

# Misperceptions and hallucinatory experiences in ultra-trail, high-altitude runners

## *Idee sbagliate ed esperienze allucinatorie in ultra-trail, corridori d'alta quota*

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**SUMMARY. Background.** The Mountain Activities Neuro-behavioural Research Programme is a research project born in the 2<sup>nd</sup> Unit of Psychiatry, Department of Clinical and Experimental Medicine at the University of Pisa to investigate the effects of altitude on the mental and neuro-behavioural aspects of people performing activities in mountainous areas. **Methods.** In this study, after elaborating a standardised data collection form, based on traditional psychopathology notions, to classify the misperceptions reported by the athletes taking part, we investigated the various types of these misperceptions in 21 athletes (including only one female), with a mean age of  $44.90 \pm 8.51$  (min 33 and max 58). **Results.** The athletes reported different kinds of misperceptions. It was possible to highlight three different clusters of athletes, based on the similarities between the kinds of misperceptions reported in each cluster: (a) anomalies in the intrinsic characteristics of perceptions (i.e. depersonalisation and derealisation), (b) illusions and (c) hallucinations. **Conclusions.** This study supports the concept that anomalous perceptual experiences may occur independently of the context of psychiatric or neurological disorders. The chance of observing hallucinatory phenomena outside the context of psychiatric disorders and in extreme environmental conditions among ultra-trail runners may offer a unique opportunity to those intending to study psychopathological conditions in a 'para-physiological' context.

**KEY WORDS:** high altitude, hallucinatory experiences, misperceptions, ultra-trail runners, sleep deprivation.

**RIASSUNTO. Introduzione.** Il Mountain Activities Neuro-behavioural Research Programme è un progetto di ricerca nato nella seconda Unità Operativa di Psichiatria Universitaria del Dipartimento di Medicina Clinica e Sperimentale dell'Università di Pisa, con lo scopo di studiare gli effetti dell'altitudine su aspetti mentali e neurocomportamentali di soggetti che svolgono attività agonistica in montagna. **Metodi.** In questo studio, usando una scheda per la raccolta standardizzata dei tipi di dispercezioni secondo la psicopatologia classica, abbiamo valutato il tipo di dispercezione provata da 21 atleti (20 maschi e 1 sola femmina) con età media di  $44,90 \pm 8,51$  anni (compresa fra 33 e 58) durante l'attività agonistica. **Risultati.** Le dispercezioni riportate dagli atleti durante l'attività agonistica possono essere raggruppate in tre diversi cluster: (a) anomalie delle caratteristiche intrinseche delle dispercezioni (per es., depersonalizzazione e derealizzazione), (b) illusioni e (c) allucinazioni. **Conclusioni.** Questo studio rafforza il concetto che anomalie delle senso-percezioni possano verificarsi anche in contesti non neuro-psichiatrici. La possibilità di poter osservare fenomeni allucinatori al di fuori della psichiatria e in ambienti competitivi estremi come quello dei "runners" in montagna, offre un'opportunità unica per lo studio di fenomeni psicopatologici in contesti para-fisiologici.

**PAROLE CHIAVE:** alta quota, esperienze allucinatorie, ultra-trail runners, deprivazione di sonno.

## INTRODUCTION

The relationship between high-altitude exposure and psychic and cognitive dysfunctions has long been under investigation; many researchers have tried to investigate whether and how altitude could influence the psychic and neuro-behavioural structure of the subjects who were exposed. Several studies have attempted to correlate affective symptoms, fluctuations in levels of anxiety, misperception phenomena

and cognitive functions with altitude, obtaining results that are at times contradictory<sup>1-6</sup>.

The Mountain Activities Neuro-behavioural Research Programme is a research project launched in the Department of Clinical and Experimental Medicine of the 2<sup>nd</sup> Unit of Psychiatry at the University of Pisa, with the aim of investigating the effects of altitude on the mental and neuro-behavioural aspects of people performing activities on mountains. Work, tourism and sport bring many people to practise

their activities at medium and high altitudes on mountains, and a significant number of these subjects may experience symptomatic disorders related to adaptation to reduced oxygen partial pressure in the atmosphere. Some authors suspect that these maladaptive reactions are accompanied by an increase in people's levels of anxiety, particularly in those who suffer from certain anxiety disorders or who are in various ways prone to develop it<sup>7-16</sup>.

