DEVELOPMENT OF A MODEL OF 'SEE AND AVOID' IN PARACHUTING

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The UK military undertakes in-depth investigations of serious parachuting accidents, which have recently included two mid-air collisions. The analysis of these accidents identified that collision avoidance in parachuting uses similar processes to the see-and-avoid task performed by aircraft pilots. However, no research was identified that had explored see-and-avoid when parachuting. Accordingly, a model of parachuting see-and-avoid was developed which consisted of six stages which must be performed in sequence for a collision to be avoided successfully. Each stage of see-and-avoid was associated with key errors, the likelihood of which was influenced by a range of factors within the individual, their operating environment, and equipment. The model of see-and-avoid can be applied to identify human factors influences in a parachute accident and in the development of initiatives to improve parachuting safety.

Parachute jumping represents an area of injury and fatality risk in aviation. Accordingly, the Royal Air Force Centre of Aviation Medicine (RAF CAM) was tasked to provide Human Factors (HF) support to the investigation of parachuting accidents involving UK military personnel. Two recent accidents involved a collision between two parachutists while under canopy control in the late stages of the descent. These collisions were unintended and led directly to the injuries sustained in the accident. Therefore, the investigation undertaken by RAF CAM aimed to identify why the parachutists collided, what HF issues may have increased the likelihood of the collision, and what could be done to reduce the likelihood of such collisions in future.

The British Parachuting Association (BPA) Operations Manual (1998) states that "*throughout the descent parachutists should be aware of other parachutists and, if necessary, take avoiding action*". As such, collision avoidance relies on the parachutists maintaining adequate look out, which reflects the pilot's task to see-and-avoid other air traffic.

While a number of detailed studies have characterised the pilot's see-and-avoid task, no research has been identified that has explored see-and-avoid during parachuting. Therefore, the aim of this work was to review the applicability of see-and-avoid aviation research to collision avoidance during parachuting, and use this to develop a model of Parachuting See-and-Avoid (PSA).

Method

Literature regarding see-and-avoid in aviation was reviewed in relation to the parachuting environment. The literature review included journal articles, aviation accident investigations, technical reports, and advice from regulators. The stages of see-and-avoid that have been specified for aviation were identified from the literature, and compared against the parachuting task to provide an initial model of PSA. For each stage in the initial model, key errors and HF issues which would prevent that stage from being effective were described. The completed model was reviewed informally within the team, and further refined through application in two parachuting accident investigations.

Results

The PSA model is presented in Figure 1. The left hand column in Figure 1 outlines the stages of see-and-avoid, and the right hand column outlines key errors which would prevent that stage from being effective. Each stage in the left hand column must occur successfully for a collision to be avoided.

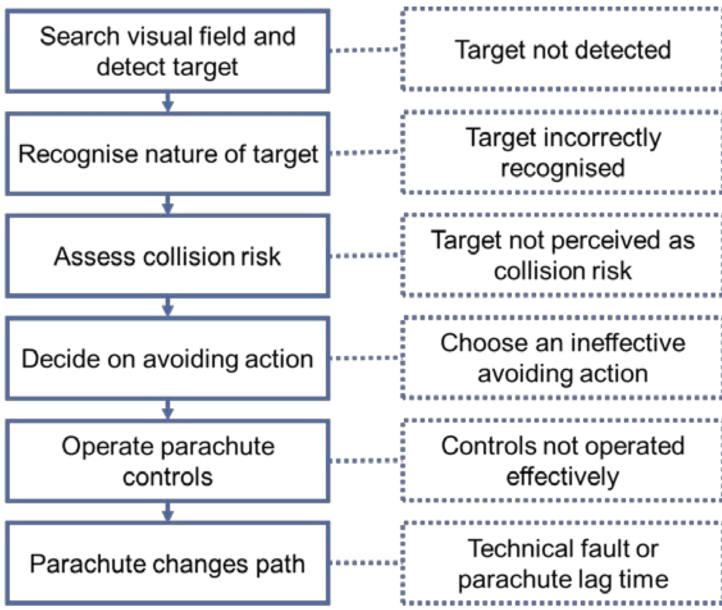

Figure 1. Model of see-and-avoid in parachuting.

Search, detect, and recognise target

As shown in Figure 1, the first stage of PSA is to search the visual field to detect the target. The target may be another parachutist, but could refer to any other collision hazard. In the second stage the nature of the target is recognised. These initial stages are fundamental for see-and-avoid to be successful, but can be influenced by a wide range of factors.

