Risk Assessment, Decision Making and Their Impact on Safety in Sports Parachuting

by

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This document is dedicated to of Zak. Those of us privileged with having known you carry your memory with us every time we jump. Blue skies always, brother.

Abstract

This document submits for consideration a research into the human factors, that impact the safety of sports parachuting, or skydiving. The research focuses specifically on the areas of human cognition, risk-assessment, and decision-making and how these factors contribute to skydiving injuries and fatalities. Sports parachuting is, by its nature, a high-risk activity, and this risk is part of the appeal of the sport. Despite the risk, the sport enjoys a high safety record. Reliable equipment, strict standards, and adequate training contribute much to this safety record. This leaves human factors, specifically risk assessment and decision-making in a very dynamic environment, as the significant factor contributing to injuries and fatalities in the sport. What factors and how do they interact to make an otherwise competent skydiver assess the situation incorrectly and make poor decisions has not been investigated in depth or specifically focused on sports parachuting.

Keywords: decision-making, human cognition, human factors human performance, risk assessment safety, skydiving, sports parachuting

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Risk Assessment, Decision Making and Their Impact on Safety in Sports Parachuting

Chapter I

This Graduate Capstone Project (GCP) is an investigation into the human factors that impact the safety of sports parachuting, or skydiving. This project focuses on the areas of human cognition, risk-assessment, and decision-making to understand how these factors contribute to skydiving injuries and fatalities.

Sports parachuting, or skydiving is, by its nature, a high-risk activity, and this risk is part of the appeal of the sport. According to the United States Parachute Association (USPA), the governing body for the sport in the United States, its membership has grown from 3,353 members in 1961 to 39,827 at the end of 2018 (USPA, 2019b). Despite the risk, the sport enjoys a high safety record. In 2019, out of approximately 3.3 million sports parachute jumps in the United States, there were 15 skydiving fatalities recorded for a fatality rate of 0.45 per 100,000 jumps. During the same year there were 2,522 reported injuries requiring care at a medical facility for an injury rate of 76 per 100,000 jumps (USPA, 2020a).

Reliable equipment, strict standards, and adequate training contribute much to this safety record. A commonly held belief by the general public is that most skydiving fatalities occur because of equipment failure; specifically, the parachute failing to deploy. However, the data collected by the USPA indicates that modern sports parachute equipment is extremely reliable, as long as it is properly maintained (USPA 2020). The modern sports parachute rig (the complete parachute assembly a skydiver wears) is composed of a suspension harness for the skydiver body that distributes the canopy opening shock, a container with two sections, one each for main and reserve canopies, a canopy deployment system, and a cutaway system to release the main canopy and deploy the reserve canopy in case of a malfunction with the main canopy if necessary. While the main canopy is typically packed by the skydiver, the reserve canopy is classified as a life-saving device by the FAA and must be inspected and repacked every 180 calendar days by an FAA-certified parachute rigger (Parachute Equipment and Packing, 2020). This requirement ensures that the reserve will deploy properly if needed.

Skydivers have the option of adding additional approved safety devices to their rigs. One of the most revolutionary safety devices developed recently is the automatic activation device (AAD). It is a microprocessor-controlled device installed in a skydiving rig that senses altitude and descent rate. If a skydiver descends below a set altitude at a speed above a set threshold (both "hard" preprogrammed by the AAD manufacturer), the AAD will activate and release the reserve canopy. Also, many skydivers chose to equip their rigs a reserve static line (RSL) or a main-assisted reserve deployment (MARD) device. Either of these devices shorten the time it takes for the reserve canopy to deploy. The only instrument that a skydiver uses is an altimeter. Skydiving altimeters come in a variety of types, they are also extremely reliable, and provide the skydiver with information on the altitude above ground level (AGL).

Unlike other aeronautical activities, sports parachuting involves a direct and physical interaction of the human and the environment. All information about the skydiver's very dynamic environment is collected directly from sensory inputs. All responses to these inputs are executed by movements of the skydiver's body. This information needs to be processed, evaluated, and acted upon very quickly and accurately. A typical sports parachuting jump begins when the skydiver exits the jump aircraft at somewhere between 10,000 and 14,000 feet AGL (but below 14,000 feet MSL). Depending on what activity is performed during freefall, the skydiver will reach a terminal velocity of approximately 100 miles per hour (MPH) about 15 seconds after exiting the aircraft and will freefall for approximately 45 to 60 seconds. At that point, the jumper will be at approximately 2,500 to 3,500 feet AGL and will initiate the main canopy deployment at this time. 2,500 feet AGL is the minimum deployment altitude mandated by USPA. At this altitude, the skydiver is approximately 14 seconds from impacting the ground if he or she remains in freefall. After canopy deployment, the skydiver will spend 3 to 5 minutes gliding under canopy and maneuvering for landing at, or near, the desired landing spot.

Significance of the problem

The preceding description of the typical sports parachute jump illustrates why human cognitive processes involving risk assessment and decision-making are vitally important to safety in this sport. Although the data demonstrates that the sport enjoys a remarkable safety record for such a high-risk activity, fatalities do occur, and any fatality is unacceptable. The data collected by the USPA from several years indicate that the main cause of sports parachuting injuries and fatalities continues to be human error (USPA, 2020a). Furthermore, investigation into these fatalities suggests that most of these fatalities were avoidable.

In many of the reported accidents, the fatality occurred because the parachutist involved deliberately performed unsafe actions while under a fully functioning parachute. This suggests fact that one or more factors interfered with the human decision-making process and resulted in an accident. Had the skydiver involved made different decisions and taken a different course of action the accident could have been avoided.

The historical data on skydiving fatalities also indicate a plateauing of the number of fatalities. This suggest that efforts to reduce fatalities have become less effective with time.

Statement of the problem

The problem that this research project attempts to address is to understand how and why an otherwise competent skydiver assessed a situation incorrectly and made poor decisions that resulted in an injury or fatality.

This problem has not been investigated in depth within the specific context of sports parachuting. Investigations into sports parachuting fatalities typically do not progress beyond identifying the immediate cause of the accident (the poor or incorrect decision that led to the accident). To understand why the accident happened, research needs to investigate deeper into the root cause or causes of the accident. Identifying and the root cause and understanding why it is the root cause is the first step towards taking action to prevent further occurrences and improve safety.

Purpose Statement

The purpose of this research project is to conduct a research into the human factors that impact the safety of sports parachuting, or skydiving. The research focuses on the areas of human cognition, risk-assessment, and decision-making and how these factors contribute to skydiving injuries and fatalities. The expectation is that identifying and understanding the factors that contribute to making poor decisions and errors will provide a different perspective of the nature of this problem and possibly identify different courses of actions to improve the quality of decisions and further reduce fatalities and serious injuries. A long-range expectation is that this research project may encourage further research into the subject and contribute to further improvement in the safety of the sport.

Research Question

This research project investigates the following:

- What are the specific factors that affect human cognition during sports parachute jumps?
- How do these factors affect and interact to disrupt the risk assessment and decision-making process and influence a skydiver to make poor decisions?

Delimitations

The scope of the research is limited by the time allowed for the MHSF 691 Graduate Capstone Research Project (GCP) course of the Worldwide Campus. The scope is also limited to publicly available data previously collected by the USPA's Safety and Training Department and the National Transportation Safety Board (NTSB). Other appropriate and reliable data sources, such as public records of official accident investigations conducted by law enforcement agencies, may be used if relevant.

Data that could provide personally identifiable information is excluded from this research project to protect the privacy and confidentiality of individual and avoid needing an Institutional Review Board (IRB) approval.

Limitations and Assumptions

The scope of the research is limited to analyzing data of accidents and incidents in the United States where the injuries or fatalities were directly related to a sports parachuting jump. The scope is limited to analyzing data from the previous 5 years (2014 through 2019) so that the project can be completed in the time required.

Injuries or fatalities from accidents or incidents that were indirectly related to a sports parachute jump are excluded from this research. However, certain actions and events indirectly related to a sports parachute jump may be included if the data demonstrate that these actions were a contributing factor to a sports parachuting fatality or injury.

Injuries and fatalities that occurred outside the scope and definition of sports parachuting, such as BASE (Buildings, Aerials, Spans, Earth) jumps and military freefall jumps, are also excluded from this research. However, incidents identified during the data collection phase of the project that demonstrate appropriate risk analysis and decision-making may be included in the research for comparison purposes.

The data collected for this research project does not include information on factors external to the sports parachuting environment that could impair cognitive processes during a jump. These include pre-existing medical conditions or being under the influence of alcohol or other substances (whether legal or illegal). The research project assumes that all the jumpers involved possessed normal cognitive functions.

