NEÜ PRESS

MEVLANA TIP BİLİMLERİ
MEVLANA MEDICAL SCIENCES
eISSN:2757-976X

ARAŞTIRMA MAKALESİ/RESEARCH ARTICLE

DOI:http:/dx.doi.org/10.56752/Mevmedsci.2024.59
Mev Med Sci, 2024; 4(2): 45-53

Assessment of in-Flight Spatial Disorientation Events Among Military Pilots

Askeri Pilotlarda Uçuşta Yaşanılan Spasyal Dezoryantasyon Olaylarının Değerlendirilmesi

Abdurrahman Engin Demir[1], **Ahmet Akin**[2]

[1]University of Health Sciences, Institute of Defensive Health Sciences, Department of Aerospace Medicine, Ankara, Türkiye
[2]Neoks Hiperbarik Oksijen Tedavi Merkezi, Bursa, Türkiye

Makale Tarihleri/Article Dates:
Geliş Tarihi/Received: 26 May 2024
Kabul Tarihi/Accepted: 25 July 2024
Yayın Tarihi/Published Online: 20 August 2024

Sorumlu Yazar/Corresponding Author:
Abdurrahman Engin Demir,
University of Health Sciences, Institute of Defensive Health Sciences, Department of Aerospace Medicine, Ankara, Türkiye
e mail: aengindmr@hotmail.com

Açıklama/Disclosure: Yazarların hiçbiri, bu makalede bahsedilen herhangi bir ürün, aygıt veya ilaç ile ilgili maddi çıkar ilişkisine sahip değildir. Araştırma, herhangi bir dış organizasyon tarafından desteklenmedi. Yazarlar çalışmanın birincil verilerine tam erişim izni vermek ve derginin talep ettiği takdirde verileri incelemesine izin vermeyi kabul etmektedirler.

ÖZET

Havacılıkta Spasyal Dezoryantasyon (SD), bir pilotun uçağın yeryüzüne veya yakınındaki diğer hava araçlarına göre konumunu veya hareketini yanlış algılaması durumudur. SD olaylarının uçuşta ne sıklıkta yaşandığını ve ne seviyede tehlike yarattığını değerlendirmek amacıyla yaşları 24-46 arasında değişen 203 pilota anket uygulanmıştır. Helikopter pilotları en sık 'Gece Görüş Gözlüğü (GGG) kullanımına bağlı his yanılgısı' (%93.8) ve 'Brownout- whiteout illüzyonu (%93.8) nakliye uçağı pilotları en sık 'Yaklaşma ve iniş sırasında his yanılgısı' (%82.6) ve jet pilotları en sık 'Anti-collision ışıklarının bulut/sis yansımalarının yarattığı his yanılgısı' (%92.7) ve 'Leans illüzyonu' (%92.7) nedeniyle SD yaşamıştır. Genel maksat helikopteri pilotları ile taarruz helikopteri pilotları arasında 'Brownout- whiteout illüzyonu'nun uçuşta yarattığı tehlike skorları açısından anlamlı bir fark bulunmuştur (p<0.001). Bu pilotlar arasında 'Yeryüzü gökyüzü ışıklarının birbirine karıştırılması yanılgısı' yaşanma sıklığı açısından da anlamlı bir fark bulunmuştur (p=0.035). Jet, helikopter ve nakliye pilotları arasında da bu illüzyonun yaşanma sıklığı açısından anlamlı bir fark saptanmıştır (p<0.001). Havacılıkta hala sürmekte olan SD sorunu ve bunun uçuş emniyeti üzerindeki yıkıcı etkileriyle başa çıkabilmek için, pilota özel uçuş profilleri geliştirilmeli ve her bir uçak modeline özgü SD simülasyonların fizyolojik eğitimlere dahil edilmelidir.

Anahtar Kelimeler: Pilot, Spasyal dezoryantasyon, Uçuş, Havacılık, İnsan Faktörleri

ABSTRACT

Spatial Disorientation (SD) in aviation is the incorrect perception that a pilot has of the position or movement of the aircraft in relation to the Earth or other nearby air vehicle. A survey was conducted on 203 military pilots, with ages between 24-46. Helicopter pilots had the largest number of illusions caused by 'NVG (Night Vision Goggle)- related illusions' (93.8%) and 'Brownout-whiteout illusion' (93.8%), while transport aircraft pilots had the highest number of 'SD during final approach and landing' (82.6%), and jet pilots had the highest number of 'Illusion of anti-collision light reflection from clouds/fog' (92.7%) and 'Leans illusion' (92.7%). A significant difference in severity scores of 'Brownout- whiteout illusion' was found between utility helicopter pilots and attack helicopter pilots (p<0.001). There was also a significant difference in the frequency of 'Star-ground light confusion illusion' between those pilots (p=0.035). Significant difference in the frequency of this illusion was also found among jet, helicopter and transport pilots (p<0.001). To cope with the ongoing problem of SD and its detrimental effects on flight safety, it is crucial to develop pilot-specific flight profiles and incorporate SD simulations particular to each aircraft model into the physiological trainings.

Key words: Pilot, Spatial disorientation, Flight, Aviation, Human factors

Atıf yapmak için/ Cite this article as: Demir AE, Akin A. Assessment of in-Flight Spatial Disorientation Events Among Military Pilots. Mev Med Sci. 2024; 4(2): 45-53

INTRODUCTION

The human body is well-suited for maintaining its orientation and perception on Earth at a gravitational force of 1 G. This is upheld by the interaction of the somatosensory, vestibular, and visual systems. However, during flight, as the maneuverability and technological capabilities of the air vehicles have shown notable changes in time, it has been observed that aerial dynamics, some excessive movements, and unusual flying situations turn out to be causing misinterpretation of insufficient or conflicting orientational inputs provided by these sensory systems. Therefore, it is inevitable that pilots will encounter difficulties in maintaining their spatial orientation in the aerospace environment, where they are subjected to movements with varying power, duration, and direction, as well as different visual alterations and illusions (1).

