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Decision making under hypoxia: Oxygen depletion increases risk seeking for losses but not for gains

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Abstract

We report a preliminary study that compared decisions made in an oxygen depleted environment with those made in a normoxic environment. Participants were presented with a series of choices that involved either losses or gains. For each choice they were forced to choose between a sure thing and a gamble of the same expected value. For choices involving losses, participants were more risk seeking in the oxygen depleted environment; for those involving gains, no difference was found.

Keywords: oxygen depletion, hypoxia, risk aversion.

1 Introduction

Hypoxia is the result of an inadequate oxygen supply to the cells and tissues of the body. Low aerial oxygen concentration is first detected by sensory receptors in the carotid body and then relayed to the hypothalamus (Kalia & Welles, 1980; Swanson & Sawchenko, 1983). The body responds to the decrease in the oxygen arterial saturation by increasing heart rate, blood pressure, ventilation, and the production of stress hormones (Buchheit, Richard, Doutreleau, Lonsdorfer-Wolf, Brandenberger, & Simon, 2004; Fishman, Fritts, & Cournand, 1960; Richalet, Letournel, & Souberbielle, 2010). Such alterations are driven by the sympathetic nervous system and could reach awareness if oxygen depletion is sufficiently high. However, mild oxygen depletion is not easily detected by higher-order brain structures (Herman & Cullian, 1997).

Research has investigated the effects of hypoxia on human cognitive functions (Virués-Ortega, Buela-Casal, Garrido, & Alcázar, 2004). Most studies focused on basic functions, such as visual perception, memory, attention, and language (Lieberman, Protopapas & Kanki, 1995; Lieberman, Protopapas, Kanki, Reed & Youngs, 1994; Nelson, Dunlosky, White, Steinberg, Townes & Anderson, 1990; Townes, Hornbein, Schoene, Sarnquist & Grant, 1984). The data show that a 15% reduction in the arterial blood oxygen saturation diminishes individuals' concentration capacity and muscular coordination, which impairs language production and visual perception (Ward, 1975). A 25% reduction in the arterial blood oxygen saturation diminishes memory performance and induces emotional lability and major motor impairments.

With the present research we aim to investigate the effect of hypoxia on judgment and decision making. We believe that such research is worth pursuing for two reasons. First, people frequently experience mild levels of hypoxia, such as during prolonged physical exercise, underwater diving, high altitude recreational activities (e.g., mountaineering, paragliding, parachuting) or a flight when a defect occurs to the cabin pressurization system. Second, bad judgments and decisions during these activities can be fatal.

Although there is no direct research on the impact of hypoxia on judgment and decision making, there is research concerning the impact of its effect (stress). Current views on cognitive system architecture nested within dual-process approaches (Evans, 2003; Kahneman & Frederick, 2003; Reyna, 2004) suggest that stressful conditions affect decision-making by broadening the prevalence of intuitive, automatic processes over analytic, deliberative ones. In stressful situations individuals might rely on simple rules of thumb or heuristics, rather than on analytic processes that aim to maximize subjective utility. Although heuristics in certain contexts are efficient

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guides for routine but complex tasks (Gigerenzer & Todd, 1999; Kahneman, Slovic & Tversky, 1982), in others they can lead to systematic biases. For example, recent research (Porcelli & Delgado, 2009) has shown that acute stress induced by keeping ones hand in freezing water modulates gamble decisions, partially exacerbating a bias known as the *reflection effect*: people's tendency to avoid risk to secure a certain gain and to seek risk to avoid a certain loss (Kahneman & Frederick, 2007; Kahneman & Tversky, 1979).

With the present research we investigated whether oxygen depletion also leads to an exacerbation of the reflection effect. In a laboratory setting, we compared decisions made in a mildly oxygen-depleted environment with those made in a normoxic environment. In contrast to previous studies where participants were aware of the stressor used (e.g., time pressure; cold water; social pressure), participants in the present study were not aware of the mild oxygen depletion. We investigated the reflection effect using a task adapted by De Martino, Kumaran, Seymour, and Dolan (2006) where participants had to make a series of forced binary choices between a sure thing and a gamble of the same expected value, either in the domain of gains or losses.

