BMJ Open Sport & Exercise Medicine

Free Fall Acrobatics to Reduce Neck Loads During Parachute Opening Shock: Evaluation of an Intervention (ACROPOSE)

Anton Westman,[1,2] Björn O Äng[1,3,4]

To cite: Westman A, Äng BO. Free Fall Acrobatics to Reduce Neck Loads During Parachute Opening Shock: Evaluation of an Intervention (ACROPOSE). *BMJ Open Sport Exerc Med* 2016;**2**: e000108. doi:10.1136/bmjsem-2015-000108

► Prepublication history for this paper is available online. To view these files please visit the journal online (http://dx.doi.org/10.1136/bmjsem-2015-000108).

Accepted 24 February 2016

[1]Division of Physiotherapy, Department of Neurobiology, Care Sciences and Society, Karolinska Institutet, Huddinge, Sweden
[2]Department of Anesthesia and Intensive Care Medicine, Karolinska University Hospital, Huddinge, Sweden
[3]Department of Physical Therapy, Karolinska University Hospital, Stockholm, Sweden
[4]Centre for Clinical Research Dalarna, Falun, Sweden

Correspondence to
Dr Anton Westman;
anton.westman@ki.se

ABSTRACT

Introduction: Neck pain is a widespread health problem in the skydiver athlete population, epidemiologically linked to repeated exposure to parachute opening shock (POS). During POS, a parachutist is subjected to considerable deceleration forces. This study aims to evaluate the use of preventive free fall acrobatics to reduce the biomechanical load on the neck of parachutists during parachute opening.

Methods and analysis: Interventional study with a cross-over, within-subject, repeated measures design. Two consecutive skydives are made on the same day with random ordering of either an 'intervention jump' or a 'control jump'. The intervention jump contains two acrobatic elements prior to main parachute extraction: Reducing parachute deployment airspeed and positioning the human body head high. The primary outcome measure is the magnitude of initial Gx deceleration. All other directions of accelerations will be measured as well, as will magnitudes of multidirectional jerks (rates of changes of accelerations) and lower neck torque. Repeated within group measures analysis of variance will be used to quantify effects, and regression used to test for relationships between the elements of the intervention.

Ethics and dissemination: Regional Medical Research Ethics Committee of Stockholm approval 2015/1189-31. The intervention protocol has been systematically prevalidated with an emphasis on participant safety. The study will be conducted in compliance with the Declaration of Helsinki, and its results published in peer-reviewed journals, preferably Open Access, to maximise access for the target athlete population.

Trial registration number: NCT02625896. Pre-results.

INTRODUCTION

Since its inaugural world championships in 1951, the sport of skydiving has grown and diversified considerably. Excluding tandem passengers, 200 000 skydivers in some 40 countries perform more than five million skydives annually.[1] Over the years, safety and equipment has improved, and skills and competitive events have evolved.[2] However, a visiting old-timer will notice that one familiar sound remains: the rattling thunder in the sky of opening parachutes, repercussive of the brutal forces that skydivers are subjected to when their sports equipment decelerates them from a velocity >200 to <30 km/h within a few seconds. The reported incidence of serious injuries caused by parachute opening shock (POS) is, fortunately, low,[3] but anecdotal information and articles published in skydiving magazines, as well as case studies found in the medical literature, suggest repeated POS exposure to be an important health problem in this population of athletes, impeding their sports participation.[4 5] In the Swedish skydiver population, the self-reported 1-year neck pain prevalence is 45% with a 1-year prevalence of neck pain attributed to POS of 25%.[6] A general population estimate is, by comparison, 37%.[7] A high number of parachute jumps during the past 12 months and having a high wing-loading (the ratio of total suspended weight to wing platform area) were shown as risk factors for neck pain in the Swedish skydiver survey, suggesting highly active skydivers using small main parachutes to be at risk.

Previous studies on the effects of POS on humans are scarce. The physics of ram-air POS has been investigated using load cells integrated to the risers of standard ram-air parachutes, showing hard and subjectively painful POS deceleration magnitudes reaching 9–12 times Earth's gravitational acceleration (a dimensionless ratio commonly denoted G).[8] From these empirical data, it has been estimated that the maximum deceleration experienced by skydivers during parachute opening is proportional to the square of their velocity prior to the descent of the 'slider' reefing device. The relationship