Spatial Disorientation (SD) in aviation refers to a pilot's erroneous perception of the position or motion of the aircraft in relation to the Earth or other nearby aircraft. During flight, pilots may experience various events and illusions linked to SD, which can pose a threat to flight safety and lead to near misses and accidents. SD is a critical issue in aviation medicine due to its significant impact on flight safety and its role in causing accidents (2). The rate of SD-caused aircraft accidents in military aviation has been reported to be as high as 20%, with approximately 80% of these accidents resulting in fatalities (3.4). From 1991 to 2000, SD accounted for 20.2% of Class A accidents in the United States Air Force (USAF), making it the main cause. Additionally, the fatal accident rate for SD accidents was three times greater compared to accidents not caused by SD (1). A 2003 study conducted on helicopter accidents in the USAF revealed that the prevalence of SD was 27% (5).

Mishap data has been shown to be a valuable resource to learn about the impact of SD and its detrimental consequences in flight operations. Nevertheless, these data sometimes provide limited information and remain inadequate for assessing additional contributing factors. In some mishap investigation reports, it may be said that SD was decontextualized and a variety of contents of SD were individually assessed as contributing factors although they could have explicitly been attributed to SD (6.7). Gibb et al's (3) article highlights two key factors that may have received little attention in mishap reports: the lack of information regarding the pilot's behavior prior to the accident, and the investigators' inadequate evaluation of the effects of SD. These factors were potentially overlooked due to underreporting and inaccuracies in the mishap reports. Besides, that SD requires multi-pronged assessment and involves a wide range of illusions and misperceptions may sometimes cause failure to recognize and determine SD as a substantial contributor to the accident. The personal statements and experiences of each pilot regarding their misperceptions during flight provide an additional source of information that is not involved in reported incidents. Survey-based studies can provide sufficient information about episodes of SD and its potential hazards because pilots can accurately characterize the SD-related situations, clarify the misperceptions, and explain how these factors affect their flight skills. Hence, their statements and experiences can serve as strong evidence that may help in clarifying the underlying reasons, categorizing the illusions, and clearly identifying additional scenarios associated with SD.

The frequency distribution of SD illusions and their correlations with a variety of factors, including mission profiles, types of air vehicles, psychological factors, flying experience, meteorological conditions, use of various displays and viewing devices, and so forth, have been surveyed in many studies from different countries (8-11). Even though SD has plagued Turkish military pilots and caused numerous accidents, no survey-based research has been conducted to date. In this study, we aimed to collect comprehensive information from Turkish Armed Forces (TAF) pilots by employing a questionnaire-based survey about the frequency, types, and risk levels of each SD episodes that they experienced in different types of air vehicles.

METHODS

Subjects

A survey was conducted on 215 active pilots who applied to periodic aeromedical examinations and physiological trainings at the Aircrew Health Research and Training Center, Turkey. In accordance with the health aptitude regulations for Turkish military personnel, all pilots serving in TAF are required to undergo physiological trainings (Human centrifuge, SD, Hypobaric hypoxia, Ejection seat, and Night vision trainings) in this center every four years (12). Therefore, it was possible to interact with pilots operating various air vehicles in different regions and squadrons throughout the country. Each pilot was subjected to a close interview to enhance their awareness through the study, minimize any errors, and thus collect more accurate data.

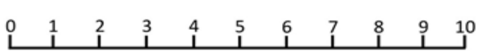
Survey design

A comprehensive survey was developed by evaluating some studies that used questionnaires to gather information on in-flight SD events experienced by military pilots (5,8,13). The questionnaire collected data on the pilots' demographic characteristics, total flight hours, most flown air vehicle type, flight conditions during which SD events occurred, frequency of illusions experienced primarily in the air vehicle type with the greatest number of flight hours, and severity levels of the experienced illusions. Pilots were instructed to consider their SD experiences encountered on real flight missions, rather than their training flights, while responding to the questions. The ones who have experience flying various air vehicles throughout their career were requested to respond to the questions based on the type of air vehicle they flew the most frequently during their active missions. Questions about illusions included a brief definition for each, helping to refresh the individual's knowledge. The participants were requested to choose the frequency grades of each illusion they experienced. The grades were categorized as "Never", "Seldom", "Often", and "Usually". The pilots who selected the "Never" grade were considered to have not experienced the illusion, while those who selected any of the other grades were considered to have experienced so.

The pilots were also asked to declare the severity scores they thought the illusion they experienced during the flight created. The severity levels of each illusion in flight were determined using a Visual Analog Scale (Figure 1). The numerical scale ranged from 1 to 10, with 1 representing an SD event defined as "Flight safety not in danger, easy to control, no risk of accident", and 10 indicating an event defined as "Flight safety at risk, difficult to control, high risk of accident". Additionally, if any, pilots were requested to write the most notable illusion they experienced during a flight. The air vehicles questioned were classified into three main categories: jet, transport aircraft (TA), and helicopter. Helicopters of various types were categorized as Utility Helicopters and Attack Helicopters, based on their intended purposes.

Statistical Analysis

Descriptive statistics of the data were computed using the arithmetic mean, standard deviation, percentage values, minimum, and maximum values. The study examined the associations between different groups using Chi-square and Fisher's Exact test. The "One-Sample Kolmogorov-Smirnov test" was applied to assess the normality of the data distribution. The "Student t test" was used for comparing paired groups with normal distribution and homogeneity of variance. The "Mann-Whitney U test" was employed for comparing parameters that weren't comparable to a normal distribution and lacked homogeneity of variance. The groups of three were compared using "Analysis of variance" for parameters that had a normal distribution and homogeneity of variance followed by Tukey's multiple comparison, and "Kruskal Wallis H Test" for parameters that did not have a normal distribution and did not have homogeneity of variance. For the analyses, a significance level of α=0.05 was used. Values below this threshold were considered to indicate a statistically significant difference. The statistical analysis was carried out using the SPSS 19.0 software.