Moreover, sports activities would seem to be related to some unusual phenomena; Hurdziel et al.<sup>15</sup> reminded their readers that ultra-trail experience a wide range of symptoms, ranging from lags in responding to cognitive tasks to visual hallucinations.

These misperceptions, as well as sensations of floating, even though peculiar in their nature, were not associated with a neurological deficit or psychiatric disorder of any kind<sup>16-27</sup>.

Recently, psychotic episodes during exposure to extreme altitude (over 3,500m) have been systematically collected and analysed, but not yet acknowledged as a distinct clinical entity<sup>28</sup>.

Brugger et al.<sup>29</sup> investigated unusual perceptual experiences in a group of extreme-altitude climbers (above 8,500m) without supplementary oxygen, confirming earlier anecdotal evidence of hallucinatory experiences during mountain activities at extreme altitude.

Our research programme aims to identify the neuro-behavioural and psychic features of human adaptation in extreme environmental conditions among ultra-trail runners participating in the Tor des Géants®, one of the best-known ultra-trail races, which is held annually in the Aosta Valley (Northern Italy). Trail running is a sport which, when there are steep gradients, combines running with 'hiking', which in this context means running 'on any unpaved surface'. This activity is usually marked out by the considerable length of the routes, as well as by significant differences in level, both positive and negative. In the last few years, ultra-trail running, because of its rising popularity, has led to a remarkable increase in the frequency of 'extreme' endurance races all over the world<sup>30-33</sup>. According to a 2010 special report on trail running published by the Outdoor Industry Foundation, "4.8 million Americans ages 6 and older participated in trail running in 2009"<sup>34</sup>. One of the best-known races in the world is the Tor des Géants®, which has been held in the Aosta Valley since 2010. The total length of this race is 330 km (205 miles), to be completed in less than 150 hours, but every year an average of about 40% of the athletes taking part do not complete the race within this time limit.

Together with physical, stress-related problems, it is well established that runners accomplish these kinds of races with minimal sleep and under extreme psychological conditions<sup>35-38</sup>. During mountain sports activities, athletes must consider technical difficulties together with the climate, terrain and altitude. Even though there are studies focusing on physical adaptation to extreme conditions in mountain activities and on the temperamental traits of these athletes, there is a shortage of data about the neuro-behavioural and psychic features of human adaptation to adverse conditions in such situations<sup>39-45</sup>.

During our clinical interviews, we were impressed by the high rate of temporary hallucinatory experiences reported by the athletes in the recruited sample. That result was unexpected because, in a way diverging from previous studies, these hallucinatory experiences occurred at "relatively low" altitudes<sup>24,29</sup>.

This datum led us to investigate these phenomena in greater depth and to work out a classification system, based on traditional psychopathology notions, to bring clarity to our analysis of the misperceptions reported by the athletes<sup>46,47</sup>.

In the present study, we have focused our attention on the prevalence of temporary hallucinatory phenomena occurring in athletes performing in the Tor des Géants® race by describing their essential features and the possible correlated factors. This could be recognised as a unique opportunity to study psychopathological phenomena in a 'para-physiological' context in the athletes directly involved, outside the framework of psychiatric or neurological disorders.

## METHODS

### Setting

A trained medical staff member of the Psychiatric Clinic, Department of Clinical and Experimental Medicine, at the University of Pisa went to Courmayeur in the Aosta Valley (Northern Italy) to first recruit and then evaluate ultra-trail participation in the Tor des Géants®.

This race consists of a route of 356 km with a positive difference in the above-sea level from start to finish of about 2,700 metres; those competing cross the territory of 34 towns. The race takes place in a single stage, with no limits on speed, but with a limited time allowed, in semi-self-sufficiency.

The path of the Tor des Géants® includes many high-altitude stretches, some of them at an altitude of over 3,000 metres, with weather conditions that can be very difficult (wind, cold, rain, snow, ice), alternating with stretches at much lower altitudes, where weather conditions may be different or the opposite. The runner must expect to face different climatic conditions during the day and night hours. Accurate physical training, optimal psychic condition and a real capacity for personal autonomy are mandatory requirements for those facing this race.

