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Research report

Behavioral and neuroimaging responses induced by mental imagery of threatening scenarios

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HIGHLIGHTS

- Imaginary of imminent threat scenarios increased fMRI signal of the dorsal midbrain.
- Activity in vmPFC was reduced during the imagination of imminent threat scenarios.
- Activation pattern was consistent with animal data and actual threat situations.
- Imminent and potential threats modulate brain structures related to fear and anxiety.
- Mental imagery is a reliable method to study the neurobiology of behavioral processes.

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ABSTRACT

Functional neuroimaging studies have shown that actual situations of uncertain or distant threats increase the activity of forebrain regions, whereas proximal threats increase the activity of the dorsal midbrain. This experiment aimed at testing the hypothesis that brain activity elicited by imagined scenarios of threats with two different magnitudes, potential and imminent, resembles that found in response to actual threats. First, we measured subjective responses to imagined scenarios of potential and imminent threats compared with neutral and pleasant scenarios. The same scenarios were used as a paradigm in a functional magnetic resonance imaging experiment. Behavioral results show that the scenarios draw a gradient of hedonic valence and arousal dimensions. Both potential and imminent threat scenarios increased subjective anxiety; the imminent threat scenario also increased feelings of discomfort and bodily symptoms. The functional magnetic resonance imaging results revealed modulations of BOLD signal in the ventromedial prefrontal cortex by potential threat and in the periaqueductal gray matter by imminent threat. These results agree with previously reported evidence using actual threat situations, indicating that mental imagery is a reliable method for studying the functional neuroanatomy of relevant behavioral processes.

1. Introduction

Studies of nonhuman animal species have provided substantial evidence of specific defensive behaviors depending upon the features of the threatening situation, which include magnitude, distance and ambiguity of the threat, as well as the availability of escape or hiding places [1]. Risk assessment is an adaptive defensive response when the threat has a high level of ambiguity and/or is at a safe distance. Flight is an adaptive strategy when the threat is proximal, unambiguous, of high magnitude and an escape route is available. Otherwise, when there is no available route or hiding place, defensive threat and attack are the adaptive responses most often performed [2–4].

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Aiming to verify the correlation between animal and human defensive strategies, Blanchard et al. [4] proposed a set of imagery scenarios that vary along the mentioned threatening dimensions. These scenarios were tested in Hawaiian [4] and Brazilian [5] healthy volunteers, and the results pointed to a resemblance between nonhuman and human defensive repertoires [6]. Perkins and Corr [7] used the same scenario set and found an association between psychoticism, as one characteristic of personality, and the evaluation of defensive magnitude which, in its turns, influenced the defensive choices and orientation to direction away from threat source. Animal studies have also provided evidence for neural substrates of defensive reactions [8]. Risk assessment behaviors are related to increased activity in forebrain areas [9,10]. The midbrain periaqueductal gray matter (PAG), whereas also involved in mediating risk assessment behavior [11,12], is commonly associated with urgent responses, such as flight and fight [9,10].

A series of well-designed functional magnetic resonance imaging (fMRI) studies found a parallel between nonhuman and human defensive neural processing. In short, they have shown that distant or potential threats are associated with activity in the ventromedial prefrontal cortex (vmPFC), but as the threat becomes nearer and intense, brain activity shifts to the PAG [13–15]. In these experiments, actual threat situations were used. One study used a predator-prey videogame, controlled by the experimental subject [13], and the other simulated a tarantula moving back and forth from one of the subject's bare foot [15].

Knowledge about the neurobiology of defensive behaviors can be relevant for the understanding of mental disorders, mainly anxiety disorders. However, modeling threat situations in human subjects is not only expensive and possibly painstaking, but also has ethical and practical limitations. These shortcomings could be surmounted if mental imagery proves effective in changing brain activity in meaningful ways. Because reported evidence has shown that mental imagery can reproduce subjective responses and brain activity that are expected in real situations [16,17], we aimed at testing the hypothesis that brain activity elicited by imagined scenarios of distal and imminent threats would resemble that found in response to actual threats.