0: Flight safety not in danger, easy to control, no risk of accident
10: Flight safety at risk, difficult to control, high risk of accident

Figure 1. Visual Analog Scale used for the severity levels of each illusion in flight

RESULTS

A total of 12 pilots were found to have not fully completed the surveys and excluded from the study. The study analyzed the surveys of 203 pilots, aged between 24 and 46, with an average age of 32.83±4.95. These pilots had total flight hours ranging from 500 to 6200, with an average of 1710.59±1029.53. Out of 203 pilots, 68 (33.5%) were jet pilots, 112 (55.2%) were helicopter pilots, and 23 (11.3%) were transport aircraft pilots (Table 1). The pilots were requested to rank the flying conditions in which they experienced SD most frequently compared to the flight conditions in which they experienced it least frequently (Table 2). 78 pilots (38.4%) specifically identified VFR (visual flight rules) to IFR (instrument flight rules) transitions as the flight conditions when they most frequently faced SD. Upon analyzing the air vehicle types separately, it was shown that VFR-IFR transitions were the most reported flight condition associated with SD, followed by night IFR conditions.

The frequency rates of all questioned illusions depending on the type of air vehicle was analyzed (Table 3), and it was found that pilots experienced the highest rate of 'SD during final approach and landing' (78.8%), followed by 'Illusion of anti-collision light reflection from clouds/fog' (75.9%)

Table 1. Distributions of air vehicles and pilots

Air vehicle categories	Air vehicle types	Pilots n	%
Jet	F-16	33	48.5
	F-4	29	42.6
	F-5	4	5.9
	T-38	2	2.9
Helicopter	UH-1	62	55.4
	AH-1	16	14.3
	AS-532	12	10.7
	UH-60	11	9.8
	AB-212	8	7.1
	AB-412	3	2.7
Transport Aircraft	CN-235	14	60.9
	C-130	4	17.4
	C-160	4	17.4
	KC-135R	1	4.3

Table 2. Distribution of flight conditions in which pilots with different air vehicles experienced illusions

Flight conditions		Jet (n=68)	Helicopter (n=112)	Transport (n=23)	Total (n=203)
VFR-IFR transitions	n (%)	28 (%41.2)	39 (%34.8)	11 (%47.8)	78 (%38.4)
Night IFR	n (%)	26 (%38.2)	10 (8.9)	9 (%39.1)	45 (%22.1)
Day IFR	n (%)	7 (%10.3)	7 (%6.3)	2 (%8.7)	16 (%7.9)
Day VFR	n (%)	2 (%2.9)	5 (%4.5)	1 (%4.3)	7 (%4.3)
Night VFR	n (%)	2 (%2.9)	2 (%1.8)	1 (%4.3)	5 (%2.5)

Table 3. Frequency distribution of all illusions experienced by each air vehicle type. NVG: Night Vision Goggle, HUD: Head Up Display

Illusions and misperceptions	Jet (n=68)	Helicopter (n=112)	Transport Aircraft (n=23)	Total (n=203)
Illusions during final approach and landing	53 (%77.9)	88 (%72.1)	19 (%82.6)	160 (%78.8)
Illusion of anti-collision light reflection from clouds/fog	63 (%92.7)	79 (%70.6)	12 (%52.2)	154 (%75.9)
NVG-related illusions	15 (%28.3)	105 (%93.8)	-	120 (%72.7)
Leans illusion	63 (%92.7)	62 (%55.4)	18 (%81.3)	146 (%71.9)
Fascination illusion	47 (%70.2)	74 (%66.1)	15 (%65.3)	136 (%67.7)
Vection illusion	46 (%67.7)	71 (%63,4)	9 (%39.2)	126 (%62.1)
Illusion of cockpit lights reflection on the windscreen	54 (%79.5)	61 (%54.5)	6 (%26.1)	121(%59.6)
Star- ground light confusion	49 (%72.1)	64 (%57.2)	5 (%21.8)	118 (%58.1)
Coriolis illusion	50 (%73.6)	49 (%43.8)	13 (%56.6)	112 (%55.2)
Autokinesis	42 (%61.8)	60 (%53.6)	9 (%39.2)	111 (%54.7)
HUD-related illusions	36 (%56.3)	19 (%48.8)	-	55 (%53.3)
Tendency to fly level to sloping clouds or terrain	42 (%61.8)	46 (%41.1)	13 (%56.6)	101 (%49.8)
Fixation to the stars	41 (%60.29)	48 (%42.9)	2 (%8.7)	91 (%44.8)
Nose-down illusion	50 (%78.9)	14 (%12.5)	12 (%52.2)	81 (%39.9)
Flicker vertigo	-	54 (%48.5)	-	-
G-excess illusion	34 (%50)	35 (%31.3)	8 (%34.8)	77 (%37.9)
Nose-up illusion	49 (%72.1)	13 (%11.7)	15 (%65.3)	77 (%37.9)
Giant hand phenomena	31 (%45.6)	30 (%26.8)	10 (%43.5)	71 (%35)
Graveyard spiral	19 (%28)	22 (%19.7)	2 (%8,7)	43 (%21.2)
Inversion illusion	28 (%41.2)	2 (%1,8)	7 (%30.5)	37 (%18.2)
Brownout- whiteout illusion	-	105 (%93.8)	-	-

and 'Night Vision Goggle (NVG)-related illusions' (72.7%). Helicopter pilots had the largest number of illusions caused by 'NVG- related illusions' (93.8%) and 'Brownout-whiteout illusion' (93.8%), while transport aircraft pilots had the highest number of 'SD during final approach and landing' (82.6%). The most prevalent forms of illusions experienced by jet pilots were 'Illusion of anti-collision light reflection from clouds/fog' (92.7%) and 'Leans illusion' (92.7%). The overall frequency rates of all illusions were also depicted in Figure 2.