### Sample

The inclusion criteria do not refer to gender or age limits, or even the ability to sign an informed consent document to allow data processing. The exclusion criteria included: the inability of these subjects to follow the indications fixed in the protocol (confused state or psychomotor agitation), and an ongoing history of drug use. Our sample consisted of 21 subjects with an average age of 44.90 ± 8.51 (min 33 and max 58) with 20 males (95.2%) and one female (4.8%). 16 athletes (76.2%) were Italians, 1 Turkish (4.8%), 1 French (4.8%), 1 Dutch (4.8%), 1 Scottish (4.8%) and 1 Japanese (4.8%). This sample included two (9.5%) athletes with a positive family history of psychiatric disorders, but no one presented a documented personal history for psychiatric disorders. 3 subjects (14.3%) had made use of psychostimulants (e.g. MDMA, methamphetamine, cocaine) throughout their lives. None of them were currently receiving therapy for any chronic medical pathology.

### Assessment

#### Misperceptions

Moving according to the traditional principles of psychopathology, we opened an inventory to properly specify the misperceptions reported by athletes.

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According to Jaspers, abnormalities in perception occur when a real object is perceived in a distorted way or when there is a perception, despite the absence of an object. Among the entire class of misperceptions, four significant differentiations can be made:

- perceptual anomalies;
- anomalies affecting the intrinsic characteristics of perceptions;
- dissociation of perceptions;
- false perceptions.

Perceptual anomalies include: quantitative alterations both in the sense of an increased intensity of perceptions (hyperaesthesia), and in the sense of attenuation of perception (hypoesthesia); qualitative changes (dyschromatopsia, xanthopsia, chloropsia, erythrop-sy, palinacusia); alterations of a spatial form (micropsia, macropsia/dismegalopsia, porropsia, metamorphopsia, parapsopia, teleopsia, pelopsia, alloaesthesia, akinetopsia); alterations of the experience of time; associated sensations or synaesthesia.

The anomalies affecting the central characteristics of perceptions or alterations of the state of consciousness are distinguished either by an altered perception of one's body image or by a feeling of the extraneousness of the perceived world often associated with unpleasant or pleasant affective tones (depersonalisation, de-realisation, autoscopic phenomena). Autoscopy is the experience of a person who sees him- or herself outside their bodies while knowing that what they see is none other than that same perceiver. It is not a simple visual alteration, because kinaesthetic and bodily sensations must be present, too.

The dissociation of perceptions occurs when two associated perceptions do not merge in their relationships in harmony with the real data.

False perceptions are distinguished by illusion, hallucination, pseudo-hallucination, and hallucinosis.

The term illusion means a psycho-sensorial disorder in which external stimuli merge with subjective psychic elements to form a perceptive whole that does not correspond to reality, although it does give rise to the idea (producing an inadequate perception of the object). In other words, illusions do not involve either the transformation of the subjective experience of reality or the loss of the limit between external and internal reality. They are misinterpretations of actual external stimuli. Factors favouring illusions are the misidentification of the stimulus, a particular attitude of expectation related to the emotional state (waiting for a threat, an adverse event, a pleasant encounter), or a lowering of the attention threshold, as happens in fatigue, stress, abuse of stimulants and other circumstances.

There are, in the classic analyses, four types of illusion: illusions of inattention, affective illusions, illusions of completion (physiological or integrative) and pareidolia.

Pareidolia, the fourth type of illusion arises from primary sensory stimuli that can be structured and integrated to the point of assuming the characteristics of a lively image, without the participation of affective factors or inattention. The contribution made by attention does not imply a redefinition of illusory configurations, as happens in affective and inattentive illusions. In a cloud with blurred contours, we identify a large animal, in a group of spotted spots on the wall the figure of a ship or a person. Indefinite stimuli are interpreted through a constructive-fantastic elaboration.

Pseudo-hallucinations are a category of mental images that, even if bright and vivid, lack the concreteness of perceptions; they are viewed in full consciousness, and are recognised as different from real perceptions. They are not localised in physical space, but in a subjective space.

