Designing For Intuitive Safety in Backcountry Snowsports:

A Multi-Disciplinary Exploration of Snow Science, Heuristic Strategies and Field Research to Design a Better Backcountry Skiing Pack

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Abstract

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Winter recreationists, especially backcountry skiers and splitboarders, need to rescue and provide care for companions if they are caught in an avalanche, a universal skill taught in avalanche education. However, minimal research has been done on users ability to recall and execute this training, unprompted, and no research has examined if the design of equipment (backpack, shovel, probe for example) can improve user's recall and performance. To examine this problem, a survey was used to assemble demographic profiles of backcountry recreationists. Complete, in-situ simulations of single-rescuer companion rescues were performed using a sample population selected using the created demographic profiles. Finally, two modifications to users backpacks, utilizing known nudge strategies, were tested in abbreviated simulations of single-rescuer companion rescues. This research reveals that a large majority of backcountry skiers and splitboarders have received adequate rescue training and are able to perform a rescue from memory. However, digging strategy and subsequent medical care were found to be weak spots in the rescue process, diminishing survival chances for buried victims. Rescuers appear to be in a "flow state" as described by Csíkszentmihályi, and are not influenced by tested nudge strategies. However, research revealed some effective design strategies which were distilled and implemented in the design of a backpack for skiers and splitboarders.

Preface

Two points should be noted before reading this thesis. The first is that this thesis deals with death or near death situations, often and sometimes explicitly. The author understands that this is not for everyone or appropriate at all times in one's life. For those struggling with with loss or grief related to adventure sports, the following resources can connect one with adventure-informed mental health professionals:

americanavalancheassociation.org/resilience-project
americanalpineclub.org/grieffund
soar4life.org
bttt.run

Secondly, while this thesis attempts at universality, a number of aspects should be noted that enforce a degree of specificity. The research that undergirds this was conducted in a El Niño season. Research was only performed in a maritime snowpack, in the United States of America. Finally, all participants received avalanche training in America, primarily through the American Institute of Avalanche Research and Education (AIARE) curriculum. While the author believes the results to elucidated universal principles, more work, in other sports, climates and educational traditions, is always needed.

Something odd out of the right corner of his eye… a long, blue-tinged crack in the snow.

Then a sound and the snow reverberated with a hollow noise like a giant hand knocking on a giant pumpkin.

…The snow all around him was moving, breaking into thick slabs.

…Already he was instinctively dropping into a low crouch, arms extended for balance… [A]drenaline pumped into his system… [D]anger was all around him: a slab avalanche, big, soft plates of the new snow fracturing into chunks and falling away down the slope like an old building dynamited for demolition that drops to earth in a sudden cloud of dust.

[He] swung his board to the right, toward the far edge of the crumbling mass, riding the churning snow like a surfer in the foam… for one second… two seconds… three seconds…

A 3-foot-thick slab of snow slammed him from behind, knocking him off his feet.

Onto his back… he could feel the avalanche gaining speed, churning snow all around him… 40, 50, 60 miles per hour… tumbled over… submerging… swimming with his arms to stay on top… feet pinned by his board… tumbled over again… a breath of air mixed with powder snow… like swimming in the foam of a breaking wave… wondering when it will stop… wondering if it will slam into trees or rocks… it was slowing… swim hard for the surface… one hand over the mouth to create an air pocket… shove the other to the top to signal the others… the snow suddenly turning heavy and dense and dark…

…and then it stopped.

from *Last Breath* by Peter Stark, *"The Cold Hug of the White Sphynx"*

In the nineteenth century, Fritjof Nansen wrote that skiing washes civilization clean from our minds by dint of its exhilarating physicality. By extension, I believe that snow helps strip away the things that don't matter. It leaves us thinking of little else but the greatness of nature, the place of our souls within it, and the dazzling whiteness that lies ahead.

from *The Snow Tourist* by Charlie English

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Introduction

By all statistical measures, life is a dangerous activity. Using data from 2022, the most recent that is available, every day, an adult in the United States has about a 1.3 in 50,000 chance of dying for any reason[1]. Using the statistical term of art, this danger would be pegged at 26.9 micromorts, a micromort representing a one in a million chance of dying[2]. The dangers of life are numerous, comprising both dramatic dangers like industrial accidents, automobile collisions and food poisoning as well as more pedestrian, chronic conditions like heart disease, cancer and stroke.

For human beings, the biological process of death is inevitable[3]. Despite this inevitability, a great deal of effort has been put into reducing the danger humans are exposed to, and delaying the potential injury and death that humans face[4]. Standards writing bodies like the Underwriters Laboratory (UL) and International Convention for the Safety of Life at Sea (SOLAS) have led to products or environments that are safer, for example lamps that are less likely to start a house fire or ships that have adequate safety equipment for the passengers they carry[5,6]. Public health agencies like the Centers for Disease Control and Prevention (CDC) work to prevent epidemics and reduce the impact of chronic conditions[7]. The Food and Drug Administration (FDA) ensures that food available for sale is safe to eat and medicines are effective[8]. The National Transportation Safety Board's (NTSB) standards have produced airplanes, trucks and ships manyfold safer than those in use in even the 1970's[9]. Though small, these improvements have borne great fruit. In 1967, when the NTSB was founded[10] (all other mentioned organizations were founded before this date), the average American had a life expectancy at birth of 70.7 years[11]. In 2024, this life expectancy had increased to 79.9[12], a result of the reduced danger of everyday life, though COVID-19 severely curtailed life expectancy progress[13].