Upon analyzing the severity scores of pilots, it was found that helicopter pilots had the highest score (7.85±2.19) for the 'Brownout-whiteout illusion', jet pilots had the highest score (6.68±2.03) for the 'Coriolis illusion', and transport aircraft pilots had the highest score (6.93±2.19) for the 'Fascination illusion' (Table 4). 93.8% of helicopter pilots experienced the 'Brownout-whiteout illusion', and the severity score associated

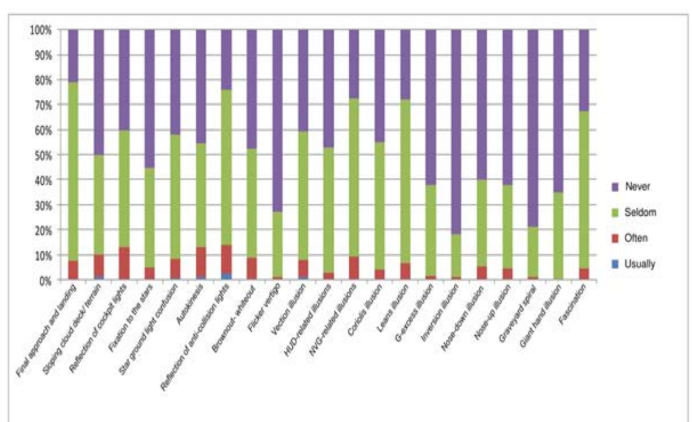


Figure 2. The overall frequency rates of all illusions

Table 4. Severity scores of illusions according to aircraft types. NVG: Night Vision Goggle, HUD: Head Up Display

Illusions and misperceptions	Jet (n=68)	Helicopter (n=112)	Transport Aircraft (n=23)	Total (n=203)	p value
NVG-related illusions	6.53± 2.00	7.05± 2.19	-	6.98± 2.16	0.338
Fascination illusion	6.23± 2.32	6.57± 2.12	6.93± 2.19	6.49± 2.19	0.560
Leans illusion	6.62± 1.94	5.85± 2.41	6.33± 1.65	6.42± 2.11	0.302
Giant hand phenomena	6.13± 2.35	6.23± 2.51	5.50± 2.07	6.08± 2.36	0.558
Coriolis illusion	6.68± 2.03	5.41± 2.15	5.85± 2.15	5.98± 2.08	0.749
Graveyard spiral	5.74± 1.79	5.82± 1.99	5.50± 3.54	5.77± 1.91	0.969
Vection illusion	5.54± 2.05	5.54± 2.34	5.44± 1.74	5.53± 2.18	0.983
Star- ground light confusion	5.69± 2.53	5.08± 2.16	4.80± 2.95	5.32± 2.35	0.367
Illusion of anti-collision light reflection from clouds/fog	5.76± 1.98	5.08± 2.17	4.17± 1.40	5.29± 2.08	0.021
HUD-related illusions	4.92± 1.99	5.84± 2.32	-	5.24± 2.13	0.138
G-excess illusion	4.62± 2.00	5.63± 2.13	4.50± 1.77	5.06± 2.08	0.104
Tendency to fly level to sloping clouds or terrain	4.55± 1.90	5.39± 2.15	4.62± 1.66	4.94± 2.01	0.201
Fixation to the stars	4.78± 1.85	5.04± 2.18	2.00± 1.41	4.86± 2.05	0.145
Nose-up illusion	5.08± 2.03	4.46± 1.27	4.87± 1.85	4.84± 1.88	0.651
Illusion of cockpit lights reflection on the windscreen	4.78± 1.92	4.77± 2.14	3.83± 1.60	4.73±2.01	0.670
Autokinesis	4.45± 1.97	4.73± 2.09	4.22± 1.92	4.59± 2.02	0.734
Inversion illusion	5.04± 1.67	3.67± 0.58	4.57± 1.99	4.29± 1.75	0.072
Nose-down illusion	3.69± 1.57	4.29± 2.05	3.92± 2.27	3.83± 1.76	0.658
Flicker vertigo	-	5.59± 1.79	-	-	-
Brownout- whiteout illusion	-	7.85± 1.99	-	-	-

with this illusion was 7.85±1.99. The severity scores of this illusion between utility helicopters (8.27±1.94) and attack helicopters (6.38±1.20) were evaluated, and a statistically significant difference was found (p<0.001). Helicopter pilots (93.8%) were also found to be the most susceptible to experiencing 'NVG-related illusions' during flight. Additionally, they had the highest average severity score, with an average of 7.05±2.19.

It was observed that jet pilots (72.1%) were the most likely to experience the 'Star- ground light confusion illusion' and the mean severity score for this illusion was 5.69±2.53. There was no statistically significant difference observed among jet, helicopter and transport pilots in terms of the severity scores of this illusion (p=0.367); however, there was a statistically significant difference between those pilots in terms of the frequency of experiencing this illusion (p<0.001). There was also a statistically significant difference between pilots of utility helicopters and attack helicopters in terms of the frequency rates of experiencing this illusion (p=0.035). Jet pilots had the highest rate, at %79.5, of experiencing the 'Illusion of cockpit lights reflection on the windscreen', and there was a statistically significant difference between pilots of utility helicopters and attack helicopters in terms of the severity scores of experiencing this illusion (p=0.016). It was found that jet pilots (61.8%) were the most likely to experience the 'Autokinesis illusion'. There was no statistically significant difference observed among jet, helicopter and transport pilots in terms of the frequency of experiencing this illusion (p=0.734). There was a statistically significant difference between utility helicopter pilots and attack helicopter pilots in terms of the frequency of experiencing this illusion (p<0.001).

DISCUSSION AND CONCLUSION

Upon an overall evaluation of all the illusions investigated in our study, it's obvious that pilots experienced the highest frequency of SD events during the final approach and landing phases of the flight. During the final approach and landing phase, the pilot's workload typically increases as they've got to concurrently evaluate multiple factors, such as assessing meteorological and runway conditions, communicating with Air Traffic Control, considering runway condition, etc. Additionally, they should pay attention to maintain an accurate final approach angle. Research carried out in the US Air Force and the US Navy revealed that approximately 12 to 25% of accidents linked to SD took place during the final approaching and landing stages (4.14). A study investigating commercial airplane accidents revealed that 70% of controlled flight into terrain (CFIT) incidents occurred during landing phases, indicating the presence of the same problem within civilian aviation (15).