List of Acronyms

AAD	Automatic Activation Device
AGL	Above Ground Level
BASE	Buildings, Aerials, Spans, Earth
EP	Emergency procedures
FAA	Federal Aviation Administration
GCP	Graduate Capstone Project

G-LOC	G-induced loss of consciousness
IRB	Institutional Review Board
MARD	Main Assisted Reserve Deployment
MSHF	Master of Science in Human Factors
MPH	Miles Per Hour
MSL	Mean Sea Level
NTSB	National Transportation Safety Board
RSL	Reserve Static Line
USPA	United States Parachute Association

Chapter II Review of the Relevant Literature

Human cognition

Sternberg & Sternberg (2017) provides a broad reference of human cognition, memory models and memory processes, problem solving, decision making and reasoning.

Campbell & Bagshaw (2002), Maresh, Woodrow, Webb (2016), and Introduction to aviation physiology (FAA, 2016) provide concise information on aviation physiology and aviation psychology. The discussion on human information processing, the reliability of human decision, and the effects of self-imposed stress and its contributing factors, including the use of alcohol, drugs, tobacco, an individual's level of physical fitness, dietary practices, fatigue, disruption of the circadian rhythm (Schmidt et al, 2007), and lifestyle-related factors (FAA, 2016) are factors that affect physical and mental performance and should be considered when identifying the root cause of an accident.

Sports parachuting activities and environment

The most authoritative source of information on matters related to sports parachuting is the USPA. Their publications (2019b, 2020b, 2020c) provide comprehensive information on sports parachuting operations, rules and procedures, and demographics. Katz, (2009) provides background information on sport parachuting operations from a pilot's perspective. Zaretsky (2011) provides a first-person account of the experience of a sports parachute jump.

Risk perception, risk assessment, decision-making, and human error

Sternberg & Sternberg (2017) also provides comprehensive reference information on problem solving, risk assessment and risk tolerance, and their role in the decision making process.

According to Hunter (2002) there are three major theories of risk tolerance. The first one is risk homeostasis. This theory proposes that each one of us has a threshold of what we consider acceptable risk, and we adjust our behaviors to avoid exceeding this threshold. We can call this a "play-it-safe" approach. The second one is the zero-risk theory. This theory proposes that we perceive risk as a function of the likelihood of a hazardous event occurring. The more we engage in a behavior without a negative consequence, our confidence increases, and we perceive an ever diminish risk when we engage in that activity. The third theory is the threat avoidance theory. This theory proposes that, as we engage in a behavior, we build experience that help us anticipate hazardous event, thus avoiding negative consequences and reducing risk.

The seminal research on human error conducted by Reason (1990) provides a very useful model to describe and categorize this phenomenon. Human errors can be categorized by the error types and the error forms. Error types are classified according to cognitive level or the performance level in which they occur.

Cognitive level errors are classified by where in the decision-making process the occur:

- Planning stage – mistakes
- Storage stage – lapses
- Execution – slips

Performance level error types are classified as follows:

- Skill-based – slips and lapses (errors in task execution)
- Rule-based mistakes (errors in recalling the correct way of performing a task)
- Knowledge-based mistakes (errors in the fundamental knowledge needed to perform a task)

Meissner & Wittmann (2011) presents information on the cognitive mechanism that is at the root of the subjectivity of time perception that humans experience.

Skydiving accidents and fatalities

The USPA has a vested interest in promoting safety in the sport. Thus, they collect, analyze and report on sports parachuting injuries and fatalities for training and educational purposes. Their annual accident summaries (2015, 2016, 2017, 2018, 2019a, and 2020a) provides detailed information and analysis to the sports parachuting community for awareness and education purposes. The analyses conducted by Bell (2020), Crouch (2019, 2020), and Sitter (2018) expand on the USPA fatality summaries and provide an insight into the contributing factors and chain of events to these accidents.

Chapter III Methodology

Research Approach

The data being analyzed in this research project is not numerical data that can be analyzed statistically. Also, the research question guiding this research project attempts to answer a "what" and perhaps "why." Therefore, a qualitative methods research approach is most appropriate.

Design and Procedure

This research study is a meta-study using grounded theory methodology. A grounded theory methodology is appropriate for this research project. In grounded theory research design, data is collected and analyzed to identify patterns or relationships that can lead to develop hypotheses or theories. The research study by Barrows, Mills, & Kassing, (2005) on a related subject follows this same methodology.

A purposeful sample is selected from the data for analysis. The data is coded accordingly and analyzed to identify commonalities in the sample that relate to risk assessment and decision-making.

Apparatus and Materials

There are no apparatus or materials necessary for this research study.

Sample

The population for this study is small (94 fatalities). Also, this research study is focused on accidents that are attributable to poor decisions made by skydivers. For these reasons, a purposeful sample of the accidents meeting the above criteria is selected for analysis.

Source of the Data

The primary source is data on sports parachuting accidents and incidents in the United States collected by the USPA's Safety and Training Department. Other sources of data may include data from the National Transportation Safety Board (NTSB) and other appropriate and reliable data sources, such as public records of official accident investigations conducted by law enforcement agencies may be included if they provide information relevant to the research.

Validity

The nature of the data being analyzed and the questions this research project attempts to understand indicates that a grounded theory methodology is the most appropriate for the analysis. The data used for the analysis was previously collected and analyzed by reputable sources. Its accuracy and reliability have already been ascertained. These factors support the validity of the conclusions derived from the data analysis of this report.

Treatment of the Data

The data used for this analysis was collected from the USPA's Safety and Training Department data and other appropriate and reliable data sources. The data includes the following elements:

- Demographic information about the jumpers involved such as age, experience, level of licensing
- Relevant details of the mishap jump such as type of jump, weather conditions, equipment used, type of malfunction experienced, and eyewitnesses' reports.
- Details about the mishap uncovered during the accident investigation
- Other relevant information available

Because the population for this study is small, a purposeful sample is selected from the data for analysis. The sample includes the fatalities in the seven (out of fourteen) categories with the most fatalities in the population. The fatalities in the sample account for 80% of the fatalities in the population. The data from these sources has already been screened to preserve privacy and confidentiality of the subjects in the original analysis. There is no concern regarding preservation of their privacy and confidentiality in this research project.

Chapter IV Results and Discussion of Results

Results

The data collected by the USPA on the 94 sports parachuting fatalities in the United States from 2014 to 2019 was reviewed and categorized using the USPA standard reporting categories. Table 1 presents a summary of the data. Although the number of licensed jumpers and the number of jumps in the United States has steadily increased in recent years, the number of fatalities has decreased during the same period (USPA, 2020c).

Table 1

Summary of Sports Parachuting Fatalities in the United States 2014 to 2019

Categories	2015	2016	2017	2018	2019	Totals
Incorrect Emergency Procedures	2	4	7	4	2	19
Equipment problem	4	4	2	2	3	15
Landing problems not involving turn	3	2	2	1	1	9
Unintentional low turn	1	1	2	1	4	9
No or low cutaway/reserve deployment	2	2	2	0	2	8
Medical	1	2	1	4	0	8
Intentional low turn	2	1	2	0	2	7
Canopy collision	2	1	2	0	0	5
No or low pull	2	0	2	0	0	4
Freefall collision	0	2	1	1	0	4
Main/reserve downplane or entanglement	2	0	0	0	0	2
Collision with jump aircraft	0	1	0	0	1	2
Camera entanglement	0	1	0	0	0	1
Reserve bridle entanglement	0	0	1	0	0	1
Totals	21	21	24	13	15	94

Note: categories are arranged by total number of fatalities

The data was then organized by categories and ranked by the number of fatalities. Figure 1 presents this data in graphical form.