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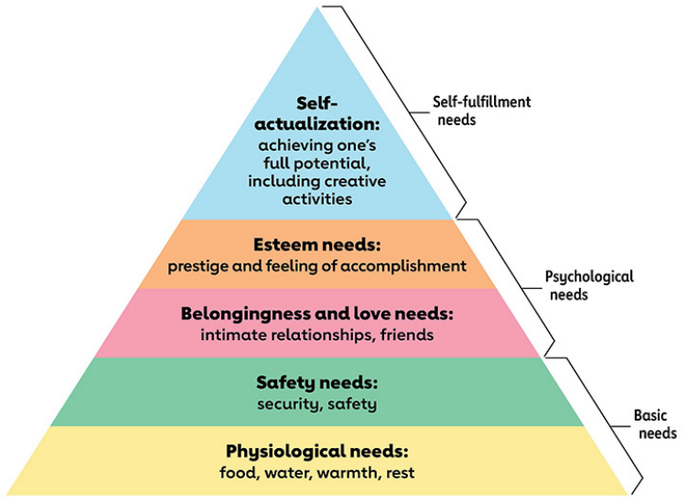
10. National Transportation Safety Board, We Are All Safer: Lessons Learned and Lives Saved 1975-2005.
11. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, "World Population Prospects - 2022 Revision" (United Nations, n.d.), https://population.un.org/wpp/.
12. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, "World Population Prospects - 2022 Revision."
13. Elizabeth Arias, Ph.D. et al., "Provisional Life Expectancy Estimates for 2021," NVSS Vital Statistics Rapid Release, August 2022, https://www.cdc.gov/nchs/data/vsrr/vsrr023.pdf.



Maslow's Hierarchy of the Needs

Most of the previously mentioned danger is inherent to everyday life, caused by the foods we eat, the cities we inhabit, the ways we must get to work and what we do there. Viewed through the lens of Abraham Maslow's Hierarchy of the Needs[14], these dangers are encountered while meeting what are known as the deficiency needs, e.g. the needs for food, shelter and employment, among others. However, a risk of injury or death is not relegated to the deficiency needs, but can also present itself when humans engage in activities that contribute to their growth needs. These growth needs comprise what Maslow originally termed *the love needs*, *the esteem needs* and *the need for self-actualization*[15]. These needs drive humans to seek, for example, romantic relationships, prestige in one's career and the desire to fulfill one's purpose in life. Psychology has long studied the risk taking behavior of those seeking career, social or romantic fulfillment[16,17]. Returning to Maslow's theory, these growth needs can be seen as so fundamental and so desirable that humans are willing to subject themselves to a certain degree of risk or danger to achieve these needs.

While *the love needs* and *the esteem needs* are well defined and well understood, *the need for self-actualization* is less defined and more debated[18]. Maslow described this need succinctly as the desire "to become everything that one is capable of becoming."[19] The exact way this desire is expressed will vary from person to person. For some, these needs may be met by writing poetry, becoming an ideal parent or scientific discovery[20]. For others, fulfillment may be found on a motorcycle, screaming at 200 mph (322 km/h) through the narrow winding roads on the Isle of Man.

The Isle of Man TT may be one of the most dangerous activities humans engage in to meet their needs for self actualization. The race, whose history traces back to 1907, takes place on a 37.7 mile (60.6 km) course made up of closed public roads[21]. A racer participating in the 2022 edition of the race exposes themselves to 60,000 micromorts over the two weeks of practice laps and racing[22]. Nevertheless, participants in the race report that the race, for them, represents the fulfillment of their life's ambition, a venue to fully exist, to

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18. Barbara Engler, Personality Theories: An Introduction, 8th ed (Boston, MA: Houghton Mifflin, 2009). 369.
19. Maslow, "A Theory of Human Motivation."
20. Maslow, "A Theory of Human Motivation."
21. R. A. Sille, N. J. Ronkainen, and D. A. Tod, "Experiences Leading Elite Motorcycle Road Racers to Participate at the Isle of Man Tourist Trophy (TT): An Existential Perspective," Qualitative Research in Sport, Exercise and Health 12, no. 3 (May 26, 2020): 431–45, https://doi.org/10.1080/2159676X.2019.1618387.
22. The 2022 Isle of Man TT Races of the race featured 100 participants (including sidecar passengers) and 6 fatalities. Richard Petrie, "Isle of Man TT: After Record Death Toll in 2022, How Do You Make the Most Dangerous Motorsport Event Safer?," BBC Sport, May 27, 2023, https://www.bbc.com/sport/northern-ireland/65725502.