Transport aircraft pilots were found to have the highest occurrence of 'SD events during the final approach and landing', compared to pilots of the other two air vehicle types. Transport aircraft pilots typically perform multi-location flights, requiring takeoffs and landings on different runways. Many studies reported that pilots were more likely to experience illusions while landing on runways that they are not familiar with (16,17). Given the frequent meteorological changes and climate variations in Turkey (18), as well as the unique structure of each runway due to its physical characteristics and surroundings, it can be concluded that the likelihood of transport aircraft pilots encountering 'SD events during the final approach and landing' was increased.

Our analysis revealed that VFR-IFR transitions were the common flight conditions during which all pilots experienced the highest occurrence of SD events. Pilots operating jets, helicopters, and transport aircraft have reported the highest occurrence of SD events during VFR-IFR transitions, and during IFR conditions at night or in adverse weather conditions, respectively. The study conducted by Bellenkes et al. (14) revealed that VFR-IFR transitions significantly contribute to a large number of accidents linked to SD. According to a survey, including 440 pilots in the United Kingdom, it was found that the most severe SD events experienced by pilots were during VFR- IFR transitions (19). Studies reported that VFR- IFR transitions significantly increased the occurrence of SD events (10,20). During transitions between VFR and IFR flights, the flight conditions undergo rapid and successive changes. The pilot tries to quickly maintain an adaptation to these continually changing flight conditions, increasing the likelihood of experiencing SD. During these transitions, the quick entry and exit to and from cloud clusters may induce motion parallax, potentially leading to pilot misperception, particularly in formation flights. This SD event may be depicted by the experience of an F-4 aircraft pilot who participated in our study:

"During a formation flight, I felt I was flying faster than the leader during repeated VFR-IFR transitions through the clouds. As a result, I suddenly pulled the throttle, lowering my speed and leaving the formation. Fortunately, I was able to get out of the cloud clusters, regain my visibility, and rejoin the formation."

The recent helicopter crash, that resulted to the tragic loss of NBA superstar Kobe Bryant, his daughter Gianna, and six other people might also be considered a significant example of accidents related to SD, especially in conditions when there is a lack of external visual cues. On January 26, 2020, the Sikorsky S-76B helicopter collided into a hillside close to the Southern California coast. The National Transportation Safety Board (NTSB) accident investigation concluded that the crash was probably caused by the pilot's inability to maintain proper orientation while flying in fog, partly low clouds and mist covering the hillsides. The adverse weather conditions led to inadvertent entry into instrument meteorological conditions (IMC), which in turn caused the pilot to encounter SD and lose control (21).

'Leans illusion' was found to be one of the commonly experienced illusions by jet pilots in our study. Furthermore, this illusion is the second most prevalent misperception experienced by transport pilots, with a frequency of 81.3%. It was also found to be the most severe illusion compared to others, with a mean score of 6.93±2.19. 'Leans illusion' leads to an erroneous sensation of banking when the attitude indicator show that the aircraft is flying straight and level, or a sensation of flying straight and level when the cues and indicator show the opposite (1). It has been reported as the primary sensory illusion experienced by pilots in numerous studies (1,8,22). This illusion can insidiously develop, and even if the attitude indicator accurately displays the aircraft's position, the pilot may struggle to accept it as true until visual references become available, since the vestibular and proprioceptive system have a stronger influence (23). One of the participants, an F-16 pilot, described it vividly:

"After taking off, we entered a cloud cluster at 2000 ft and came clear of the clouds at 10.000 ft. My exit was, I remember, 90 degrees banked and about 25 to 30 degrees nose up. I was particularly struggling to convince myself that I was in level flight while I was flying inside the clouds. I haven't sweated this much in my sixteen years of flying. All went back to normal as soon as I emerged from the clouds and provided full visibility."

'Coriolis illusion', with a mean severity score of 6.68±2.03, was identified as the most severe illusion experienced by jet pilots. Among all three types of aircraft, jet pilots had the highest frequency rate of experiencing 'Coriolis illusion', at 73.6%. A study showed that the 'Coriolis illusion' was experienced by 39% of pilots, with a majority of those affected being F-4 pilots (24). 'Coriolis illusion', which is a highly dangerous illusion that causes a pilot to experience an unpleasant feeling of rotating immediately after moving their head during a prolonged, constant rotational turn, is commonly encountered in highly maneuverable jet aircraft, as well as in helicopters and transport aircraft. A survey research conducted on SD in the US Air Force revealed that the prevalence of 'Coriolis illusion' was 62.2% among jet pilots and 42.6% among helicopter pilots (5). Within the scope of our investigation, a significant proportion of helicopter pilots, specifically 43.8%, stated having experienced this illusion. According to Previc (25), there have been reports of helicopter pilots experiencing this problem while performing steep turns during flights. An UH-1 pilot among the participants had an extensive experience with this illusion:

"During a left bank turn, the second pilot, who had turned his head to check the left side, unexpectedly overbanked the helicopter to the left. I quickly took control and maintained level flight."

During our interviews, helicopter pilots also reported that they employed head movements in order to check out the flying area because their field of view was restricted when using NVGs. They also mentioned that they particularly experienced 'Coriolis illusion' while performing sharp turns. A study found that the susceptibility to vestibular sensory illusions linked to rotation is increased when using a NVG, suggesting that visual field limitation can impact vestibular sensitivity (26). Therefore, helicopter pilots ought to remember to abstain from making abrupt and rapid head movements while flying with NVGs.

