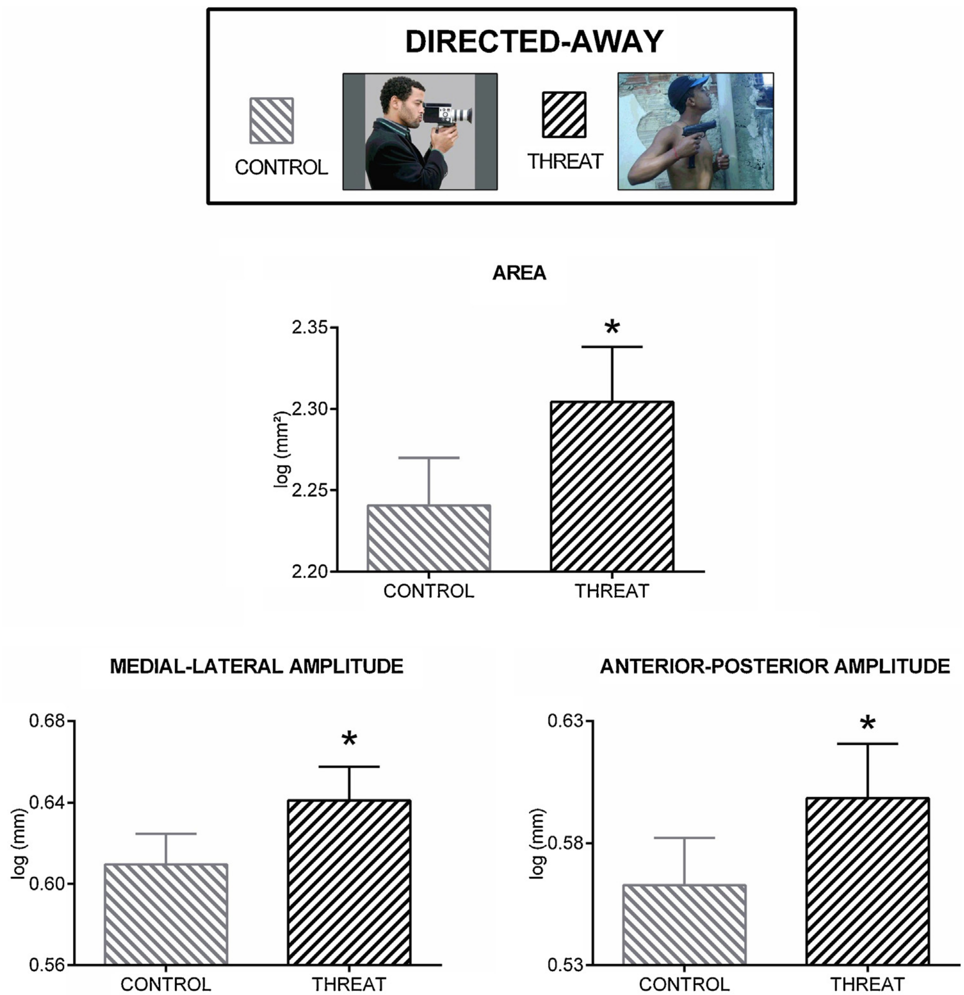

Fig. 5. Threat (gun) directed-away *versus* control (non-lethal object) directed-away. Amplitude of body sway (area, medial–lateral standard deviation and anterior–posterior standard deviation) is augmented for exposure to threat directed-away compared to matched control set. $N = 71$, data are expressed as mean ± SEM, $^{*}p < 0.05$.