2 Method

A sample of 30 right-handed university students [14 males (mean age 23.3 years ± 4); 16 females (mean age 20.5 years ± 1.9)] volunteered to participate in the study. They were informed that the aim of the study was to investigate the effects of high altitude on decision making. All participants took part in three research sessions, which were separated by a 7-day interval: a familiarization session in normoxic condition (oxygen concentration of 20.9%); a control session in normoxic condition (identical to the familiarization session); and an experimental session in hypoxic condition (oxygen concentration of 14.1%). These parameters were chosen because they simulate respectively an altitude of 0 meters above sea level (normoxic) and an altitude of 3,000 meters above sea level (hypoxic).[1] The familiarization session was always first and aimed to familiarize participants with the laboratory (i.e., the hypoxic room[2]) and the computer-based decision tasks. The order of the normoxic and hypoxic sessions was counterbalanced: 15 participants received the normoxic session followed by the hypoxic session, while the rest received the reverse order. To eliminate potential demand characteristics, participants and experimenter were blind as to the order of the sessions.

Table 1: The subjective feelings questionnaire. The 11 items were partially adapted from the HADS scale (Hospital Anxiety and Depression Scale). They involved general anxiety items (Q1 to Q7), and specific anxiety items related to the hypoxic room (Q8 to Q11). For each item, participants could respond by selecting one of four options: 1= Not at all; 2= A little bit; 3= Yes, but not very much; 4= Yes, absolutely.

Number	Item
Q1.	I feel tense, restless.
Q2.	I sense fear, as something negative is going to happen.
Q3.	Worrying thoughts keep buzzing around in my head.
Q4.	I can sit here and feel relaxed.
Q5.	I have a strange feeling, like butterflies in my stomach.
Q6.	I feel restless, as I should stay in movement.
Q7.	I feel panic.
Q8.	I have shortness of breath.
Q9.	I feel dizzy.
Q10.	I feel euphoric.
Q11.	I have a feeling of heaviness.

The procedure was identical in all three sessions. Participants entered the room one at a time, the experimenter applied to them technical equipment that measured some physiological parameters, and then asked them to watch a neutral video on mountain settings for 20 minutes, to allow enough time for the physiological alterations to take place. Subsequently, participants had to perform a psychomotor speed task followed by the target risk-taking task. These tasks will be described in detail below. To assess whether participants were aware of the oxygen manipulation, at the end of each session we asked them to state which condition they believed it was,[3] and to fill a questionnaire concerning self-reported feelings (Table 1).

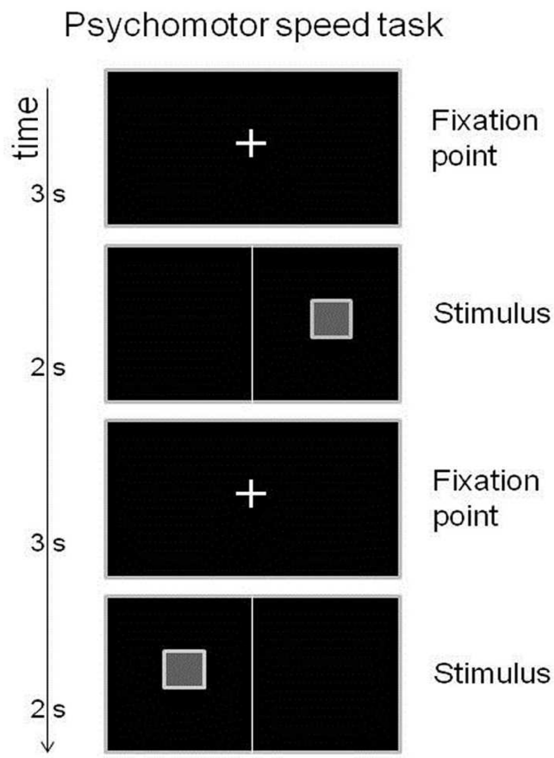
We measured two physiological parameters during each session: heart rate and oxygen arterial saturation (SaO2). Heart rate was recorded in 5 sec intervals (Polar Electro Oy, Kempele, Finland). SaO2 was measured by

[1] In a pilot experiment (N=7) we identified the 14.1% of oxygen concentration as the one producing the best tradeoff between significant physiological alterations and lack of awareness of the oxygen manipulation.