Position within visual field. For a target to be detected, it must be present within the visual field. The ability to detect a target that is within the visual field will then depend on its position at the centre or periphery of the visual field, the apparent size of the object, and any relative movement (Scott and Wright, 2016).

Visual contrast. The contrast between a target and the background against which it is viewed is a key determinant of the ease with which it is detected (Scott and Wright, 2016). Particular considerations in parachuting are the canopy colours, differentiation between the canopy and the sky/ground, and the background complexity. Environmental conditions such as light levels, visibility, and glare can all influence the visual contrast of the target and so the ease with which a target can be detected (Kroemer and Grandjean, 1997).

Alerting equipment. Where there are no tools available to alert the individual to a target, visual search will be non-directed and associated with a lower level of success (Australian Transport Safety Bureau (ATSB), 1991). While alerting systems are common place in commercial aviation, such systems are not used in parachuting. In parachuting, an alert may be provided by another parachutist giving a warning or an instructor or safety officer giving talk down instructions.

Equipment obstructions. The parachute canopy and risers, and the parachutist's goggles and helmet could limit field of view. Scratches or marks on the goggles could also reduce visibility.

Time to search visual field. Given the range of movement possible in parachuting, potential targets could be in a large proportion of the airspace and so even with the application of a highly efficient visual search strategy it could take considerable time to perform a complete search of the visual field.

Attention and distraction. Attentional resources are limited and so if a parachutist's attention is targeted at one particular area this is likely to be at the expense of other areas; so if attention is directed away or distracted from the target, then it may not be detected.

Workload and stress. Parachuting is perceived as a high stress task and so has been used as an experimental context for research on physiological responses to stress. This research has shown that physiological stress responses are found before, during, and after parachute jumps (Chatterton, Vogelsong and Hudgens, 1997) and that stress from parachuting could reduce cognitive performance (Taverniers, Smeets, Lo Bue, Syroit, Van Ruysseveldt, Pattyn and von Grumbkow, 2011). However, there have been few studies into the effect on performance and there is no evidence to indicate if workload and stress varies through the jump, between different types of parachuting, or between parachutists.

Environmental stressors. Stressors such as hypoxia, noise/wind rush, vibration, and temperature could influence target detection during parachuting. However, there has been relatively little research to characterise the impact of these factors in the parachuting environment. For instance, while it is known that hypoxia can lead to impairments to decision making, reaction times, and vision, as well as changes in attitude to risk (Hodkinson, 2011; Petrassi, Hodkinson, Walters, and Gaydos, 2012) there have been no studies exploring the effect of hypoxia on performance during the dynamic environment of a parachute jump. Overall noise levels have been measured in civilian parachuting, indicating a noise level of approximately 105dB across all phases of the jump (aircraft flight, free fall and under canopy; Penman and Epstein, 2011); however, no study has been identified which measures the noise levels at each stage of the jump. No research has been identified to determine the levels of vibration found when parachuting.

Diffusion of responsibility. Diffusion of responsibility is *"The process by which individual's may fail to act in a situation requiring intervention as a result of the presence of other people"* (Stratton and Hayes, 1999). The scope for diffusion of responsibility to influence see-and-avoid behaviour has been considered in relation to piloted aircraft (ATSB, 1991) and may be applicable to parachuting.

Assess collision risk

Once detected, the parachutist must determine if the target poses a collision risk. This task involves assessment of the other's trajectory and speed in relation to the parachutist's own flight path. Many of the same factors which reduce the likelihood of detecting and recognising the target could also influence this task – particularly the visibility of the target, workload, and environmental stressors. However, there are also HF issues specific to the decision process.

Nature of the flight paths. The parachutists may only be on a conflicting path for a short period of time which could limit the opportunity for the collision risk to be assessed. Unpredictable movements by either of the parachutists would also make it difficult to assess the risk of collision.

Judgement of speed, trajectory, and size. Assessment of own and other's speed, trajectory and size during a parachute descent is purely visual and so subject to a range of visual illusions and misjudgements which could lead the parachutist to believe that a collision was less likely than it was.

Gathering additional information to reduce the likelihood of misjudgement takes time and so reduces the time available to take avoiding action.