Our study found that 'NVG-related illusions' had the third highest frequency, accounting for 72.7% of events. Additionally, these illusions were regarded as the most severe, with a score of 6.98±2.16. A research conducted in the USA found that helicopter pilots had a higher incidence of 'NVG-related illusions' compared to jet and training pilots, with a rate of 72.3% (5). NVGs are optical devices that improve vision by amplifying the available light in the surrounding area, even in low-light conditions. Aside from enabling efficient flight capabilities, NVGs and advanced night vision systems also have several side effects, including diminished contrast, decreased visual acuity, limited visual field, and impaired depth perception. Besides, the use of focal vision, characterized by the clear and conscious identification of objects, poses challenges in effectively and accurately performing additional tasks that demand meticulous and conscious visual participation, such as reading and understanding flight displays, evaluating the flight plan, and navigating. These side effects and cognitive workload may contribute to an increased risk of encountering misperceptions (27). Some negative effects of NVGs, such as limited vision field and impaired depth perception, may be highlighted by a noteworthy experience of a helicopter pilot encountered during a flight using NVG:

"While I flew with NVG, I noticed the runway too late on my initial approach. I thought I was descending too fast as I got closer to the ground, and I lost my sense of orientation. We avoided a possible accident when the other pilot took control."

'Brownout-whiteout illusion' is one of the misperceptions that frequently lead to helicopter pilots experiencing SD events. Our study found that 93.8% of helicopter pilots experienced this illusion, with a mean severity score of 7.85±1.99. Furthermore, a significant proportion of helicopter pilots, specifically 17.2%, reported experiencing this misperception as "Usually". 'Brownout-whiteout illusion' happens when the helicopter's fast rotating propellers generate a dense cloud of dust or snow on a sandy or snowy terrain, causing visibility abruptly to decrease to zero. The frequency of this illusion and its impact on accidents are primarily influenced by operational and meteorological factors. During the Gulf War in 1991, US Army helicopters often encountered brownout events while operating in the desert (28). In a study, which investigated incidences of SD in helicopter flights in the USA between 2002 and 2011, it was shown that there was an increase in the frequency of accidents linked to SD in 2003. It was also noted that this increase occurred coincided with the beginning of Operation Iraqi Freedom (OIF) and was attributed to the lack of preparedness for desert conditions and the presence of sandstorms and dust clouds in the operation region, which had a negative impact on low-altitude flight conditions (29). A different study found that 65% of 68 helicopter pilots experienced 'Brownout-whiteout illusion' (30). Out of the helicopter pilots included in our study, 82.2% (n=91) were affiliated with the Land Forces Command and Gendarmerie General Command. 98.9% of them experienced 'Brownout-whiteout illusion', with 18.7% experiencing it 'usually'. The mean severity score was determined to be 7.88±2.01. Furthermore, a statistically significant difference ($p<0.001$) was observed between utility helicopters (8.27±1.94) and attack helicopters (6.38±1.20) in relation to the severity of this illusion.

Utility helicopter pilots primarily operate in Eastern and Southeastern Anatolia, along the border where mountainous terrain is prevalent, and frequently perform operational flights (31,32). These missions involve quick transportation of personnel and supplies to border outposts and forces in active operations. Additionally, aeromedical evacuation operations are frequently conducted. In countries with difficult ground transportation, the lack of appropriate runways often prevents helicopters from landing near outposts and operational sites where troops are stationed. The utility helicopter is the most used type of helicopter in all these missions. It can land on the terrain during good conditions and hovers close to the sandy or snowy ground during adverse conditions. These factors increase the risk of accidents due to Brownout-whiteout illusion'. An UH-1 pilot mentioned about his SD experience due to this illusion:

"In 2008, when flying in the operation region in Southeastern Anatolia, I experienced SD due to the lack of external references and whiteout illusion while hovering just a few feet above the snow-covered terrain during personnel landing. I had to quickly hand over control to the other pilot."

The jets have a bubble-like or dome-shaped canopy that provides a wide visual field to the pilot. As a result, the stars in the sky are viewable to the pilot in their peripheral vision while flying in the open air. Our investigation revealed a statistically significant difference among the pilots regarding the frequency of 'Star-ground light confusion', a condition in which a false sensation can be experienced when ground lights are mistaken for stars ($p<0.001$). It was hypothesized that jet pilots may be more susceptible to this misperception as a result of the unique design of the canopy structure. There is an assumption that a similar relationship between the canopy structure and the 'Star- ground light confusion' might also exist in the 'Illusion of cockpit lights reflecting on the windscreen' and the 'Autokinesis illusion'. 'Autokinesis illusion', which is characterized by the appearance of a stationary light as if moving after being glanced at for an extended period in the darkness, can arise from the reflection of multiple light sources, including stars in an unclouded sky, certain light sources from the ground, or the reflection of cockpit lights from the canopy. A survey study on SD revealed that 56% of participants had 'Autokinesis illusion', and the pilots involved in the study reported several types of autokinesis (8). The F-16 aircraft's bubble canopy acts as a reflective surface, enabling the cockpit lights to reach the pilot's field of vision and giving rise to the perception of virtual images (33). It was found in our study that jet pilots, comprising 79.5% of the sample, were the most susceptible to the 'Illusion of cockpit lights reflecting on the windscreen'. Furthermore, there was a statistically significant difference between pilots operating utility helicopters and attack helicopters (AH-1) in terms of their rate of experiencing this illusion (p=0.016). Regarding the 'Autokinesis illusion', jet pilots were shown to have the highest incidence of autokinesis, with a rate of 61.8%. When the questionnaires were analyzed in detail, 1 jet pilot and 1 helicopter pilot, who reported experiencing the 'Autokinesis illusion' "Frequently" were specifically F-16 and AH-1 pilots, respectively. There was a statistically significant difference in the frequency of experiencing this error between utility helicopter and attack helicopter pilots (p<0.001). Based on the layout and coverage of the canopy of jet aircraft and AH-1 helicopter, it can be said that pilots of aircraft with bubble canopies are more susceptible to this illusion. Furthermore, there was a statistically significant difference between the pilots of utility helicopters and attack helicopters in terms of the frequency of experiencing this illusion (p=0.035). The AH-1 helicopter differs itself from other helicopters by featuring a dome-shaped canopy structure (34). According to a research, 36% of helicopter pilots experienced 'Autokinesis illusion' due to reflections of in-cockpit lights on the canopy. Our study hypothesized that the canopy structure could be a contributing factor to the higher incidence of this illusion among AH-1 pilots compared to other helicopter pilots.