Figure 1

Summary of Sports Parachuting Fatalities in the United States 2015 to 2019 by Categories

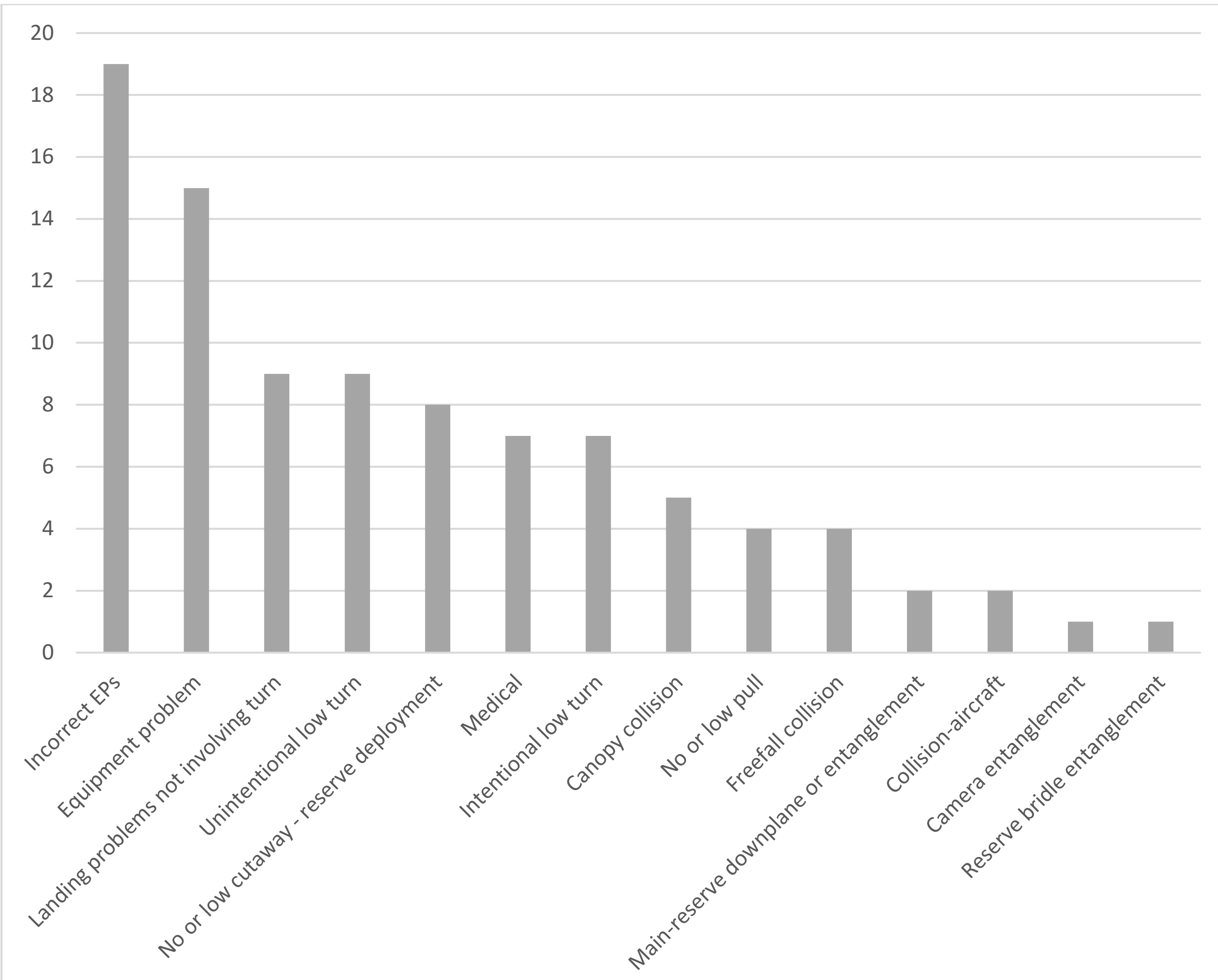


Figure 2 present demographical data on the fatalities categorized by the USPA-issued licensed held by the jumpers. This provides a rough estimate of the level of experience that the jumpers involved in these fatalities. Table 2 provides reference information on the minimum requirements a jumper must meet to hold and exercise the privileges of each license granted by the USPA (USPA, 2020b). Although demographic data on the number of active jumpers segregated by license level was not available to the researcher, the population of licensed jumpers in each license level is smaller than the population of the preceding license level. This suggest that the probability of suffering a fatal accident increases as a function of the license level.

Figure 2

Summary of Sports Parachuting Fatalities in the United States 2015 to 2019 by Experience Level

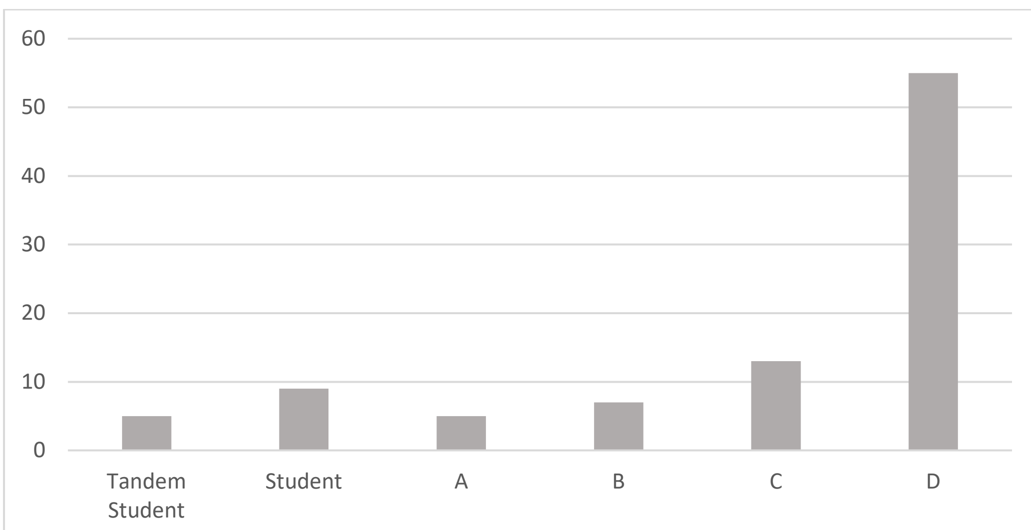


Table 2

Minimum Requirements for Awarding of USPA Licenses

A-license	B-license	C-license	D-license
	USPA A-license	USPA B-license	USPA C-license
25 freefall skydives	50 jumps	200 jumps	500 jumps
all USPA A-license proficiency requirements	30 minutes of controlled freefall	60 minutes of controlled freefall	3 hours of controlled freefall
5 formation freefall skydives of at least 2 participants	10 formation skydives, 5 of which must be of at least 3 participants	50 formation skydives, 10 of which must be of at least 4 participants	100 formation skydives, 25 of which must be of at least 8 participants
			Completed at least one of the following:
	Live water landing training		a) 1 intentional water landing
	10 landings within 10 meters of target	25 landings within 2 meters of target	b) 50 landings within 2 meters of target
			c) Canopy formation stack of 3 or larger
			d) 2 night jumps with at least 20 seconds of freefall
	All USPA canopy piloting proficiency requirements		
Passed USPA A-license written and oral exams	Passed USPA B-license written exam	Passed USPA C-license written exam	Passed USPA D-license written exam

Although classified as “students”, tandem students are, for all practical purposes, “passengers.” Tandem students receive brief orientation training of what to expect and what actions to take when instructed to do so by their tandem instructors. They are completely dependent on the instructions and actions of their tandem instructors. They do not have the training or ability to execute independent actions in case of a malfunction. The data on fatalities involving tandem students do not indicate that the tandem students contributed in any way to the accidents.

The data presented in Figure 2 indicates that student jumpers had more fatal accidents than A or B licensed jumpers. Two of the reported fatalities were student jumpers on their very first jump. Although concerning, this is not unexpected, given the risks involved and inexperience of the student jumpers. The typical student has only academic training and simulated practice to rely on if faced with an unexpected situation. Regardless of which of the three USPA-approved training methodologies is used, all student jumpers are on their own once they are under canopy with only radio communication with an instructor at the landing area for guidance and assistance. They are required to perform correctly in a very dynamic, unfamiliar, sensory-intense, and stressful environment.

The decrease in the number of fatalities for A-licensed jumpers compared to student jumpers is also not unexpected. Typically, newly licensed jumpers are keenly aware of the limits of their abilities and tend to take more conservative and prudent decision. The increase in fatalities for B- and C-licensed jumpers is not unexpected given that each successive license level allows the jumper to engage in more advanced, challenging, and riskier activities. However, the quadrupling in the number of fatalities for the most experienced, D-licensed, jumpers was unexpected and cause for concern.