Decision time. The time required to recognise a collision will vary depending on a wide range of factors including the clarity of information regarding the collision risk, training, and experience. FAA Advisory Circular 90-48D suggests five seconds is required to recognise a mid-air collision risk, although the extent to which this applies to decision making while parachuting is not known.

Training and experience. It is not known if training in assessing collision risk could improve parachutist's judgement. However, a greater level of training and experience at the tasks being performed could improve decision making at critical times.

Decide on avoiding action

Having identified that there is a risk of a collision, the parachutist must choose an appropriate avoiding action. Workload, environmental stressors, training, experience, and decision time could influence this task, alongside three factors specific to this stage of PSA.

Procedures. Where procedures are available for the parachutist to adopt to avoid the collision, and the parachutist is aware of those procedures, it may be possible to achieve a reliable level of performance.

Diffusion of responsibility. Responsibility for collision avoidance is placed with the upper parachutist during a descent (BPA, 1998). This clear specification of roles is beneficial in preventing confusion when deciding on an avoiding action, but could lead the lower parachutist to delay making a necessary avoidance decision due to a perception (conscious or otherwise) that the upper parachutist would take the action.

Freezing response. Although response to emergency situations has often been characterized as 'fight or flight', the response to freeze - or take no action - has also been observed. Leach (2004) characterizes the freezing response as reflecting a situation in which *"no behavioural schema"* exists and the person perceives that the time to choose the appropriate behaviour is longer than the time available. Such a response could be anticipated in a PSA if the parachutist does not feel able to select and implement a suitable response in the perceived time available before the collision.

Implement avoiding action

The final two stages of the PSA model reflect the human and system tasks to implement the avoiding action. As with the previous stages, the operation of the controls could be influenced by workload, environmental stressors, training, and experience. However, the nature of the tasks associated with implementing avoiding action introduces novel influences.

Equipment usability. The design of the controls for adjusting the canopy could impact on the ease with which actions are implemented.

Reaction time. Simple reaction times (for a simple motor action to a stimulus) can be as short as 0.15 secs, and for a simple choice between three options it has been estimated that reaction time could be as fast as 0.4 secs (Kroemer and Grandjean, 1997). This figure is in line with the FAA Advisory Circular 90-48-D which uses a reaction time of 0.4 secs once a course of action has been selected. However, no data was identified which recorded the time taken to operate parachute controls.

Physical characteristics. The size, shape, and other physical characteristics of the parachutist can impact on their ability to operate the parachute controls. In particular, the anthropometry of the upper body and the parachutists' strength are relevant to the task of taking action to avoid a collision. Injury, either pre-existing or sustained during the jump may also impact on the parachutist's ability to implement the required actions.

Lag time. There will be a lag time between the parachutist operating the control and the parachute changing direction which could influence the ability to avoid the collision.

Discussion

RAF CAM has developed an initial model of PSA which has been adapted from models of similar tasks undertaken by aircraft pilots. The PSA model has been applied during the investigation of two parachuting accidents. In these investigations, the use of the model enabled the investigator to characterise which stages of PSA had been successful, and where shortfalls may have occurred. As such, the model contributed to understanding what happened during the accident.

The inclusion of the factors that could influence each stage of PSA within the model was particularly beneficial during the investigation process as it enabled a wide range of factors to be considered and provided a framework against which the available evidence could be compared. By reviewing the evidence against these factors, the PSA model contributed to understanding why the collision avoidance process was unsuccessful. In doing so, the analysis identified changes which could be made to improve safety and reduce the likelihood of recurrence. The two HF investigations produced a total of 23 recommendations which covered issues including training, parachuting equipment, and talk down practices.

In developing and applying the PSA model it has become apparent that there were a number of areas where adequate research was not available to determine if a factor could influence the risk of a collision. In particular, further research is required to determine the impact of workload and stress, hypoxia, noise, and vibration on performance during parachuting tasks. Further work is also required to conduct full scrutiny of the PSA model. To date the model has only been applied to two parachuting accidents, both involving military personnel; therefore further assessment would be required to determine the suitability of the model for both military and civilian parachuting. However, the initial work presented in this paper suggests that the application of the PSA model could be beneficial to improving safety and reducing the risk of mid-air collision in parachuting.

Acknowledgements

The authors acknowledge the contribution of the relevant Service Inquiry and Defence Accident Investigation Branch personnel to the analysis presented in this paper.

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