SD has been one of the major problems in military aviation by decreasing operational effectiveness and causing accidents resulting in the loss of air vehicles and personnel (35). Therefore, it necessitates a comprehensive evaluation from multiple angles. Pilots' knowledge of SD has progressively grown alongside improvements in SD trainings. The current approach of training for SD continues to rely on the utilization of simulators and units that accurately replicate flying conditions in a safe ground environment (36,37,38). These trainings provide an extensive variety of realistic illusions, as well as assistance on how to deal with them. Despite an increased awareness of SD among pilots and development of advanced training devices enabling to demonstrate veridical ground-based training profiles, SD-related accidents continue to occur. Military pilots in all NATO member countries undergo regular SD training, which includes frequently updated application profiles (39). While updating, it would be beneficial to collect a brief account of each pilot's previous SD experiences at the beginning of the training process. This will assist instructors to identify the specific conditions and maneuvers in which they experienced SD events. By doing so, pilot-specific flight profiles could be developed and implemented, enabling a focused approach to addressing SD during trainings. This approach is considered to enhance awareness as well as readiness for SD.

Etik Kurul: The Ethical Committee of the Gulhane Military Medical Academy approved the protocol of the study. (Date: 11th of March, 2014, Number: 50687469-1491-223-14/ 1648.4-592).

Çıkar Çatışması: Çalışmada herhangi bir çıkar çatışması yoktur.

Finansal Çıkar Çatışması: Çalışmada herhangi bir finansal çıkar çatışması yoktur.

Sorumlu Yazar: Abdurrahman Engin Demir, University of Health Sciences, Institute of Defensive Health Sciences, Department of Aerospace Medicine, Ankara, Türkiye

e-mail: aengindmr@hotmail.com

REFERENCES

1. Benson AJ, Stott JR. Spatial Disorientation in Flight. Ernsting's Aviation Medicine, 4th Edition, Edward Arnold Ltd, New York, 2006, 433- 58.
2. Newman RL, Rupert AH. The magnitude of the spatial disorientation problem in transport airplanes. Aerosp Med Hum Perform. 2020;91(2):65–70.
3. Gibb R, Ercoline B, Scharff L. Spatial disorientation: decades of pilot fatalities. Aviat Space Environ Med. 2011;82(7):717-24.
4. Lyons TJ, Ercoline WR, Freeman JE, et al. Classification problems of U.S. Air Force spatial disorientation accidents, 1989-91. Aviat Space Environ Med. 1994 Feb;65(2): 147-52.
5. Matthews RJS, Previc F, Bunting A. USAF spatial disorientation survey. In: Spatial disorientation in military vehicles: causes, consequences and cures. La Coruña, Spain, 15-17 April 2002. Report No: NATO RTO-MP-086. https://www.faa.gov/sites/faa.gov/files/about/office_org/headquarters_offices/avs/MP-086-07.pdf (Accessed 10 June 2024).
6. Accident Investigation Board Report: F-16CM, T/N 89-2108, Utah Test and Training Range, Department of the U.S. Air Force; 22 June 2009. https://www.airandspaceforces.com/PDF/SiteCollectionDocuments/Reports/2009/September%202009/Day30/F-16_crash_AIB_062209.pdf (Accessed 06 June 2024).