between parachute size and opening shock is complex, and related to whether the opening sequence evolves normally, or an abnormal 'instant opening' occurs, for example, because of premature line release. In the latter case (which may add up to a parachute opening injury event requiring emergency medical care), the skydiver experiences higher decelerations with a large parachute, whereas in a normal opening, smaller ram-air parachutes of current models are noted to frequently open 'harder' than larger ones. This may be, at least partly, explanatory for the above mentioned epidemiologic finding that a high wing-loading is a risk factor for neck pain. As the number of abnormally hard openings experienced reasonably should increase with number of skydives, it can be speculated whether it is the repetitive exposure to 'normal' openings (what is accepted as accelerometrically 'normal' in this population would probably be unacceptable for humans in other areas of society, eg, occupational health) or an accumulation of hard openings, or a combination of both, that may explain the established relationship between many skydives and neck pain. Fighter pilots, another population vulnerable to accelerations, have experienced neck pain after exposures to 4 G, and unexpected decelerations of 2 G have been shown to cause soft-tissue damage in necks of fighter pilots.[9 10]

Observational data from our group (manuscript submitted) suggest POS as composed of two biomechanically dissimilar phases. The first phase contains an initial high jerk in dorsal to ventral direction, that is, 'pulled backwards, suddenly', denoted negative Gx by a standard linear motion coordinate system,[11] when the initial deceleration rotates the skydiver from a prone belly-to-earth body position to an upright position. The next, upright, phase contains the maximum deceleration sustained, that is, 'pulled upwards, hard', namely, positive Gz. During the first phase, the moment arm from the risers-to-rig connection at the shoulders versus the centre of the mass of the head, is long and likely to yield a high torque in the neck. Our observational data show that the neck muscle activity during POS is high, even supramaximal for some muscle groups, and that anticipatory motor control may be a strategy among experienced skydivers in order to protect the neck during POS.[12] Anticipatory muscle activity appeared to be somewhat variable, possibly related to variations in the parachute deployment sequence. From these biomechanical outcomes, causal relations to neck pain cannot be rejected. Therefore, given an overall aim of decreasing the neck pain prevalence in the skydiver population, it would seem that a desirable next step in our translational research programme would be to evaluate an intervention strategy that may serve as a candidate for large-scale population implementation.[13]

Haddon suggested that physical hazards to humans may be conceptualised as related to technological, environmental or human factors.[14] In a sport, it is desirable to prevent injuries by the way the sport is practised, for example, by human factors such as athletic skill and technique. Preventive strategies should, ideally, be time/resource-efficient, sports specific, preventive of both acute as well as stress injuries and designed with feasible future wide-scale implementation in mind.[15] In skydiving, a number of athletic techniques to prevent POS-related health problems have been proposed over the years. These appear to be based on subjective, personal experiences and have been dispersed from skydiver to skydiver, in articles in skydiving magazines and on website posts.[16] Two of these proposed techniques to prevent POS-related health problems are to reduce parachute deployment airspeed and to position the human body head high just prior to main parachute extraction. The previously mentioned physics data support a free fall velocity reduction, and observations made by our group, noting the relatively long moment arm from the risers-to-rig connection at the shoulders versus the centre of the mass of the head during the first 'jerk-phase' of POS, may support having a head high overall body attitude at POS onset.

This study aims to evaluate the use of free fall acrobatics to reduce the biomechanical load on the neck of parachutists during parachute opening. The acrobatic intervention consists of two separate elements: reducing parachute deployment airspeed and positioning the human body head high, just prior to main parachute extraction.

METHODS AND ANALYSIS

Study design

This interventional study will use a cross-over, within-subject, repeated measures design with randomised ordering of performing either an 'intervention jump' or a normal 'control jump' in the first of two consecutive skydives on the same day, as shown in figure 1, based on the CONSORT Flow Diagram.[17] Repeated within group measures analysis of variance will be used to quantify effects on initial Gx-load and torque from the head as relevant for the lower neck. Regression will in addition be used to test for relationships between how well each element of the intervention will be executed (reduction of airspeed and head-high reduction of moment arm from the head complex to the lower neck) on these same variables, that is, initial Gx-load and torque relevant for the lower neck. Based on an estimated real-world 30% effect size and a desired 0.9 power level, sample size calculations suggest 16 participants as sufficient for parametric analyses. To allow for data losses due to expected technical difficulties, the sample size will be increased to 20 participants.