Hallucinations are false perceptions, which subjectively possess the basic characteristics of perception, but arise without adequate sensory stimuli (perception of the object). They are placed in outer space with the traits of concreteness and spatiality (unlike imagination) and carry the same conviction of certainty as reality. They are divided into simple, compound, combined and functional. They can be auditory, visual, gustatory, olfactory, somesthetic and coenaesthetic.

Hallucinosis is a mental state giving rise to conscious hallucinations, which are recognised and criticised as such by the patient. This basic fact is the main characteristic that differentiates hallucinosis from the production of hallucinations<sup>44</sup>.

#### *Other variables*

Our investigation also includes the ability of athletes to complete the race and the presence of the following adverse events other than misperceptions: Gastrointestinal Symptoms, High Altitude Disease, Urinary Symptoms, Resistant Insomnia, Acute Anxiety, Distress Call, Trauma and Osteomuscular Symptoms.

#### **Statistical analysis**

We reported the number and percentage of cases presenting misperceptions, and then we clustered cases based on misperception typology, according to the squared Euclidean distances and using the method of the average linkage between groups. We described the clusters deriving from the statistically significant divergences found between misperceptions of different types, on the basis of the chi-squared test between clustered groups.

## **RESULTS**

None of the athletes in our sample reported alterations of spatial forms, alterations of the experience of time, synaesthesia, dissociations of perceptions, pseudo-hallucinations, or hallucinosis. Twenty-one athletes reported different kinds of misperceptions from those just mentioned. Six (28.6%) athletes described perceptual anomalies; of those six, 4 (19.0%) illustrated qualitative abnormalities, 1 (4.8%) a quantitative one and, in the case of 1 (4.8%) athlete, both types. Five (23.8%) athletes reported anomalies in the intrinsic characteristics of perceptions: 3 (14.3%) described derealisation, and 1 (4.8%) both derealisation and depersonalisation; lastly, 1 (4.8%) referred to autoscopic phenomena. Nineteen (90.5%) athletes had false perceptions and, of these subjects, 11 (66.7%) had only illusions (inattentive, affective and pareidolia), while 5 (38.1%) athletes reported only hallucinations: of those 5, three (14.3%) spoke about simple ones and two (9.5%) complex ones. Three athletes (14.3%) described both illusions and hallucinations, with 2 (9.5%) of them attesting to illusions plus simple hallucinations and the third (4.8%) to illusions plus complex hallucinations. The nature of the reported illusions was visual in 14 (66.7%) athletes. The exception was complex hallucinations, in which visual and auditory elements were combined in a single experience (involving 14.3% of the athletes); the symptoms of derealisation, depersonalisation and autoscopic phenomena, which are part of the coenaesthetic typology, were described

by 5 (23.8%) athletes, of whom 2 (9.5%) reported uniquely coenaesthetic elements, 2 (9.5%) also described visual illusions and 1 reported coenaesthetic elements plus simple hallucinations. Every athlete reporting such events was evaluated for any medical and psychiatric condition, family history and previous or current substance abuse. None of these athletes turned out to have any significant medical or psychiatric illness, family history of psychiatric disorder, any other contact with mental health operators, or was known to have been exposed to psychotropic substances.

Table 1 shows the clinical characteristics of three separate groups according to the membership of each cluster found among our subjects.

The first cluster included 2 (9.5%) athletes, and it was distinguished by anomalies in the intrinsic characteristics of perceptions (depersonalisation and derealisation), with a statistically significant difference ( $p < 0.028$ ). This difference resulted in a higher degree of significance when the subgroups for depersonalisation ( $p < 0.007$ ) and derealisation ( $p < 0.009$ ) were included. In this cluster there were no examples of false perceptions.

The second cluster was the most strongly represented (11 athletes, 52.4%) and comprised males reporting illusions (with a statistically significant difference,  $p < 0.002$ ). In this cluster, 6 athletes (54.5%) also reported experiencing qualitative and quantitative anomalies in their perceptions, but the statistically significant difference was lower ( $p < 0.022$ ).

The third cluster included 8 (38.1%) athletes, and it was differentiated by the presence of hallucinations, with a sharp, statistically significant difference ( $p < 0.000$ ). Of these athletes, as many as 5 (62.5%) said they had simple hallucinations ( $p < 0.005$ ).