The ranking presented in Table 1 was used to select a purposeful sample for further analysis. The purposeful sample includes the following categories:

- Incorrect emergency procedures
- Equipment problem
- Landing problems not involving turn
- Unintentional low turn
- No or low cutaway/reserve deployment

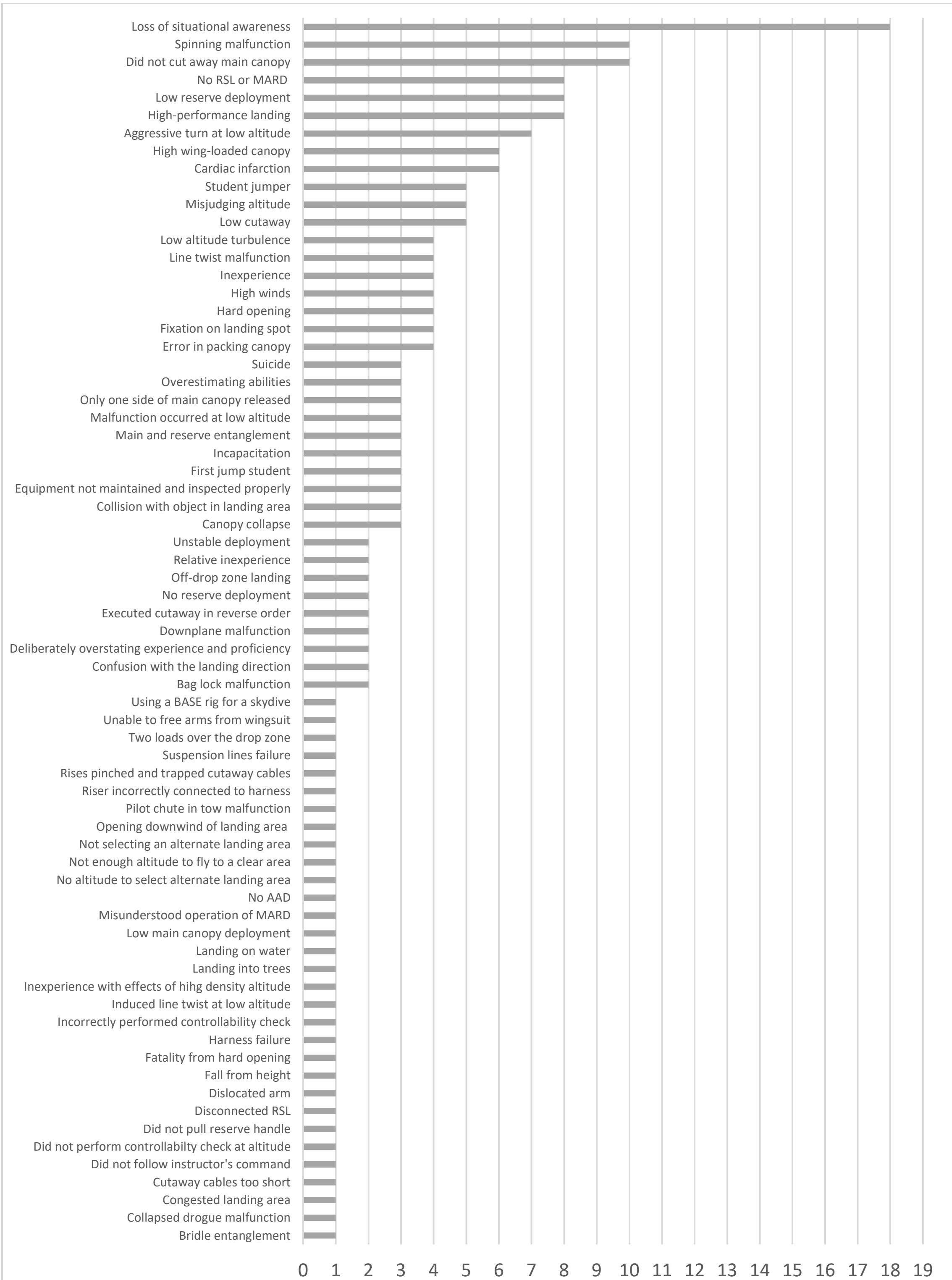
- Medical
- Intentional low turn

These seven categories were selected because the data indicates they have the highest likelihood of resulting in a fatal accident and they represent 80% of the fatalities in the population.

The data from the sample was further analyzed to identify relevant details or contributing factors that could lead identifying common themes or trends that manifested themselves across categories. The analysis identified 203 instances of 69 distinct relevant details or contributing factors. Of these, 172 instances of 38 common themes within the sample were identified. The analysis also identified 31contributing factor that occurred only once in the sample. Although these cannot be considered common themes, they are still important and relevant to this research project. The analysis also indicates that in many of the accidents, two or more common themes were factors in the same. For example, six of the eight fatalities categorized as "no or low cutaway/reserve deployment" exhibited the same three common themes of "loss of situational awareness", "spinning malfunction," and "no RSL or MARD". These same three common themes were identified 36 times in the sample and account for 55% of the common theme occurrences. Figure 3 presents the results of this analysis grouped by the frequency that these themes were encountered.

Figure 3

Common Themes in Sports Parachuting Fatalities in the United States 2015 to 2019



Discussion of Results

The data indicates that 34 of the 75 fatalities in the sample (45%) involved jumpers encountering a malfunction or equipment problem and not responding appropriately or not responding at all to the malfunction or equipment problem. The data also indicates that 33 of the 75 fatalities in the sample (44%) were the result of problems or errors occurring low to the ground, leaving the jumpers with little or no time to take corrective actions. The remaining 8 fatalities in the sample (11%) were the result of medical problems.

Incorrect Emergency Procedures (19 fatalities)

In sports parachuting, emergency procedures refer to the actions that a jumper must take immediately if the jumper experiences a malfunction during the deployment of the main canopy. These actions must be executed quickly and correctly for the jumper to survive. Assuming a deployment at the minimum altitude required by the USPA of 2,500 feet AGL, and a reference freefall rate of 200 feet per second, the jumper has approximately 12 seconds before impacting the ground if no action is taken.

When a malfunction occurs, the jumper must correctly identify the malfunction and decide whether to attempt to clear the malfunction or to cut away the main canopy and deploy the reserve canopy. There are some malfunctions that potentially can be cleared given enough altitude and there are others that, by their nature, cannot be cleared and the action following identifying the malfunction is to cut away.

Standard USPA training stresses not to take more than two seconds or two attempts to clear a malfunction before cutting away a main canopy. The procedure is as follows:

1. Visually locate the cutaway handle, located on the right side of the harness, just above the jumper's diaphragm
2. Firmly grasp, "peel" the cutaway handle from its hook-and-loop fastener stowage, and completely pull the handle and cutaway cable out of the harness
3. Visually locate the reserve canopy ripcord handle, located on the left side of the harness at same height as the cutaway handle while establishing a stable belly-to-earth freefall position
4. Firmly grasp and pull out the reserve ripcord handle and with a sweeping motion clear the ripcord cable from the housing to ensure it is completely out of the harness
5. Check the reserve canopy for condition as it inflates

Three of the 19 fatalities in this category involved student jumpers. This is consistent with the raw data on fatalities categorized by license. The common theme in these fatalities was a lack of experience. This is particularly significant because two of the three student jumper fatalities in this category were on their very first jump. When faced with an emergency that needs to be responded to quickly, student jumpers lack prior experiential knowledge that can be valuable in assessing and responding to such time-critical situation. The lack of experience also affects student jumper's ability to process and evaluate the volume of sensory information they are exposed to during a jump.