toward block after they had seen the directed-away block (block 'A' followed by 'B' as in Fig. 2), there was a diminished amplitude of sway in the anterior-posterior axis (mean ± SD (log_mm); control: 0.650 ± 0.192 and threat: 0.591 ± 0.169; $p = 0.016$) and a decreased heart rate (mean ± SD (bpm); control: 88.645 ± 12.446 and threat: 86.931 ± 11.653; $p = 0.002$) for threat compared to control sets of pictures, i.e. immobility and bradycardia when facing a pointing gun (Fig. 6). There was no significant modulation in those parameters for the participants ($N = 36$) exposed to the other order (block 'B' followed by 'A'); anterior–posterior standard deviation (mean ± SD (log_mm) —control: 0.497 ± 0.160 and threat: 0.528 ± 0.168; $p = 0.187$); heart rate (mean ± SD (bpm)—control: 86.197 ± 13.803 and threat: 87.075 ± 13.395; $p = 0.104$). For this order, the threat directed-toward control pictures were subjected to first-trial effect, as described above, and participants' reduced sway and heart rate during exposure to the control "first seen" set might have masked the comparisons with the effects of the threat set. For the order block 'A' followed by 'B, on the other hand, the "directed-toward" block was the second to be presented and, by definition, its control set could not be subjected to first-trial effect (see Figs. 1 and 2).

4. Discussion

The aim of this study was to investigate biological correlates of defensive reactions to human-relevant threat, an attack with a gun. The attack-like condition was created by the presentation of pictures depicting scenes related to urban violence, in which a man was carrying a gun. The pictures in which the gun was directed away from the observer were designed to simulate conspecific threatening situations with possibility of escape, and the pictures in which the gun was directed toward the observer simulated higher risk and less chance of escape. As controls, similar pictures were presented, but non-lethal objects were carried.

4.1. Simulation of realistic threat with and without escape route

We observed that the pictures depicting a man carrying a gun were perceived as more intense and with more risk of death, and triggered more desire to escape; compared to matched control pictures (non-lethal objects). Considering that 87% of the sample has been directly or indirectly exposed to violent crime, the use of crime-like pictures seems to have contributed to make them realistic enough to simulate attack-like conditions.

In addition, the results of the comparison between the threatening stimuli ("threat directed-toward" *versus* "threat directed-away") showed that the pictures in which the gun was pointed toward the observer were evaluated as (i) more threatening, (ii) closer, (iii) with less chance of escaping and (iv) with less chance of hiding. These pictures were also perceived as less ambiguous and presenting increased risk of death. Participants reported feeling immobilized, and with more desire to escape.