The 3 clusters proved to be independent of gender, age, and race result (finishers vs non-finishers), number of reported misperceptions, and other adverse events not involving misperceptions (in the last case, independently of both typology and number of adverse events).

In summary, based on our clustering analysis, it may be stated that, during the race, athletes in our sample tended to become assignable to one of 3 groups. Most of those belonging to a group experienced a specific type of misperception: thus, a majority of those susceptible to misperceptions reported illusions, one third tended to experience simple hallucinations and the smallest group depersonalisation/derealisation.

## DISCUSSION

In our sample, a majority of the athletes who experienced visual misinterpretations (14 out of 17) described the imaginative reworking of clouds, rocks, bushes, or trees, interpreting them as fantastic beasts, such as dragons, goblins, or gremlins. These illusions, even though they were sometimes responsible for emotional distress, would seem to suggest a diagnosis of pareidolia, and may be interpreted as para-physiological phenomena related to adverse conditions<sup>48</sup>.

One subject reported more complex hallucinations, stating that, while enduring the race, his family members appeared and accompanied him for several kilometres, entertaining him with extended conversations, giving advice on how to complete the race and how to face all adversities.

The hallucination of a “sense of presence” was described by another athlete: while he was in distress over his ability to finish the race, he was helped by a competitor who, as he told us, preceded him and escorted him up to the finish line. However, as the records show, no other athlete was with him when he finished the race, and the previous runner completed his race several hours before the arrival of this proband.

During the competition, one participant was able to talk to Buddha and Gandhi about philosophical problems while having the perception of being in a dream-like state, together with the sensation of floating.

The nature of reported misperceptions corresponds to those usually described in the clinical and alpine literature<sup>16-23,38,40-43,49</sup>; in just a few cases the nature of the hallucinations was more complex and was phenomenologically closer to hallucinatory phenomena related to organic brain damage or major psychosis (such as Bipolar Disorder or Schizophrenia).

In our sample, hallucinatory experiences were transient, without any connection with frank neurological signs, or with a general medical condition. Besides, these experiences do not seem to be associated with a full-blown psychiatric disorder or any possible diathesis for psychopathology (as might be suggested by a familial history of psychiatric disorders, psychotropic treatment/psychotherapy or history of alcohol-substance abuse)<sup>50</sup>.

The absence of a medical or psychiatric disorder permits us to hypothesise that the development of such prevalent hallucinatory phenomena may be related to the peculiar conditions connected with the race.

Among these, we can include sleep deprivation, strenuous exercise, excessive use of not illegal psychostimulant substances taken during the race (caffeine, theine), altitude changes and stress related to a sport performed on harsh terrain.

Specific data about possible links between hallucinatory experiences and high-intensity physical activities in a mountainous setting are currently unavailable. All that can be found are clinical observations about the involvement of acute hypoxaemia and hypocapnia, alteration of cerebral haemodynamic and sleep deprivation<sup>15-29,38,40-43,49-59</sup>.

The symptoms previously described usually occur after a prolonged period of vigorous exercise at high altitudes. The fact is that strenuous exercise and hyperventilation in hypoxic environments produce acute hypoxaemia and hypocapnia, respectively, although the data published so far are currently insufficient to allow any accurate assessment of the relative effect of hypoxic vasodilatation and hypocapnic vasoconstriction on cerebral perfusion and oxygenation<sup>58,59</sup>.

A causal relationship between exercise and hyperventilation, while attractive in theory, remains unproven. If a cerebral haemodynamic is the triggering cause, the delay in onset of symptoms implies that some secondary processes are involved.

Dysfunction of a specific region of the brain, if responsible for body-related processing experiences, is a replicable complication of performing at extreme altitudes. Vestibular processing and integration of sensory input occur in the parietal and temporal cortex and associated limbic structures, and inferior parietal cortex causes loss of balance and sensations of falling, paroxysmal illusions that somebody was nearby, out-of-body experiences, sensations of floating and bodily distortions<sup>51-57,60</sup>.

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Table 1. Clustered groups classified according to the misperceptions experienced.