Outcome measures

The outcome measures will be the magnitudes of multi-directional accelerations/decelerations during ram-air parachute openings expressed in terms of multiples of Earth's gravitational acceleration g using the

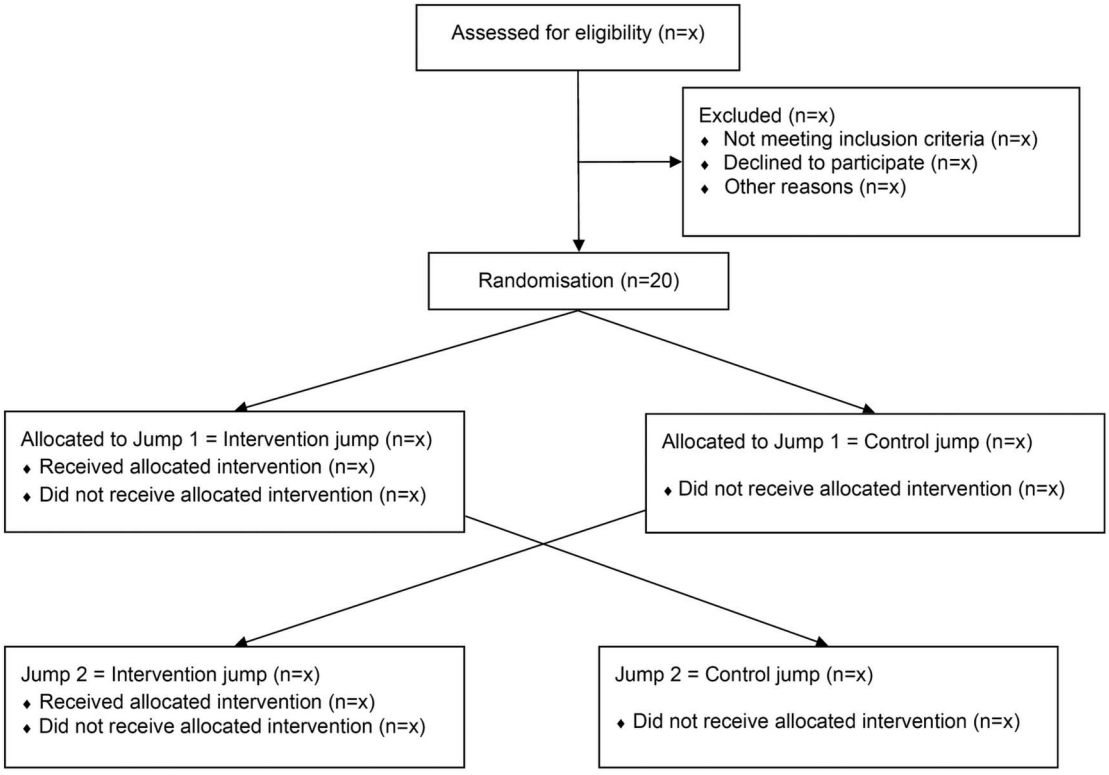

Figure 1 Diagram illustrating the basic design of the interventional study Free Fall Acrobatics to Reduce Neck Loads During Parachute Opening Shock: Evaluation of an Intervention (ACROPOSE, ClinicalTrials.gov database registration number NCT02625896). The study will use a cross-over, within-subject, repeated measures design with randomised ordering of performing either an 'intervention jump' or a normal 'control jump' in the first of two consecutive skydives on the same day; n=x denotes a prior to study unknown number of persons.

dimensionless ratio G. The study will primarily investigate hypothesised reductions of magnitude of the initial Gx deceleration, but all other directions will be analysed as well, as will magnitudes of multidirectional jerks (rates of changes of accelerations) expressed in G per second. Potential torque reductions for the lower neck motion axis will be calculated and subjective descriptions of the parachute openings by the study participants recorded.

Study population

The study population will consist of experienced skydivers of both sexes aged from 18 to 60 years, who are holders of the highest parachute certification (level D) in the Swedish Parachute Association. The exclusion criteria will be: ongoing neck problems, pregnancy, unwillingness to follow the safety regulations of the study, known patch allergy and participation in another concurrent biomedical study. Their demographics and background data will be obtained with use of a web-based questionnaire for skydivers.[18] The test participants will be recruited through electronic fora, including email lists, for highly experienced skydivers. The test participants will use their own sport parachute systems packed and maintained by themselves. The rationale for this is to maintain typical and comfortable conditions for each subject, whereas an unfamiliar system may introduce undesired psychomotor confounders, and also to maintain a high degree of external validity (as compared to using only one type of standardised parachute).

Instrumentation

A detailed description of the planned measuring instrumentation has been published separately.[19] The equipment setup in its entirety is approved for aerial use by the National Safety Officer of the Swedish Parachute Association. Multiple triaxial accelerometers are used to measure decelerations and jerks, and videography to record complex movements, including the parachute opening and head motion. Altitude and falling speed data will be collected with barometric and Global Positioning System (GPS) altimetry, using state-of-the-art skydiving devices.