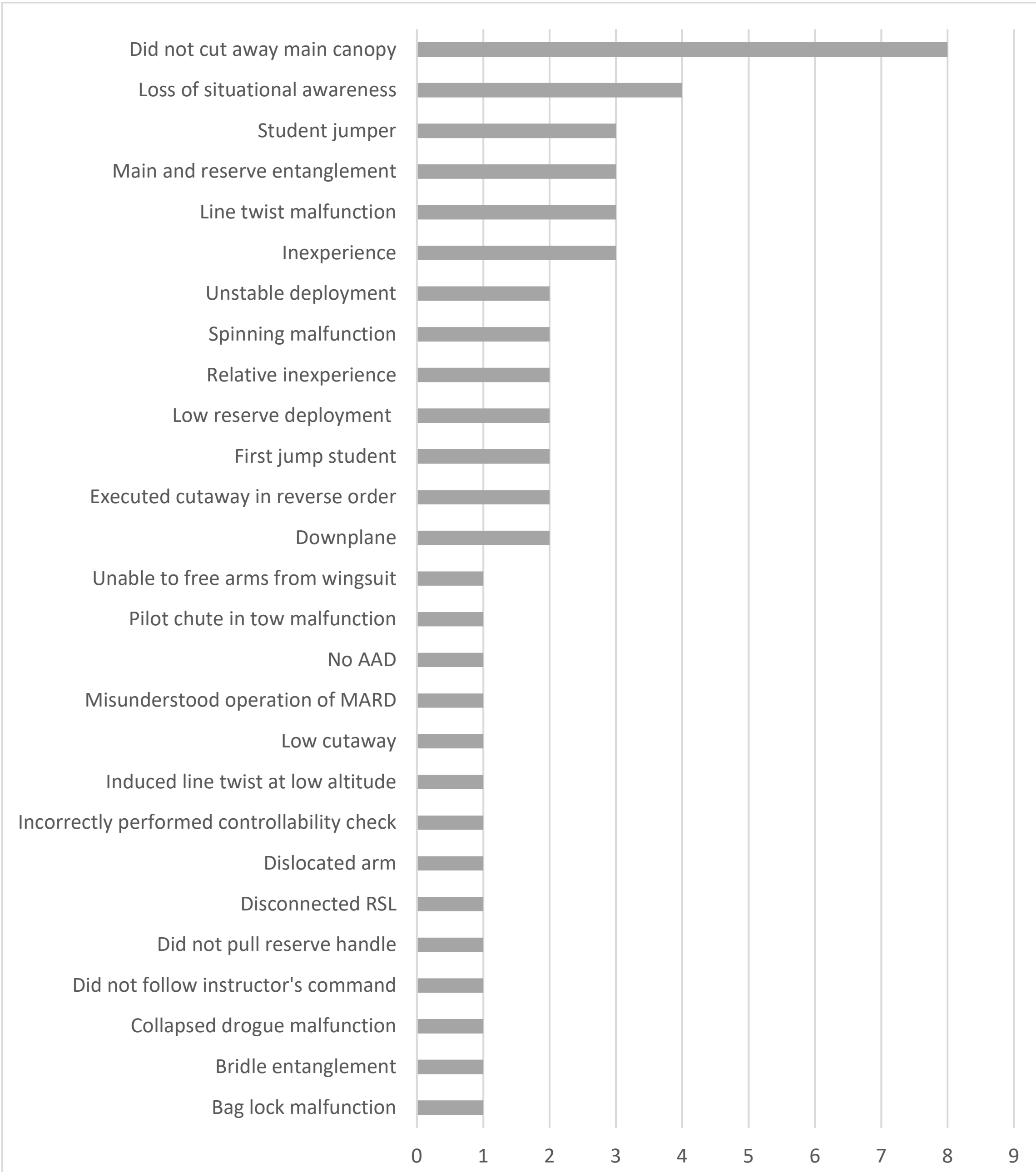
Student jumpers frequently express feeling overwhelmed by the sensory overload they experience during their first jumps. They typically also experience higher levels of stress and anxiety than more experienced jumper. This puts them in an exceedingly high state of arousal which negatively affects cognitive functions and decision-making abilities. These factors can combine to create confusion, apprehension, and in extreme instances, panic. All these can severely impact a student jumper's ability to assess a malfunction and make sound decisions on the proper course of action in response. The data on the fatalities involving student jumpers support this hypothesis. In two of the events, the jumpers did not take any action in response to the malfunction. On the third, the jumper executed the emergency procedures in the wrong order, deploying the reserve canopy before cutting away the main canopy, entangling both canopies and preventing the reserve from fully deploying.

In 8 of the 19 fatalities attributed to this category the jumper failed to cut away his or her main canopy. The second most frequent common theme in these fatalities, identified in 4 of the 19 fatalities, was a loss of situational awareness. The data on the exhibiting these two common themes indicate the jumpers experienced a malfunction at a normal deployment altitude but failed to cut away from the malfunctioning canopy or cut away too low to the ground for the reserve canopy to fully open before the jumpers struck the ground at a high rate of speed. The data suggests that these jumpers may have become focused on clearing the malfunction and lost altitude awareness.

Five of the malfunctions in this category were either line twists or spinning malfunctions. Either can quickly induce disorientation and loss of altitude awareness. The spinning malfunction is especially dangerous because the rate of rotation will increase rapidly with time if not stopped immediately. The increasing angular velocity of the spin will exacerbate the disorientation and loss of situational awareness. The increasing rotation coupled with disorientation may induce vertigo, and subject a jumper to extreme acceleration forces. These forces can make it difficult for the jumper to reach or pull the cutaway handle. They can also drive blood away from the brain inducing a hypoxic condition that would impair the jumper's cognitive functions and could result in a g-induced loss of consciousness (G-LOC).

Figure 4

Common Themes in Incorrect Emergency Procedures Category



Equipment problem (15 fatalities)

Of the 15 fatalities attributed to equipment problem, 4 were the result of a hard opening. To prevent hard openings, modern ram-air sports parachutes are equipped with a device called a slider. The slider works opposite to the aerodynamic forces inflating the canopy to constraint the speed with which a canopy inflates and therefore the deceleration forces exerted during canopy deployment. A jumper will typically decelerate from approximately 120 MPH to practically zero in about 5-7 seconds. Without a properly functioning slider, a canopy would inflate in less than half of that time. The deceleration forces can be severe enough to incapacitate a jumper, either through injury or loss of consciousness, or even fatal. The slider is a simple device and the only way for a slider to malfunction is by an error of not packing the slider properly while packing the main canopy. Eyewitness reports on these fatalities support the hypothesis that the jumpers were incapacitated by the hard opening. However, there was no data available in the USPA fatality summaries that would indicate whether the jumpers died because of the hard opening or by the uncontrolled hard landing or collision with obstacle on the ground.

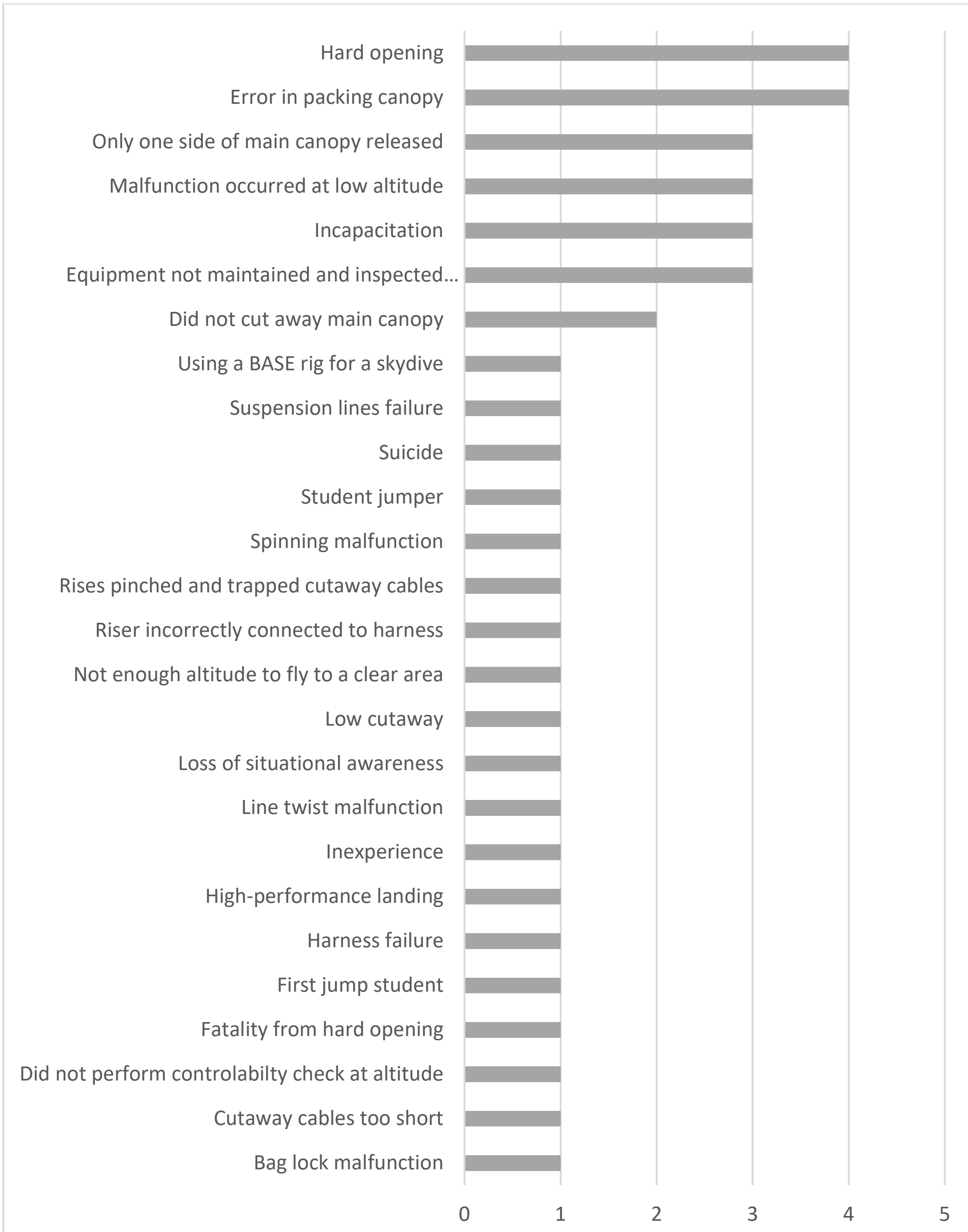
None of the fatalities involving a hard opening involved a cognitive error during the jump itself. However, all of them were the result of errors made during the packing of the main canopies involved in these accidents. These errors, or slips (Reason, 1990) create what is known as a “latent error”: an error that does not manifest itself immediately after it is made but remains undetected. The consequences of a latent error manifest themselves much later and usually affects someone other than the person who made the error. All the fatalities involving a hard opening were preventable.