	Type 1 N=2	Type 2 N=11	Type 3 N=8		
	N (%)	N (%)	N (%)	chi	p
Male Gender	1 (50.0)a	11 (100.0)b	8 (100.0)ab	9.97	0.007
Non-finishers	0 (0.0)a	2 (18.2)a	2 (25.0)a	0.66	0.719
Misperceptions					
1. Anomalies in perceptions	0 (0.0)a	6 (54.5)b	0 (0.0)a	7.64	0.022
1a. Qualitative	0 (0.0)a	5 (45.5)a	0 (0.0)a	5.96	0.051
1b. Quantitative	0 (0.0)a	2 (18.2)a	0 (0.0)a	2.01	0.366
2. Anomalies in the intrinsic characteristics of perceptions	2 (100.0)a	2 (18.2)ab	1 (12.5)b	7.15	0.028
2a. Depersonalisation	1 (50.0)a	0 (0.0)b	0 (0.0)ab	9.97	0.007
2b. Derealisation	2 (100.0)a	1 (9.1)b	1 (12.5)b	9.43	0.009
2c. Autoscopical phenomena	0 (0.0)a	1 (9.1)a	0 (0.0)a	0.95	0.620
3. Dissociations found in perceptions	0 (0.0)a	0 (0.0)a	0 (0.0)a	-	-
4. False perceptions	0 (0.0)a	11 (100.0)b	8 (100.0)b	21.00	0.000
4a. Illusions	0 (0.0)a	11 (100.0)b	3 (37.5)a	12.56	0.002
4b. Pseudo-hallucinations	0 (0.0)a	0 (0.0)a	0 (0.0)a	-	-
4c. Hallucinations	0 (0.0)a	0 (0.0)a	8 (100.0)b	21.00	0.000
4c1.Simple	0 (0.0)ab	0 (0.0)b	5 (62.5)a	10.66	0.005
4c2.Complex	0 (0.0)a	0 (0.0)a	3 (37.5)a	5.68	0.058
Physical adverse events					
1. Gastrointestinal symptoms	0 (0.0)a	2 (18.2)a	2 (25.0)a	0.66	0.719
2. High altitude disease	0 (0.0)a	1 (9.1)a	1 (12.5)a	0.29	0.863
3. Urinary symptoms	0 (0.0)a	4 (36.4)a	0 (0.0)a	4.49	0.106
4. Resistant insomnia	0 (0.0)a	3 (27.3)a	2 (25.0)a	0.70	0.703
5. Acute anxiety	2 (100.0)a	5 (45.5)a	3 (37.5)a	2.54	0.280
6. Emergency requests	0 (0.0)a	0 (0.0)a	0 (0.0)a	-	-
7. Traumas	1 (50.0)a	0 (0.0)b	1 (12.5)ab	5.04	0.080
8. Osteomuscular Symptoms	0 (0.0)a	2 (18.2)a	1 (12.5)a	0.49	0.782
9. Others	0 (0.0)a	2 (18.2)a	1 (12.5)a	0.49	0.782
	M±sd	M±sd	M±sd	F	p
Number of different types	1±0.0	1.73±0.8	1.13±0.6	2.66	0.097
Number of adverse events	2.50±0.7	2.73±1.1	2.38±1.5	0.173	0.843
Age	37.50±0.7	43.45±9.2	48.75±7.0	1.88	0.181

The temporoparietal cortex receives much of its blood supply from the lateral occipitotemporal and angular arteries, which are lower divisions of the middle cerebral artery. Under hypoxic conditions, it is possible that the blood supply is inad-

equated. Alternatively, the complex function of sensorimotor integration may be a task that is extremely sensitive to hypoxic disruption and may be an early sign of dysfunction resulting from global cerebral hypoxia. These suggestions are, however,

speculative, and it is unclear why these regions or functions appear to be particularly sensitive to hypoxic conditions.

Furthermore, some authors tend to single out sleep deprivation as one of the common causes of hallucinatory phenomena, assuming that sleep deprivation is better tolerated for up to 72 hours. In concordance with that generalisation, the runners in our sample reported that they began to experience visual hallucinations starting on the third day of the race. Within this framework, the onset of hallucinatory phenomena would be in line with the data to be found in the literature, suggesting a role for cumulative lack of sleep in the development of hallucinatory phenomena, even if at the moment these elements do not allow us to draw conclusions about a possible causal relationship<sup>16-27, 38, 40-43, 49</sup>.