Intervention

Both the intervention jump and the control jump will be made from 4000 m above mean sea level (AMSL). For safety reasons, main parachute deployment altitude will be slightly elevated; the participant is asked to deploy the main parachute no lower than 1200 m AMSL. High-speed landings will be forbidden. In the intervention jump, the test subject will perform a free

fall velocity reduction prior to main parachute deployment followed by a head high body attitude prior to main parachute extraction. Details of the manoeuvres will be given to the test subject in a written instruction. An overview description of the manoeuvres in aviation layperson's language is available at the US National Library of Medicine ClinicalTrials.gov website (NCT02625896 ACROPOSE).[20] Static laboratory anthropometrical assessments of the present author in different parachute deployment positions were performed in an attempt to determine theoretical effects on torque in the neck. These single-subject prestudies suggest that, unless a flexion forward of the head occurs, that is, as long as the nose is maintained somewhat high, pitching up the body head high to an angle circa 135° from the relative wind direction, that is, circa 45° pitched up from the flat belly-to-relative-wind plane, may theoretically reduce the head-neck lever arm (from the head centre-of-mass to the thoracocervical junction) circa 30%. From the relation between the maximum POS deceleration and velocity prior to parachute slider descent,[8] calculations were made in an attempt to determine theoretical effects by free fall velocity reductions achievable by using the human body only. These calculations suggest that a decrease in velocity from 220 km/h to 190 km/h may reduce the maximum POS deceleration circa 25%, meaning that (assuming constant mass) the maximum force may theoretically be reduced circa 25%. Thus, a successful combination of velocity reduction and head-neck lever arm reduction holds the theoretical promise of an approximately halved torque in the neck during POS. Considering the complexity of a real-world POS, we hypothesise that somewhere in the order of a 30% torque reduction may be achieved, forming the basis for the real-world effect size given above.

ETHICS AND DISSEMINATION

Participant safety considerations

Using our methodology and instrumentation, a large-scale observational study of skydivers has been completed without any known safety breaches.[12] The intervention study will be conducted in cooperation with and under the supervision of the National Safety Officer of the Swedish Parachute Association. All safety resources for sport parachuting available within the Swedish Parachute Association will be employed. Since parachute opening is critical to the safety of the parachutist, it appeared desirable to subject the intervention protocol to systematic prior risk assessment. In addition to a safety check, we also desired the opinion of subject matter experts on the relevance and feasibility of the study. Experienced skydivers were invited as independent experts and, as a result of this process, the proposed protocol underwent substantial changes and improved in assessed relevance, simplicity and safety. The results of the validation process in its entirety have been published.[21]

Ethical considerations

This study will be conducted in compliance with the Declaration of Helsinki.[22] All participants will receive oral and written information about the study, including safety aspects (eg, agreeing not to perform high-speed landings during the study), and sign a written consent to participate. All participants will be informed that they can end the study participation at any time. The study has been approved by the Regional Medical Research Ethics Committee of Stockholm (2015/1189-31) and has been submitted to the US National Library of Medicine ClinicalTrials.gov database for public availability prior to the start of participant recruitment (NCT02625896 ACROPOSE).[20]

Dissemination plan

The results will be submitted to peer-reviewed journals for publication in English. Open Access journals will be favoured, to facilitate maximum access for the sport parachutist population (a substantial number of skydivers are expected to be able to readily understand the results yet have limited access to subscription business model academic publications), and in accord with the current debate on transparency and openness in research culture.[23] Study data will be deposited in safe, long-term storage at the Karolinska Institutet, separated from the code key, according to Swedish research ethics standards and international good research practice.

DISCUSSION

This study intends to evaluate the use of athletic technique to reduce the biomechanical load on the neck of parachutists during parachute opening. The intervention consists of two separate free fall acrobatics elements: reducing parachute deployment airspeed and positioning the human body head high, just prior to main parachute extraction. The results are expected to contribute to a basis for future prevention of neck pain among skydivers, which is known to have a relation with repeated parachute opening exposure. In work addressing this health problem, our study may create a logical fork with important future implications. From static biomechanics and theoretical calculations, the planned intervention holds the promise of a halved torque in the neck during parachute opening. Though real-world results may not show such an impressive effect, it is important to examine this assumption; if it can be demonstrated to have merit, further large-scale population studies and implementation would seem warranted, possibly offering an elegant solution to a widespread health problem in this population. If, on the other hand, the planned intervention can be demonstrated to have little or no effect on its outcome variables, doubt will be cast on the conventional wisdom 'skydiver good advice' from which it is inspired, shifting future attention more pointedly towards technological factors, and towards manufacturers of parachute systems.

Acknowledgements The authors thank the Swedish National Centre for Research in Sports (Centrum För Idrottsforskning, CIF) and Gösta Fraenckel's Foundation for Medical Research, for financial support.