In the present study, we first measured subjective responses to imagined scenarios of potential and imminent threats, compared with neutral and pleasant ones, in order to estimate the ability of the scenarios to generate different threat dimensions. The same scenarios were then used as a paradigm in an fMRI experiment. We predicted that the imagination of an aversive scenario featured by potential threat would elicit activity in forebrain areas, such as vmPFC and amygdala, whereas the imagination of a scenario of proximal threat would engage midbrain areas, particularly the PAG.

2. Behavioral experiment

2.1. Material and methods

2.1.1. Participants

Twenty healthy volunteers (17 women, age = 28.5 ± 4.1) participated in this study. The participants were recruited by poster advertisements, electronic messages and personal contact. Individuals had at least 12 years of schooling, with no history of psychiatric and neurological condition. Participants were not included if they used any psychoactive substances and/or medication within two weeks before the experiment (except contraceptives). The local Research Ethics Committee of Ribeirão Preto Medical School, University of São Paulo, Ribeirão Preto, São Paulo, Brazil, approved the study and written informed consent was obtained from all participants.

2.1.2. Mental imagery paradigm

The mental imagery paradigm was composed of four scenarios, two of them extracted from the Defensive Behavior Questionnaire [4]. One scenario represented an imminent threat (scenario *Elevator*) and another potential threat (scenario *Noise*). These scenarios have been chosen because, in previous studies [4,5], the former was evaluated as the highest magnitude of threat and the lowest possibility of escape and of finding a hiding place; the latter was rated as the most ambiguous scenario. The most frequently recorded response to the *Elevator* scenario was defensive attack and to *Noise*, checking out. The other two scenarios represented an intended neutral scenario (*Meeting*) and a pleasant scenario (*Beach*), situations constructed to the study in order to contrast with the threat scenarios.

a) *Meeting* (neutral scenario): *"It is night and you are alone at home watching TV. The phone rings and when you answer the phone it is a co-worker confirming the meeting the next morning"*.
b) *Noise* (potential threat scenario): *"Late at night, it is dark and you are sleeping alone in your bed. You suddenly wake up feeling that you heard a suspicious noise"*.
c) *Elevator* (imminent threat scenario): *"Late at night, you're alone in an elevator. When it stops and the doors open, a rough looking stranger gets in fast to attack you, blocking your exit"*.
d) *Beach* (pleasant scenario): *"You are alone and slowly walking along a beach. It is the end of the day and, on the horizon, you can see the sunset. Some children invite you to complete their group that is playing volleyball"*.

A standard set of instructions was provided to all participants as follows: "*You will hear the script of a situation that we can go through. Listen to it carefully and focus on it. Imagine yourself taking part in the situation, as if it were real. Imagine the most likely feelings and reactions you would have to it, the more spontaneous responses. Once you are imagining the depicted scene, stir a finger of your right hand. Remain focused and imagining yourself in the scenario until you receive instructions to stop.*"

To elicit emotional arousal, a professional actor recorded an audio describing each script aloud, giving emotional tone to each situation.

2.1.3. Hedonic valence and arousal and quality of the mental imagery

Assessments of the hedonic valence and the arousal caused by each scenario were made with Likert-type scales based on the concept that underlies the work of Lang and coworkers [18]. The anchors of the valence scale varied from 1 (unpleasant) to 9 (pleasant), and of the arousal scale from 1 (calm) to 9 (excited).

An estimative of quality of the generated mental images was assessed through a Likert-type scale, anchored from 1 to 9, as previously proposed [19]. Seven qualities were evaluated: (a) the ease in forming the mental imagery (1 = very easy, 9 = very difficult); (b) the amount of details included in the mental imagery task (1 = highly detailed, 9 = without any detail); (c) the clarity in the image displayed (1 = very sharp, 9 = very vague); (d) the ease of maintenance of the imagery during the period proposed (1 = very easy, 9 = very difficult); (e) the changes in the detail amount during the task (1 = nothing at all, 9 = dramatic change); (f) how much of the information provided by the script was used in the imagination of the situation described in each scenario (1 = all the script, 9 = just a small portion of the script), and (g) the size of the mental imagery set (1 = very small, 9 = very large).