A common theme in 3 of the fatalities categorized as equipment problem involve improper maintenance and inspection of the equipment. These are also latent error conditions and the fatalities that resulted from these errors were completely preventable.

Two contributing factors related to equipment problems are worth noting because they also indicate completely preventable fatalities. One fatality involved using old equipment that did not conform to current safety standards. The second fatality involved using equipment that was not designed for the type of jump attempted. Both suggest anomalies in the risk assessment process of the jumpers involved that led them to rationalize, underestimate, or ignore the risks associated with using the equipment in question. This is particularly significant in the case of the jumper who used BASE-jumping equipment. BASE-jumping equipment is not designed to deploy at or near terminal velocity (the maximum velocity a body in freefall can attain because air resistance equals the force of gravity). Manufacturers of BASE-jumping equipment stress this fact and the equipment is typically clearly labeled with warning to this effect. Although the jumper in this fatality was jumping from a hot air balloon at 700 feet AGL, this was high enough for the jumper to approach terminal velocity when he or she deployed the canopy. The harness separated from the canopy and the jumper was fatally injured by the harness failure before impact with the ground.

Figure 5

Common Themes in Incorrect Equipment Problem Category



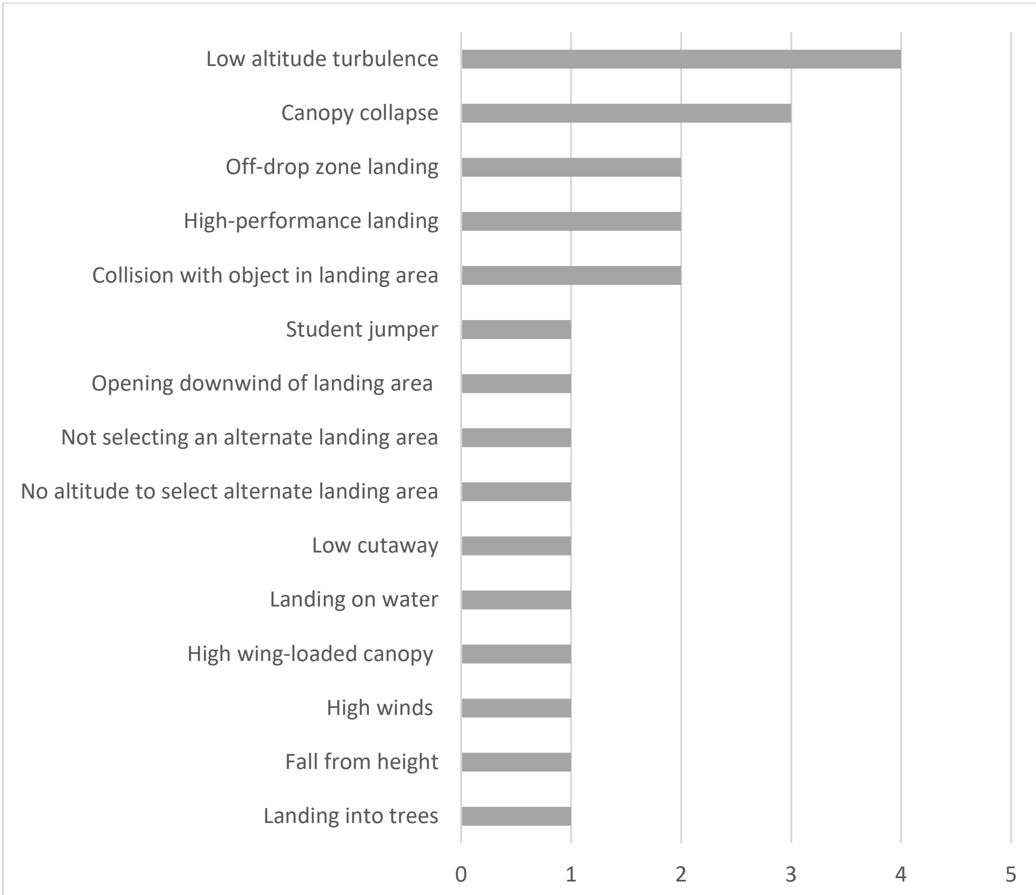
Landing problems not involving turns (9 fatalities)

A common theme in 4 of the 9 fatalities reported in this category is encountering turbulence low to the ground. Three of these four involved jumpers who were flying small, high-wing loading, canopies. A ram-air canopy is an airfoil and behaves the same way as a conventional wing. A high-wing loading (the ratio of the weight supported by a wing divided by the surface area of that wing) makes a canopy less sensitive to turbulence. However, such a wing flies at a much higher airspeed and has a much higher stall speed in all attitudes. In all three incidents, the jumpers encountered turbulence low to the ground causing the canopy to collapse without enough altitude to recover from the stall. Low-altitude turbulence is typically associated with high winds or localized convective action. However, the data on these fatalities does not provide any information on the weather conditions. Nor it provides information on the jumpers' experience and proficiency or the exact wing loading of the canopies they were flying. Any of these factors would have had a bearing on the jumpers' risk assessment and decision-making processes before the jump.

The second common factor in 3 of the 9 fatalities is the canopy collapsing at low altitude. This factor also contributed to 2 of the 4 fatalities due to turbulence discussed above. There is no time or altitude to reinflate a collapsed canopy at low altitude. A jumper has no other option but to prepare to execute a parachute landing fall (PLF - a body tuck-and-roll technique taught to all parachute jumpers since at least the Second World War in case they were faced with a hard landing) and hope for the best.

Figure 6

Common Themes in Landing Problems Not Involving Turns Category



Unintentional low turns (9 fatalities)

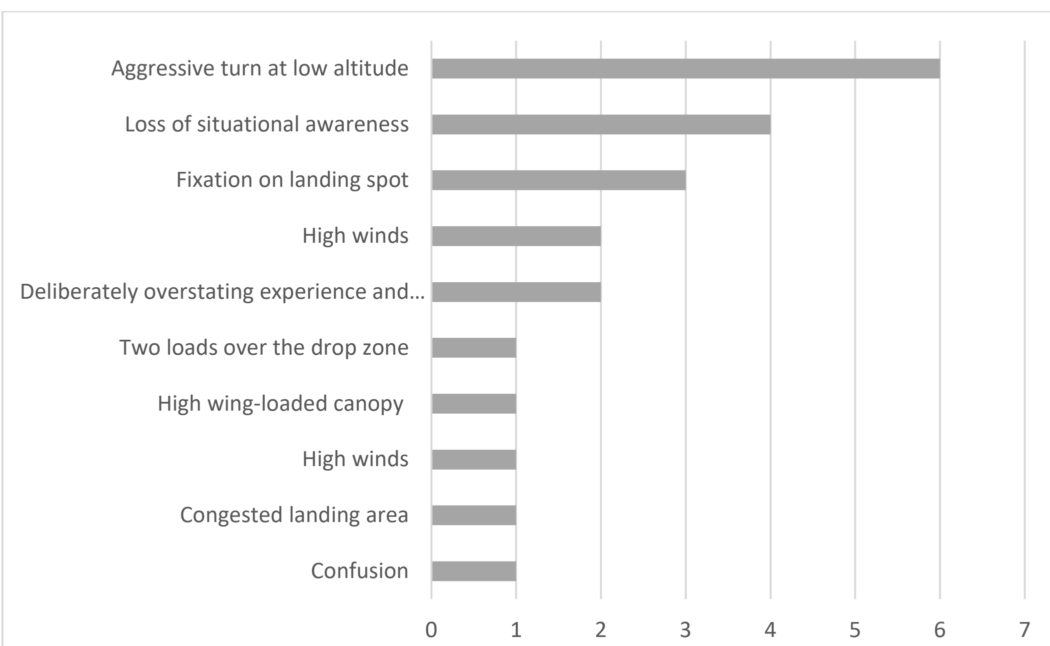
The most frequent common theme identified in 6 of the 9 fatalities in this category is performing an aggressive turn (steep bank angle and rate of turn) at low altitude. The reasons for executing such a turn include avoiding colliding with an obstacle in a crowded landing area, fixating on landing on a specific spot, and confusion about the landing direction. A jumper under canopy behaves very much like a pendulum when moved away from its vertical equilibrium position. The more it is away from equilibrium (the steeper the bank angle), the faster the system will try to move towards equilibrium. In combination with the aerodynamic forces acting upon a turning airfoil will cause the canopy to dive and accelerate during a steep turn. Even with corrective inputs from the jumper, there may be not enough altitude to recover and the impact with the ground would be at a high speed.