[2] The hypoxic room is a chamber where a hypoxic environment can be created via an air separation unit that pumps oxygen depleted air into the room: whereas the total pressure stays the same, the oxygen content (%) is reduced in order to decrease the partial pressure of oxygen in the body. In the present research room temperature (21° C) and air dampness (32%) were kept constant across sessions.

[3] "What do you think? Are we either in the 0 meters or in the 3,000 meters above sea level condition?"

Figure 1: Computer-based psychomotor speed task. Participants were presented with a sequence of 32 trials, where the target stimulus (a green square) was presented either on the right or left. Participants were instructed to respond as fast as they could by pressing the left button on a keyboard when the stimulus appeared on the left, and the right button when the stimulus appeared on the right. Both response accuracy and response times were registered.



a portable pulsoximeter (Intermed SAT-500). Measurements were taken on the index finger of the right hand. SaO2 levels were recorded at three points: end of the video (about 25 min after the entrance in the hypoxic room); beginning of the risk-taking task (about 35 min after the entrance in the hypoxic room); and end of the risk-taking task (about 70 min after the entrance in the hypoxic room). We expected higher heart rate and lower SaO2 in the hypoxic condition. Participants were asked to perform a psychomotor speed task after the video task (see Figure 1). Based on previous studies we hypothesized that hypoxia would slow down psychomotor performance (Dykiert, Hall, van Gemeren, Benson, Der, Starr, & Deary, 2010; Kobrick, 1975).

In each session, the risk-taking task was a computer-based task adapted from De Martino, Kumaran, Seymour, and Dolan (2006), in which participants had to respond to a sequence of choices (Figure 2). In each trial, participants had to choose between either a sure thing or a gamble option. The protocol was programmed in E-Prime (Psychology Software Tools, Pittsburgh). The task began with an instruction phase followed by sixteen practice trials. The task was divided in two blocks of 48 trials (16 loss frame, 16 gain frame, and 16 catch trials), ordered randomly. Each trial began with a starting amount of money (e.g., "You receive 25 €"),displayed for 2 sec. Following De Martino et al. (2006), the starting amounts of money were: 25€, 50€, 75€, or 100€. Then, the choice between a sure and a gamble option was presented, for 4 sec, either in a gain or loss frame. The sure thing was presented as the amount of money a participant could retain (in the gain frame) or lose (in the loss frame) for sure from the initial amount of money indicated in that trial. The gamble option was presented by means of a pie chart depicting the probability of winning (in green) or losing (in red) the whole initial amount of money. The expected values of each pair of options were equal. Four probabilities of winning (or losing) were used: 20%, 40%, 60%, or 80%. All variables were fully balanced across frame conditions. The two blocks were composed of the same trials, but presented in a different order, and with a reverse presentation order of the two options (left vs. right side of the screen). Sixteen catch trials in each block were included to check whether participants actively engaged in the task. In catch trials the outcomes related to the two options were not equivalent (i.e., one option was dominant as in De Martino et al., 2006). Participants were instructed to be fast and accurate. They were also told that they would not receive any feedback concerning the outcome of their decisions. Instead, at the end of the three sessions one of their decisions would be extracted randomly and be honoured with real money (between 0–100 €).

3 Results

3.1 Manipulation checks

As expected, the oxygen depletion manipulation altered physiological responses. Participants in the hypoxic vs. normoxic session showed higher heart rate [84 vs. 78.1; $t(29)=3.92$, $p<.001$, mean increase of 8.09%], lower oxygen arterial saturation [90.5 vs. 98.5; $t(29)=15.13$, $p<.001$, mean decrease of 8.08%], and higher psychomotor response times [588.6 vs. 545.7; $t(1,29)=2.6$, $p=.013$, mean increase of 8.85%]. Participants seemed unaware of the oxygen manipulation: their responses as to which session they thought they were did not deviate significantly from chance [McNemar $p=.60$]. Moreover, self-reported feelings did not differ between the hypoxic and normoxic sessions [$t(29)=1.27$, $p=.214$].