7. Aircraft Accident Investigation Board Report. F-15E, T/N 90-0231, 366 EFS, 455 AEW. Afghanistan United States Air Force: U.S. Air Force; 2009:18. https://media.defense.gov/2009/Dec/01/2001452962/-1/-1/0/18%20July%20F-15E%20AIB%20Report%20FINAL.pdf (Accessed 07 June 2024).
8. Sipes WE, Lessard CS. A spatial disorientation survey of experienced instructor pilots. IEEE Eng Med Biol Mag 2000;19 (Pt 2):35–42.
9. Holmes SR, Bunting A, Brown DL, et al. Survey of spatial disorientation in military pilots and navigators. Aviat Space Environ Med 2003; 74:957–65.
10. Takada Y, Hisada T, Kuwada N, et al. Survey of severe spatial disorientation episodes in Japan Air Self-Defense Force fighter pilots showing increased severity in night flight. Mil Med. 2009 Jun;174(6):626-30.
11. Pennings HJM, Oprins EAPB, Wittenberg H, et al. Spatial Disorientation Survey Among Military Pilots. Aerosp Med Hum Perform. 2020 Jan 1;91(1):4-10.
12. Turkish Armed Forces, The Gendarmerie General Command and Coast Guard Command Health Aptitude Regulation; 29885, 11.11.2016. 6674-6675. https://www.msb.gov.tr/Content/Upload/Docs/basin/saglik_2017.pdf (Accessed 01 June 2024).
13. Holmes SR, Bunting A, Bostock S, et al. Preliminary Survey of Spatial Disorientation in UK Military Pilots and Navigators. In: Spatial disorientation in military vehicles: causes, consequences and cures. La Coruña, Spain, 15-17 April 2002. Report No: NATO RTO-MP-086. https://www.faa.gov/sites/faa.gov/files/about/office_org/headquarters_offices/avs/MP-086-08.pdf (Accessed 10 June 2024).
14. Bellenkes A, Bason R, Yacavone DW. Spatial disorientation in naval aviation mishaps: A review of class A incidents from 1980 through 1989. Aviat Space Environ Med. 1992;63(2):128-31.
15. Scott WB. New Research Identifies Causes of CFIT. Aviation Week and Space Technology, Vol. 144, No.25, 1996, pp. 40-41.
16. Hartman, BO, Cantrell, GK. 'Psychological Factors in "Landing-Short" Accidents'. Flight Safety: J Aeromed Int 1968; 2:26-32.
17. Jin L, Lo E. A Study of Accidents and Incidents of Landing on Wrong Runways and Wrong Airports. 19th International Symposium on Aviation Psychology, 2017;107-112. https://corescholar.libraries.wright.edu/isap_2017/55 (Accessed 10 May 2024).
18. Toros H, Mokari M, Abbasnia M. Regional variability of temperature extremes in the maritime climate of Turkey: A case study to develop agricultural adaptation strategies under climate change. Model. Earth Syst. Environ. 2019;5:857–65.
19. Durnford SJ. Disorientation and flight safety of UK Army aircrew. Proceedings of the Advisory Group for Aerospace Research and Development. Aircraft accidents: Trends in aerospace medical investigation techniques. Neuilly-Sur-Seine, France: AGARD; 1992; AGARD-CP- 532: 32- 1-14. https://apps.dtic.mil/sti/tr/pdf/ADA258745.pdf (Accessed 23 May 2024).
20. Tormes FR, Guedry FE Jr. Disorientation phenomena in naval helicopter pilots. Aviat Space Environ Med. 1975;46(4 Sec 1):387-93.
21. National Transportation Safety Board. Year. Rapid Descent into Terrain, Island Express Helicopters Inc., Sikorsky S-76B, N72EX, Calabasas, California, January 26, 2020. Aircraft Accident Report NTSB/AAR-21/01. Washington, DC. https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR2101.pdf (accessed 16 June 2024).
22. Navathe PD, Singh B. Prevalence of spatial disorientation in Indian Air Force aircrew. Aviat Space Environ Med. 1994;65(12):1082-5.
23. Landman A, Davies S, Groen EL, et al. In-flight spatial disorientation induces roll reversal errors when using the attitude indicator. Appl Ergon. 2019;81:102905.
24. Diamantopoulos I, Markou I. A Spatial Disorientation Survey of Hellenic Air Force Pilots. In: Spatial disorientation in military vehicles: causes, consequences and cures. La Coruña, Spain, 15-17 April 2002. Report No: NATO RTO-MP-086. https://apps.dtic.mil/sti/tr/pdf/ADA413343.pdf (Accessed 02 June 2024).
25. Previc FH. Psychological Factors, Spatial Disorientation in Aviation, Volume 203, American Instıtute of Aeronautics and Astronautics Inc, Virginia, 2004, pp. 145-94.
26. Cheung B. Vestibular suppression while using NVGs. NATO RTA HFM 141 Symposium on "Human Factors and Medical Aspects of Day/Night All Weather Operations: Current Issues and Future Challenges" Crete, Greece; April 2007; 8-1 – 8-10.
27. Biernacki MP, Lewkowicz R. The role of visual conditions and aircraft type on different aspects of pilot workload. Appl Ergon. 2024;118:104268.
28. Previc FH, Ercoline WR. Historical Background, Concepts and Terminology. Spatial Disorientation in Aviation, Volume 203, American Institute of Aeronautics and Astronautics Inc, Virginia, 2004, pp. 1-36.
29. Gaydos SJ, Harrigan MJ, Bushby AJ. Ten years of spatial disorientation in U.S. Army rotary-wing operations. Aviat Space Environ Med. 2012;83(8):739-45.
30. Lewkowicz R, Biernacki MP. A survey of spatial disorientation incidence in Polish military pilots. Int J Occup Med Environ Health. 2020;33(6):791-810.
31. McGregor A. Arming for Asymmetric Warfare: Turkey's Arms Industry in the 21st Century. Jamestown Foundation, 2008. https://jamestown.org/wp-content/uploads/2008/06/Jamestown-McGregorTurkishArmsIndustry.pdf (Accessed 10 June 2024).
32. Kasapoğlu C, Ülgen S. Operation Olive Branch: A political-military assessment. Foreign Policy & Security 2018/2. https://edam.org.tr/wp-content/uploads/2018/01/Operation-Olive-Branch-01.pdf (Accessed 10 June 2024).
33. Kuipers A, Kappers A, van Holten CR, van Bergen JHW, Oosterveld WJ., 'Spatial Disorientation Incidents in the R.N.L.A.F.F16 and F5 Aircraft Suggestions for Prevention' AGARD CP-478: Situational Awareness in Aerospace Operations, AGARD, 1990.pp. OV-E- 1- OV-E-16. https://apps.dtic.mil/sti/tr/pdf/ADA223939.pdf (Accessed 09 June 2024).
34. Lynn R, Harse J. The Bell Helicopter AH-1 Cobra-Past, present, and future. In: Aircraft Design, Systems and Operations Conference. 1990. p. 3271. https://doi.org/10.2514/6.1990-3271
35. Lessard CS. Spatial disorientation: dealing with aeronautical illusions. IEEE Eng Med Biol Mag 2000; 19: 25 – 7.
36. Powell-Dunford N, Bushby A, Leland RA. Spatial Disorientation Training in the Rotor Wing Flight Simulator. Aerosp Med Hum Perform. 2016;87(10):890-3.
37. Lawson BD, Curry IP, Muth ER, et al. Training as a countermeasure for spatial disorientation mishaps: Have opportunities for improvement been missed? In: Mitigating Hazards to Rotary Wing Flight in Degraded Visual Environments STO-EN-HFM- 265. The NATO Science and Technology Organization; 2017. p. 3A-1–20. https://www.sto.nato.int/publications/STO%20Educational%20Notes/STO-EN-HFM-265/EN-HFM-265-03A.pdf (Accessed 12 June 2024).
38. van den Hoed A, Landman A, Van Baelen D, et al. Leans Illusion in Hexapod Simulator Facilitates Erroneous Responses to Artificial Horizon in Airline Pilots. Hum Factors. 2022;64(6):962-72.
39. NATO Standard, AAMedP-1.2. Aeromedical Training of Flight Personnel. Edition A Version 1. NATO Standardization Office (NSO), 2018. https://www.coemed.org/files/stanags/04_AAMEDP/AAMedP-1.2_EDA_V1_E_3114.pdf (Accessed 15 June 2024).