The need for sleep arises physiologically as a result of synaptic potentiation in wakefulness (new connections are made continuously in response to the environment while an individual is awake, whereas there is no corresponding downscaling or removing of associations). Slow wave sleep mediates a downscaling of synaptic strength, allowing informational efficiency to be restored for the next day. This fact would imply that, if sleep were disturbed, downscaling would be disrupted, with the consequence that the ability of the neural network to correctly detect new associations might no longer be efficient, so allowing abnormal associations to arise and persist without contextual corrections, possibly resulting in the genesis of misperceptions<sup>61</sup>.

As well as these multiple factors, psychostimulants that are taken, in some cases, at high doses, so making them able to increase the dopamine level in the mesolimbic pathway, could promote the appearance of hallucinatory phenomena<sup>62</sup>, according to the classical dopaminergic theory of positive schizophrenic symptoms<sup>63</sup>.

Undoubtedly, the risk factors to which the athletes were exposed were decisive in the genesis of reported misperceptions. However, since all the athletes were exposed to the same environmental conditions, having slept the same average number of hours per day, and having taken the same average quantities and types of psychostimulant substances, the question to be answered is the following: is there a personal substrate that predisposes each subject to develop one specific kind of misperception rather than another?

Our clustering analysis made it possible to identify three types of athletes based on the similarities between the reports given by single subjects in recounting their personal misperception.

As regards the second cluster (illusions), which included a majority of the athletes, we can say that the adverse conditions described above, which had been faced during the competition, might be necessary and sufficient to account for the genesis of the most elementary misperceptions such as, precisely, simple pareidolias or distortions of images.

It is possible, on the other hand, to hypothesize that the first cluster of patients that have reported phenomena of alteration of the state of consciousness (anomalies in the intrinsic characteristics of perception, especially derealisation and depersonalisation) have specific temperamental traits and elements of the anxious and panic-agoraphobic spectrum which, in potentially stressful conditions, could lead to the onset of such phenomena. In our opinion, it would be useful to investigate the personal characteristics of these subjects (temperament and spectrum traits).

The subjects belonging to the third cluster (hallucinations), on the other hand, could present traits specific to the psychotic spectrum: in this case too, the stressful conditions or, in particular, the use of psychostimulants – for instance, those present in the very high quantities of coffee and tea consumed by the athletes in our sample – could lead to the onset of complex misperceptions such as simple and complex hallucinations.

Based on these preliminary observations, we may hypothesize that altitude, together with extreme stress, severe fatigue, prolonged sleep deprivation and the use of a high dose of psychostimulant drugs, may function as risk factors for hallucinatory phenomena, even in a population of athletes.

It is also possible to hypothesize that specific personal, spectrum and temperamental traits may predispose to the onset of misperceptions, while also influencing the prevailing typology, as might happen, for example, in inducing depersonalisation and derealisation in subjects with temperamental anxious traits and elements of the anxious and panic-agoraphobic spectrum, or triggering more complex hallucinatory phenomena in subjects who mostly present elements belonging to the psychotic spectrum.

The limits of the study were the small size of the sample and the impossibility of assessing the duration of sleep for each athlete directly. During this data collection, we did not have the chance to directly interview the subjects who were undergoing visual misperception, and this may be the main limit of our report. A one-to-one, direct observation of hallucinatory phenomena may be the next step forward in the study of psychiatric symptomatology in ultra-trail athletes. The evaluation of temperamental and personal characteristics could also be useful in understanding the genesis of the various kinds of misperceptions.

## CONCLUSIONS

The high prevalence and the well-defined nature of visual hallucinations assessed in this sample seem to suggest that it would be well worth systematically investigating misperceptions during high-intensity activity in a mountainous environment. Anomalous perceptual experiences may take place outside the context of psychiatric or neurological disorders. The chance of observing hallucinatory phenomena independently of psychiatric disorders can be viewed as a unique opportunity for the study of psychopathological conditions in a 'para-physiological' context.

Within this scenario psychiatric and neurological research comes to be of paramount importance in this kind of 'ultra-trail' competition, as well as in other high-intensity mountain activities.

*Conflict of interests:* the authors have no conflict of interests to declare.

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