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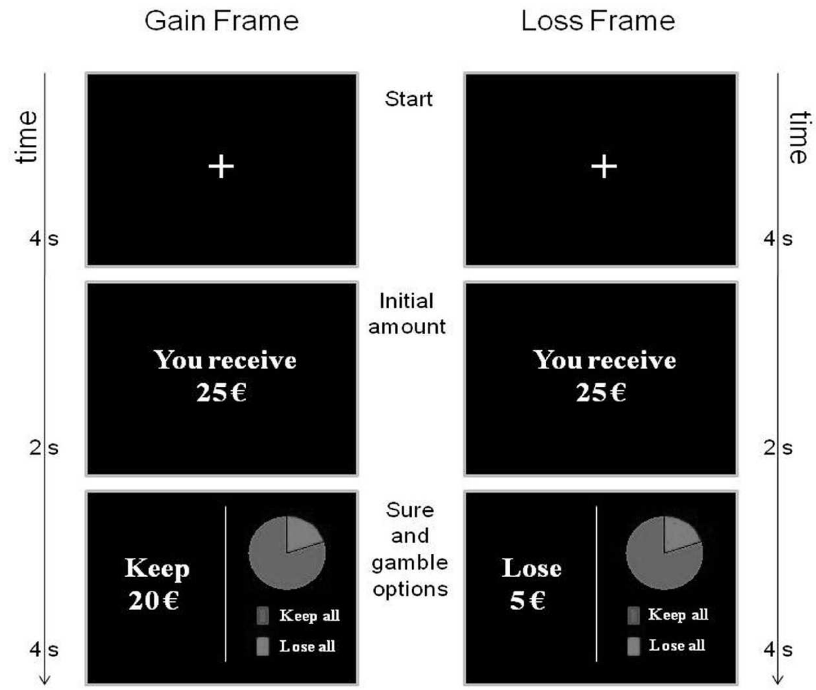
Figure 2: The computer-based risk-taking task adapted from De Martino, Kumaran, Seymour, & Dolan (2006).



3.2 Risk-taking task

Turning to the target task (see Figure 3), the effect of hypoxia on choice was examined by a 2 (oxygen level: normoxia vs. hypoxia) x 2 (decision frame: gain vs. loss) repeated measure analysis of variance (ANOVA), conducted on gamble choices.[4] Results revealed a significant main effect of decision frame, F(1,28)=33.75, p<.001, η_p^2=.55. Participants showed greater risk seeking in the loss frame than in the gain frame, both in the normoxic session [12.3 vs. 10.4, t(29)=2.95, p=.006] and hypoxic session [15.3 vs. 10.9, t(21)=5, p<.001]. Thus, independent of session and as predicted by the reflection effect, participants were more risk seeking in the loss frame (44%) than in the gain frame (33%). Results also revealed a significant main effect of oxygen level, F(1,28)=4.8, p=-037, η_p^2=.15, showing a greater risk seeking in the hypoxic condition than in the normoxic one [mean = 26.7 vs. 22.7, t(29)=2.22, p=.034], but this main effect was qualified by a significant interaction between the two factors, F(1,28)=7.77, p=.009, η_p^2=.22. Although participants in the hypoxic versus normoxic sessions were equally risk averse for gambles in the gain frame [t(29)=.55, p=.58], they were significantly more risk seeking for gambles in the loss frame [t(29)=2.83, p=.008]. This interaction does not seem to be mediated by attention. If this were the case, one should also find differences between the hypoxic and normoxic sessions for experimental trials involving gains and for catch trials, but no such differences were found (Figure 4).

4 Discussion

We reported a preliminary study that examined how a mild decrease in oxygen level (from 20.9% to 14.1%) influences the reflection effect. We found that under a mild decrease in oxygen level the reflection effect was exacerbated. The locus of the effect of hypoxia on the reflection effect was in the domain of losses. The mild decrease in oxygen level increased risk seeking in the domain of losses, but had no effect in the domain of gains.