The second common theme, identified in 4 of the 9 fatalities in this category, is loss of situational awareness. This can be a trigger factor, causing the jumper to turn aggressively to avoid an obstacle on the landing are, or it can be the result of another factor, such as fixating on a specific landing spot. Fixating on the landing spot also contributes to the loss of situational awareness. The jumper's attention becomes so focused on the desired landing spot that he or she losses awareness of everything else in the environment.

It is noteworthy that a contributing factor in 2 of the fatalities was deliberately overstating the jumper's experience and proficiency. One instance was to secure employment, the second was to attend a desired training course. In both instances, the jumper did not meet the minimum requirements, so they resorted to exaggerating their qualifications.

Figure 7

Common Themes in Unintentional Low Turns Category



No or low cutaway/reserve deployment (8 fatalities)

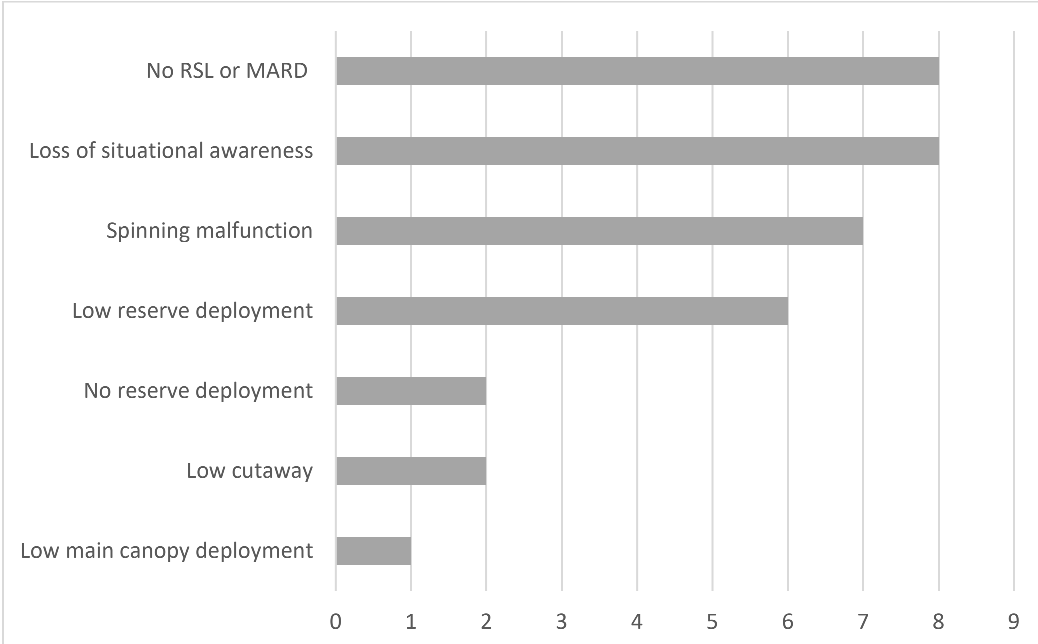
All 8 fatalities in this category have the same 2 common themes: no RSL or MARD installed and loss of situational awareness. The loss of situational awareness directly contributed to the jumpers deploying their reserve canopies too low for the reserve to fully inflate in 6 of the fatalities and cutting away the main canopies at a low altitude in 2 of the fatalities. The jumpers in the two fatalities that cut away at a low altitude did not attempt to deploy their reserve canopies.

It is likely that 7 of these incidents would have been survivable if the jumpers had equipped their parachute rigs with an RSL or MARD. Either of these devices would have deployed the reserve canopy immediately after cutting away the main canopy.

The rationalizations given for not equipping a parachute rig with an RSL or MARD are anecdotal but jumpers who argue against them state that such devices may not be effective in all circumstances requiring cutting away the main canopy, that in a case of a spinning malfunction, these devices would deploy the reserve in an unstable body position, leading to entanglement or line twist of the reserve, and that is better to fall momentarily after cutting away from a main canopy to ensure the reserve is deployed in a stable body position to avoid a malfunction of the reserve. Although the first point of this argument is true, the circumstances in which this would happen are extremely rare. The data on skydive fatalities used in this research project do not support this point and disproves the other two points of the argument.

Figure 8

Common Themes in No or Low Cutaway/Reserve Deployment Category



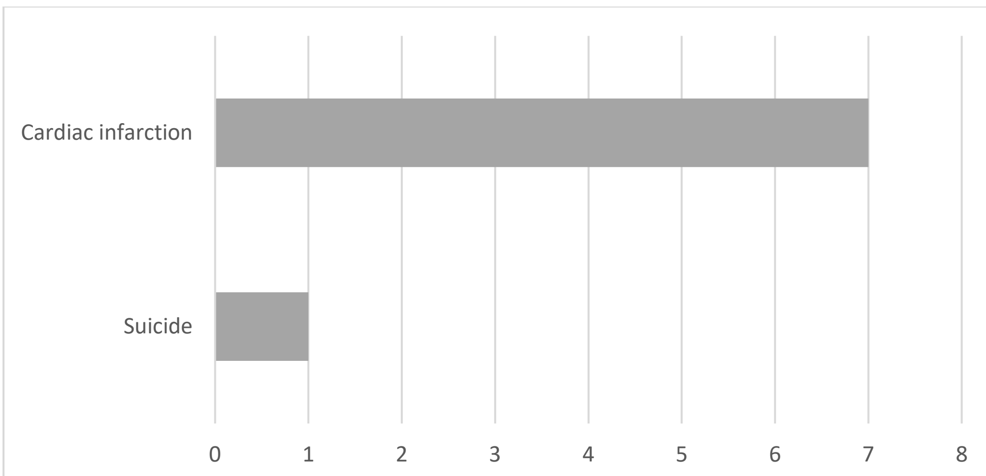
Medical (8 fatalities)

All 8 fatalities in the medical category involved licensed jumpers. Of these, 7 fatalities resulted from the jumpers involved suffering a cardiac infarction during the jump. All these jumpers were older jumpers. Although the data does not indicate that the jumpers made any erroneous decisions during the jumps that may have contributed to their death, it can be argued that in all these cases, the jumpers involved may have made personal decisions outside sports parachuting activities that placed them at greater risk of heart disease. However, there is no data readily available to validate this hypothesis.

One fatality involving a tandem instructor in this category was a case of suicide. Two other fatalities from 2015 to 2019 were in fact suicides: one student jumper fatality classified as an "equipment problem," and one experienced jumper fatality classified as a "no pull" (not deploying the main canopy). The physical evidence on all three cases, and the eyewitness testimony from the tandem student (who managed to land unassisted without any injury) confirmed the fatalities as suicides. The student jumper and the tandem instructor took deliberate actions to extricate themselves from their harnesses while under canopy. The experienced jumper left a suicide note behind. Although acts of suicide involve a faulty cognitive decision-making process, these cases are outside the scope of this research project.

Figure 9

Common Themes in Medical Category



Intentional low turns (7 fatalities)