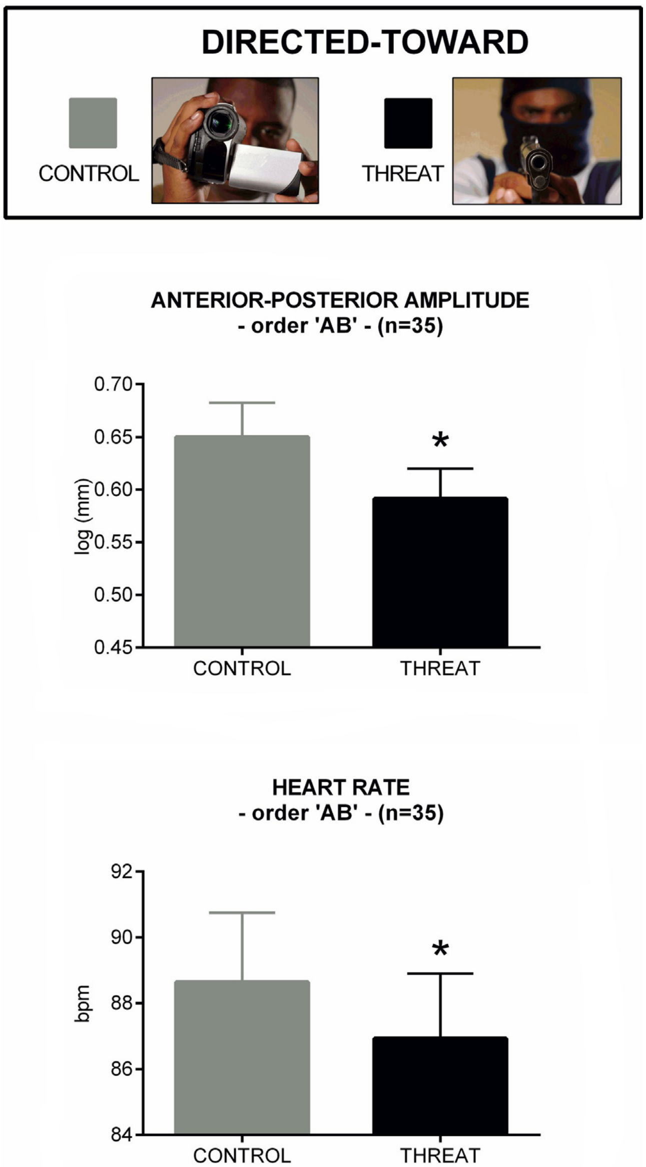

Fig. 6. Threat (gun) directed-toward *versus* control (non-lethal object) directed-toward. Anterior–posterior standard deviation and heart rate comparing exposure to threat directed-toward and matched control set. Back-and-forth sway is reduced and heart rate is lower for threat compared to matched control. Order 'AB' ($N = 35$ participants) means that the "directed-toward" block was the second to be presented and its control set was not subjected to first-trial effect. Data are expressed as mean ± SEM, $^{*}p < 0.05$.

These findings support our premise that both stimuli could simulate attack-like conditions, differing from each other in the likelihood of escaping. This was achieved through relatively "simple" threat scenes, a man carrying a gun, thoroughly matched with their respective controls. More importantly, the two relevant experimental manipulations, presence or absence of escape route, were simulated by changing a single feature, that is, the direction of the gun. As a key consequence, critical results from the experimental manipulation could be extracted from physiological recordings without the interference of other possible confounding elements.

4.2. Somatic and autonomic reactions

4.2.1. Presence of escape route

For the pictures that simulate threat with more possibility of escape, that is, when the gun was directed away from the observer, the reactivity was characterized by an increase in the amplitude of postural sway. In addition, magnitude of threat correlated positively with amplitude of sway. Moreover, within those participants who had experienced violent crime as their most traumatic event, heart rate drifted toward acceleration for participants who perceived gun pictures as more threatening. Previously, using a similar posturographic paradigm, we found a reduction of the amplitude of body sway and bradycardia to pictures of mutilated bodies [10,11]. Here, employing pictures depicting guns and presenting them to a sample with a high index of exposure to urban violence, we found a different pattern of reactions: augmented sway and absence of bradycardia or even a tendency to tachycardia. We conclude that exposure to threat directed-away pictures might have led to a predisposition to active escape, that is, resembling the "flight" stage of defense cascade.

4.2.2. Absence of escape route

For the pictures which simulate inescapable threat, that is, when the gun was directed toward the observer, the reactivity was characterized by a decrease in the amplitude of postural sway, in anterior–posterior axis, and a decrease in heart rate.

Threat directed-toward pictures were rated as more threatening than threat directed-away ones. From what was found for exposure to threat directed-away set, increase in threat magnitude *per se* should lead to even higher increases in postural amplitude and heart rate. Nonetheless, as predicted, the present results revealed that higher threat in an inescapable context triggers immobility and bradycardia. As discussed below, this represents an adaptive defensive behavior.

Among the three kinds of immobile defensive reactions[1], that is: (i) "attentive immobility" when a potential threat is detected, but the predator has not perceived the prey, (ii) "immobility under attack" when attack has begun, but an escape route is not available, and (iii) "tonic immobility" when the prey is subdued and there is a risk to life; only the first and the latter were previously subjected to biological measures in humans. "Attentive immobility" in response to potential threat was characterized by *reduced amplitude* of postural sway, primarily in the medial–lateral axis, along with *bradycardia* [10–12]. "Tonic immobility" in response to overwhelming threat was characterized by *reduced amplitude* of postural sway, accompanied by robust *tachycardia* [13]. We believe that our present results fill the gap by describing the "immobility under attack" characterized by *reduced amplitude* of postural sway in the anterior–posterior axis, along with *bradycardia*.