This preliminary finding can contribute to the scientific debate among neuroeconomists about whether the difference in risk attitudes for decisions involving gains versus losses is a by-product of a single brain system or the interaction of multiple systems. Several authors, on the basis of neuroimaging data, suggest that decisions regarding losses and gains are adequately explained by a single system that treats them asymmetrically (Tom, Fox, Trepel, & Poldrack, 2007). Other authors sustain that the difference between gains and losses supports the existence of separate systems, and that losses evoke an over-learned fear response that overrides deliberative assessments (De

[4]We also checked whether the presentation order of the control and experimental conditions and the position of the options (left or right) influenced the proportion of gamble choices; no differences were found.

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Figure 3: Percentage of gamble choices by session (normoxic vs. hypoxic) and frame (gain vs. loss). In both sessions, participants were more risk seeking for losses versus gains. Participants were generally risk averse but their risk seeking significantly increased only in the loss frame of the hypoxic session.

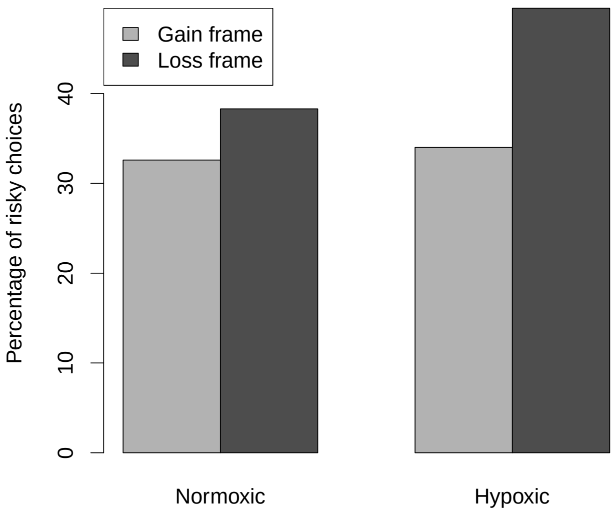
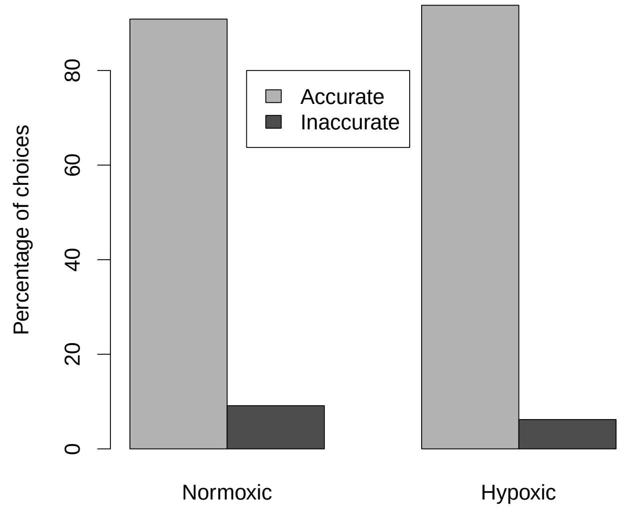


Figure 4: Percentage of accurate (and inaccurate) choices to catch trials by session (normoxic vs. hypoxic).



Martino, Camerer, & Adolphs, 2010). The interactive effect of hypoxia obtained in the present research suggests that losses and gains are treated by separated brain systems.

The present study is the first attempt to investigate experimentally the effect of hypoxia on decision-making, adding experimental support to the idea that heuristic judgment underpins decisions in high risk situations, such as ones that have to be made in adverse environmental conditions (McCammon, 2002). The present research is preliminary and thus needs to be consolidated by future research. Future research could concentrate on at least three issues. First it needs to replicate the different effect of hypoxia on decisions involving gains versus decisions involving losses. Second it needs to empirically investigate the effect of hypoxia on loss aversion. Third it needs to examine the relation between behavioral risk-taking and hypoxia (e.g., using behavioral measures and computer simulations).

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