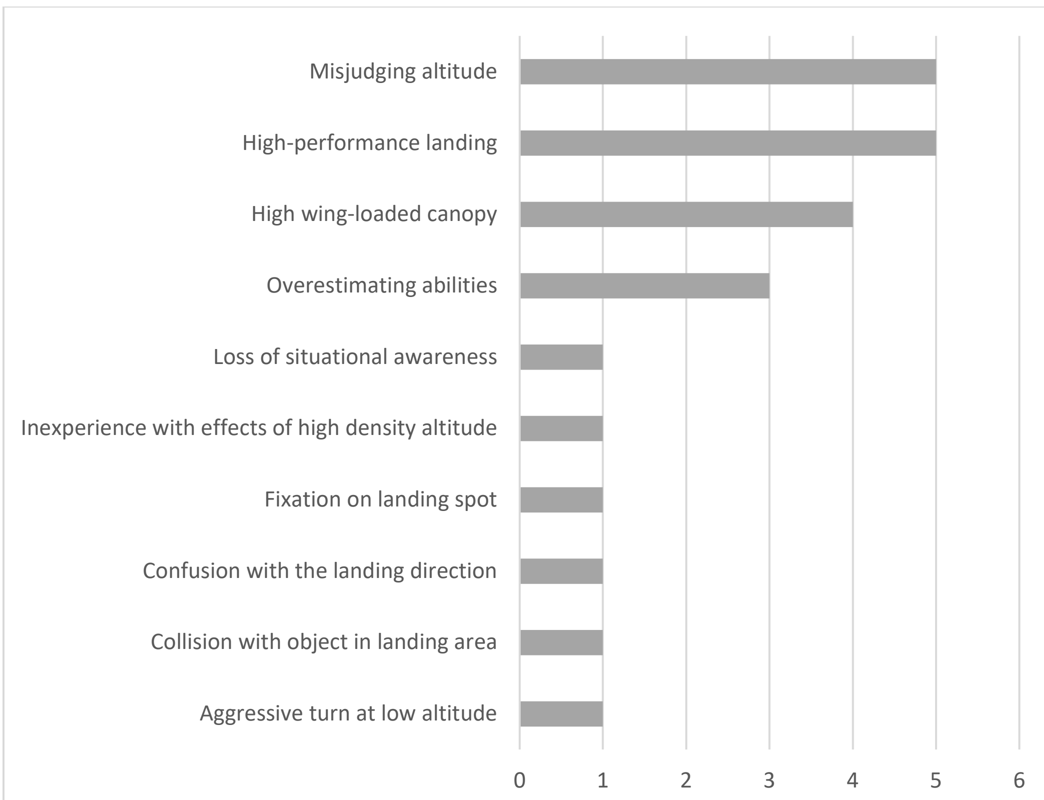
Two common themes of 5 of the 7 fatalities involving intentional low turn are misjudging altitude and executing the high-performance landing turn too low. These two factors are closely coupled because misjudging altitude led the jumpers to initiate a high-performance landing too low and impacted the ground in a high-speed diving turn.

The only instrument that all jumpers use is an altimeter. Skydiving altimeters come in a variety of models and display types. Although relatively accurate, there is no requirement to calibrate them periodically to ensure they remain accurate. There is no data to indicate whether an incorrect altimeter reading was a contributing factor in any of these accidents.

Two other related common themes were flying a high-wing load canopy and overestimating the jumper's own abilities, skills, and proficiency. Flying a high wing-loaded canopy requires a great deal of experience and proficiency. The data on the accidents involving a high wing-loaded canopy suggest that the jumpers transitioned to these types of canopies without enough experience.

Figure 10

Common Themes in Intentional Low Turns Category



General discussion

Examining the data on the complete sample, several common themes that could impact a jumper's ability to assess a situation and decide on a course of action can be identified. The data shows that the jumpers involved in these accidents experience a loss of situational awareness in 18 instances. These ranged in severity from being suddenly distracted close the ground to becoming disoriented due to a spinning malfunction.

The spinning malfunction, identified as a common theme in 10 instances, is particularly dangerous from a cognitive and decision-making processes perspective. Seldom does a spinning malfunction begin gently. The rotation will cause the brain to receive conflicting information from the sense of vision, the vestibular system, and the proprioception system. This can lead to spatial disorientation, confusion, and induce vertigo. In severe cases, vertigo can completely incapacitate a person. The malfunction will also trigger the body's natural reaction to fear, which include the release of stress hormones. These hormones are known to alter the perception of time. Combined with the loss of situational awareness, the jumper may believe he or she has more time than available to execute emergency procedures. The outcome of the accidents where the factors of spinning malfunction and loss of situational awareness contributed to the jumper executing emergency procedures, executing them in the wrong order, or not executing them at all (no reserve deployment), support this conclusion.

A second common theme that negatively impacts the decision-making process is the lack of experience, either total experience in the sport or relative experience with a particular sports parachuting activity, such as executing a high-performance landing. This common theme was identified in 25 instances across 6 common themes. Experiential knowledge is particularly important in the decision-making process. This knowledge is recalled during the decision-making process and integrated with the sensory input about the environment to evaluate the situation and select the best response. In cases where information about the environment is incomplete, such as the cases of loss of situational awareness, experiential knowledge can help a jumper make the appropriate response to an emergency or malfunction by recalling learned responses to specific malfunctions. The 3 fatalities of student jumpers on their very first jump and the cases of fatalities involving relatively inexperienced jumpers attempting to perform high-performance landings are examples of the consequences of not having that experiential knowledge available when needed.

The data identified 18 instances of decisions taken considerable time before the accidents but had a direct bearing on the outcomes. These instances can be considered cases of cognitive dissonance (Psychology world, 1998). They include the 8 instances where the jumpers that did not equip their parachute rigs with RSL or MARD systems, and the 3 instances where the physical evidence indicated that the equipment had not been maintained or inspected properly, and the 5 jumpers who overestimated or deliberately overstated their experience and proficiency. In all these cases, the jumpers “knew better”, yet their actions were contrary to these beliefs. Their actions became one of the links in the chain of events that led to these fatalities. It is important to mention that many commercial skydiving operators recognize the effectivity of RSLs’, MARD’s, and AAD. They require any licensed jumper jumping at their facilities must have a rig equipped with either an RSL or MARD, and an AAD before being allowed to jump at their drop zone.

By its very nature, sports parachuting appeals to people who have a very high risk threshold (risk homeostasis). For them, the risk is within their individual risk thresholds, partly because the rewards outweigh the risks. The relatively low probability of injury or death despite the risks (zero-risk theory) could be the rationalization used by student jumpers to have a relatively low perception of risk even though they lack the knowledge and experience to make an actual reduction in risk (threat avoidance theory). In the case of the jumpers who found themselves exceeding their skills and abilities, it is highly probable that the boost in self-confidence gained from increasing their knowledge and experience encouraged these jumpers to underestimate the risks or overestimate his/her skills and engage in a sports parachuting activities or disciplines for which they were not yet ready.

One objective that this research project was unable to accomplish was to review and analyze data from sports-parachuting injuries using the same methodology used for the fatalities. What the research discovered is that until 2018, there no central repository of this data was available. That year the USPA implemented an online anonymous incident report system for this very purpose. The system has been in operation for a short time therefore the data within it is rather limited.

Chapter V Conclusion and Recommendations

Conclusion

The analysis of the data supports the hypothesis that the errors in the human decision-making process are at the root of most sports parachuting fatalities. However, it was unexpected to identify so many common themes that did not impact the decision-making process directly during a jump. These factors influenced the jumpers to make faulty decisions in an environment where they could afford to take their time to evaluate and decide on a course of action. The jumpers' decisions breached the safeguards and defense in place to prevent human error and, combined with additional factors, resulted in fatal accidents. The challenge remains to find effective measures to address the root causes of these errors.

Recommendations

The first recommendation is to incorporate new technologies into the initial and recurrent training programs of the future. Experiential, hands-on training in a realistic but controlled environment is one of the most effective methods to improve human cognitive performance (Reese, 2011). One recognizes that experiential, hands-on training in a realistic but controlled environment is one of the most effective methods to improve human cognitive performance while maintaining safety (Reese, 2011). Realistic simulation is used effectively in other areas of aviation for this purpose. However, the very nature and dynamics of the sport make simulating sports parachuting operations particularly challenging.

In recent years, vertical wind tunnels (Dropzone.com, 2019) have proliferated worldwide and have proven to be effective tools for sports parachutists to improve their skills and control during freefall. Some commercial skydiving operators like Skydive Perris, in California have a vertical wind tunnel on site and their training syllabus requires student jumpers to spend a specified amount of time with an instructor in the wind tunnel before making their first jump. Simulating the canopy deployment and canopy flight portion of a skydive has been even more problematic. Advances in virtual reality technology (VR) have enabled the development of immersive VR-based, realistic, physical canopy flight simulators. Although these simulators were developed for training military special forces (esigma, 2018; Systems Technology, Inc., 2016), but they can be adapted easily to sports parachuting applications.

A second recommendation related to training is to make changes to standard emergency procedures training. Currently, training on emergency procedures follows the sequence of identifying the malfunction, evaluating if it can be resolved or should the jumper initiate emergency procedures to cut away from the malfunctioning canopy (USPA, 2020b). For certain malfunctions, such as a spinning malfunction, the emergency procedure should be to immediately cut away without stopping to evaluate whether it can be corrected or not.

The third recommendation is to promote applied research in the areas of human cognition and human factors specifically focusing on sports parachuting. The body of knowledge based on quantitative research specifically focusing on sports parachuting safety is very limited. This is partially due to the challenges the sports parachuting environment would pose to designing a valid and safe quantitative methods experimental research on human decision-making process. Perhaps in combination with the emergent high-fidelity virtual reality canopy flight simulator technology such a research study may be possible. The potential for uncovering new insights on how human decision making process work in this challenging environment is there.

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