Blanchard et al. [6] advanced the idea that immobility under attack embeds a concomitant action preparation to be released when escape opportunity is evoked. They observed that, as contact between predator and prey is about to take place, the probability of prey jump-attack is maximal, which, according to the authors, are facilitated by increased muscular tension. They hypothesized that this strategy may be successful in causing the predator to withdraw, giving the prey an opportunity to flee. There are reasons to suppose that immobility and bradycardia present in attentive immobility and in immobility under attack are both evolutionary adaptive strategies underneath preparatory states for action. In humans, studies of moment-to-moment action regulation (see review in Jennings and Molen [33]) emphasize cardiac slowing as being an important component of action inhibition, especially during the period preceding the occurrence of appropriate context conditions that trigger action shift. Indeed, psychophysiological studies of emotion indicate that heart rate deceleration is part of

[1] It should be noted that the word "freezing" has been used in the literature interchangeably referring to any of those three kinds of immobility, rendering those very particular defensive reactions indistinct.

defensive reactions to threat and relates to implicit preparation for possible action [34] and/or precedes mobilization for goal directed defensive action [35,36].

Although not measuring whole-body reactions, another study [35] employed a paradigm in which the picture of a gun directed to the observer loomed progressively closer. Participants could only avoid a loss (of money) by pressing a key in a final stage when the gun seemed very close. When pictures depicted closer distances and during the steps when the participant was not allowed to perform the task (i.e., was unable to escape), there was a marked heart rate deceleration and inhibition of startle reflex. Consonant with our findings, bradycardia and startle inhibition could resemble an "immobility under attack" reaction. Approaching the final stage, when the overt response was allowed, the authors [35] found signs of mobilization reflected as an abrupt sympathetic acceleration. In a more recent study, these authors employed a threat of shock paradigm in which they also described measures of sympathetic activation in a stage when the threat (shock) was most imminent and the participant could avoid the painful stimulus [37].

In a previous study from our group [38], the authors evaluated the influence of pictures depicting guns directed toward the observer, while participants had to perform a bar orientation discrimination task. In this paradigm, participants were instructed to ignore the pictures and to respond as quickly and as accurately as possible to the bars, indicating whether their orientation was the same or different, using the right or left index finger. Participants were quicker to respond in the presence of pointing gun pictures than control ones. One could speculate that the pictures induced a preparatory motoric state of the upper extremities, as in the above-mentioned study by Low et al. [35]. This parallels the description by Blanchard and Blanchard [39] of rodents under close conspecific attack, which adopt an upright immobile posture and defensive boxing.

4.3. Threat modulation was not influenced by sex

The present study found no significant modulation by sex in defense response to threat, neither directed-toward nor directed-away, in any postural parameter or in heart rate. Bradley et al. [40]. investigating the influence of sex in psychophysiological defensive reactions to aversive pictures, also found no sex-differences in heart rate—their study did not employ postural measurements. However, the authors found increased electromyographic activity of the corrugator muscle and skin conductance to unpleasant pictures in women. Hillman et al. [41], measuring mean body sway position in response to pictures, reported a significant backward movement from unpleasant pictures only for women.

Consonant with the literature, and irrespective of the experimental conditions, women showed lower amplitude of postural sway [42–44] and higher heart rate [45]. These differences could be partially explained by anthropometric differences, typified here by the lower body weight found for women.

5. Conclusions

A basic function of the motor system of all animals is to protect the body from attack. Escape is the most urgent survival strategy. However, the sight of a predator is not enough to cause an animal to flee; the behavior of the predator and its proximity also play a part.

Hediger [46] proposed the concept of the margin of safety around the body or "flight zone" which, when intruded on, triggers escape. Cortical areas involved in the sensorimotor representations of this defensive peripersonal space, as well as in the selection and coordination of defensive behavior, have been described in non-human primates [47] and in humans [48].

Urban violence is a major trigger for motor defensive reactions in humans. Assaultive trauma is characterized by forceful invasion of the peripersonal space and increases the risk for Posttraumatic Stress Disorder. Indeed, Rocha-Rego et al. [49] showed that victims of urban violence with Posttraumatic Stress Disorder present structural alteration in cortical premotor areas.

In the present work, given the previous exposure to violent crime, gun pictures simulated an invasion of the participants' margin of safety. Guns pointing away were perceived as an escapable threat while guns pointing toward were perceived as an inescapable threat. Based on the present results, when exposed to threat invading their margin of safety in a context indicating possible escape route, humans, as non-human species, engage in active escape, resembling the flight stage of the defensive cascade. Further, when exposed to threat indicating less possibility of escape, humans present an immobile response and bradycardia.

Conflicts of interest

The authors have no conflicts of interest to declare.

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