Contributors Both authors contributed to the protocol design. AW was responsible for preparation of the manuscript, which was read, improved on, and subsequently approved by BOA.

Funding This study is funded by the Swedish National Centre for Research in Sports (Centrum För Idrottsforskning, CIF; FO2015-0005) and Gösta Fraenckel's Foundation for Medical Research (2011Frae0015 and 2012Frae0005).

Competing interests None declared.

Ethics approval The Regional Medical Research Ethics Committee of Stockholm.

Provenance and peer review Not commissioned; internally peer reviewed.

REFERENCES

1. McNulty L. International Parachuting Commission Technical and Safety Committee 2010 Safety Report. 2012.
2. Westman A. *Dangers in sport parachuting [Elektronisk Resurs]*. Umeå: Univ, 2009. http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-19690
3. Westman A, Bjornstig U. Injuries in Swedish skydiving. *Br J Sport Med* 2007;41:356–64.
4. Wrobel CJ, Taubman K. Syringomyelia in skydivers. *N Engl J Med* 2003;349:309–10.
5. Crouch J. Hard openings. *Parachut* 2013;54:40–3. http://parachutistonline.com/feature/hard-openings
6. Nilsson J, Fridén C, Burén V, *et al*. Musculoskeletal pain and related risks in skydivers: a population-based survey. *Aviat Space Environ Med* 2013;84:1034–40.
7. Fejer R, Kyvik KO, Hartvigsen J. The prevalence of neck pain in the world population: a systematic critical review of the literature. *Eur Spine J* 2006;15:834–48.
8. Parks College Parachute Research Group. Parachute opening shock basics. *Outl Present 2001 Parachut Ind Assoc Symp Present by Jean Potvin Gary Peek*; 2001. http://www.pcprg.com/sym01out.htm
9. Coakwell MR, Bloswick DS, Moser R. High-risk head and neck movements at high G and interventions to reduce associated neck injury. *Aviat Space Environ Med* 2004;75:68–80.
10. Green ND. Acute soft tissue neck injury from unexpected acceleration. *Aviat Space Environ Med* 2003;74:1085–90.
11. Fryer DI. *Glossary of aerospace medical terms*. Neuilly-sur-Seine: NATO, 1971. http://www.theeuropeanlibrary.org/tel4/record/2000026994025 (accessed 6 Dec 2014).
12. Lo Martire R, Gladh K, Westman A, *et al*. Neck muscle activity in skydivers during parachute opening shock. *Scand J Med Sci Sports* 2016;26:307–16.
13. Rubio DM, Schoenbaum EE, Lee LS, *et al*. Defining translational research: implications for training. *Acad Med* 2010;85:470–5.
14. Haddon W. Advances in the epidemiology of injuries as a basis for public policy. *Public Heal Rep* 1980;95:411–21.
15. Leppänen M, Aaltonen S, Parkkari J, *et al*. Interventions to prevent sports related injuries: a systematic review and meta-analysis of randomised controlled trials. *Sports Med* 2014;44:473–86.
16. Miller S. Body Language: Helping Your Canopy Open Better. Dropzone.com. 2006. http://www.dropzone.com/safety/Canopy_Control/Body_Language_Helping_Your_Canopy_Open_Better_636.html (accessed 17 Nov 2014).
17. Consort—The CONSORT Flow Diagram. http://www.consort-statement.org/consort-statement/flow-diagram (accessed 15 Dec 2015).
18. Nilsson J, Fridén C, Burén V, *et al*. Development and validation of a web-based questionnaire for surveying skydivers. *Aviat Space Environ Med* 2011;82:610–14.
19. Gladh K, Ang BO, Lindholm P, *et al*. Decelerations and muscle responses during parachute opening shock. *Aviat Space Environ Med* 2013;84:1205–10.
20. Free Fall Acrobatics to Reduce Neck Loads During Parachute Opening Shock: Evaluation of an Intervention ACROPOSE ClinicalTrials.gov. https://clinicaltrials.gov/ct2/show/NCT02625896?term=acropose&rank=1 (accessed 30 Dec 2015).
21. Westman A, Äng BO. Validation of a free fall acrobatics intervention protocol to reduce neck loads during parachute opening shock. *BMJ Open Sport Exerc Med* 2015;1:000045.doi:10.1136/bmjsem-2015-000045.
22. World Medical Association. World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects. *Bull World Health Organ* 2001;79:373–4.
23. Nosek BA, Alter G, Banks GC, *et al*. SCIENTIFIC STANDARDS. Promoting an open research culture. Science. 2015;348:1422–5.