find the limits of their capabilities and understand what they may be, key attributes of self-actualization[23]. One TT race participant interviewed by Sille, et al. reported: "[Racing a motorbike] you're living your life, not just existing. You're fucking living your life. Most people, they're just existing."[24]

These sentiments, clear examples of Maslow's definition of self-actualization, are one of the major draws to what are sometimes called *extreme sports*[25], *action and adventure sports*[26] and *high-risk sports*[27]. Sports like BASE jumping, freeride skiing, cave diving and mountain biking are traditionally understood to be members of this group. Gunnar Breivik defines high-risk sport as "all sports where you have to reckon with the possibility of serious injury or death as an inherent part of the activity"[28]. While, like many other commentators[29], the author finds the term *high-risk sports* to exaggerate the danger participants are exposed to and to include some unintended sports like rugby and American football; the term is more commonly used in the literature than alternatives and will be used for this thesis.

While exact motivations vary and other desires may be present, most participation in high-risk sports is ultimately undertaken to fulfill a desire for what Maslow would likely understand as self-actualization[30]. Multiple studies have described what participants derive from these activities: the ability to challenge one's self[31], to achieve goals[32], to push boundaries and overcome fear[33]. The term *edgework*, developed in 1990 by Stephen Lyng, describes the experience of fulfillment or self-realization that emerges from pushing boundaries, taking risks or negotiating the edges of possibility[34]. These experiences can be immensely fulfilling, however, danger is inherent to the fulfilling aspects of these sports[35].

Most participants in high-risk sports do not wish to die or get injured, despite the risks they encounter to participate in their chosen activities[36]. To this end, much effort has been put into improving the safety standards of high-risk sports. Mitigation of inherent risks tend to fall into three categories: Improved Fitness, Better Equipment and Standardized Training.

High-risk sports are universally physically difficult and increasing physical training is

23. Francis Heylighen, "A Cognitive-Systemic Reconstruction of Maslow's Theory of Self-Actualization," Behavioral Science 37, no. 1 (January 1992): 39–58, https://doi.org/10.1002/bs.3830370105.
24. Sille, Ronkainen, and Tod, "Experiences Leading Elite Motorcycle Road Racers to Participate at the Isle of Man Tourist Trophy (TT)."
25. Eric Brymer and Robert Schweitzer, "The Search for Freedom in Extreme Sports: A Phenomenological Exploration," Psychology of Sport and Exercise 14, no. 6 (November 2013): 865–73, https://doi.org/10.1016/j.psychsport.2013.07.004.
26. Tuomas Immonen et al., "Understanding Action and Adventure Sports Participation—An Ecological Dynamics Perspective," Sports Medicine - Open 3, no. 1 (December 2017): 18, https://doi.org/10.1186/s40798-017-0084-1.
27. Laura Kiemle-Gabbay and David Lavallee, "Coping in High-Risk Snow-Sports: A Qualitative Exploration of Alpine Racing and Freestyle Athletes' Experiences," Journal of Loss and Trauma 22, no. 4 (May 19, 2017): 325–45, https://doi.org/10.1080/15325024.2017.1284517.
28. Gunnar Breivik, Empirical studies of risk sport, Skrifter i utvalg / Gunnar Breivik 5 (Oslo: Norges Idrettshøgskole, Institutt for Samfunnsfag, 1999).
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30. Tuomas Immonen et al., "An Ecological Conceptualization of Extreme Sports," Frontiers in Psychology 9 (July 24, 2018): 1274, https://doi.org/10.3389/fpsyg.2018.01274.
31. Anika Frühauf et al., "A Qualitative Approach on Motives and Aspects of Risks in Freeriding," Frontiers in Psychology 8 (November 14, 2017): 1998, https://doi.org/10.3389/fpsyg.2017.01998.
32. Gareth Jones et al., "Motivational Orientation and Risk Taking in Elite Winter Climbers: A Qualitative Study," International Journal of Sport and Exercise Psychology 15, no. 1 (January 2017): 25–40, https://doi.org/10.1080/1612197X.2015.1069876.
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35. Rhonda Cohen, Bahman Baluch, and Linda J. Duffy, "Defining Extreme Sport: Conceptions and Misconceptions," Frontiers in Psychology 9 (October 18, 2018): 1974, https://doi.org/10.3389/fpsyg.2018.01974
36. Frühauf et al., "A Qualitative Approach on Motives and Aspects of Risks in Freeriding."

needed to push the boundaries of the sport. As a historical example, Geoffrey Winthrop Young's *Mountain Craft* (1920), the definitive book on mountaineering/alpine climbing of its day[37], suggests "regular exercise in the open air — walking, running or tennis" as sufficient training for mountaineering[38]. By 2014, *Training for the New Alpinism*, widely considered the current standard for physical training for alpine endeavors[39], runs 464 pages, and provides in-depth explanations of day by day training programs that can last months and the science behind them[40]. This better understanding of physical conditioning has paid great dividends. The first ascent of the famous Cassin Ridge on Denali in 1961 took Ricardo Cassin and his party 23 days to reach the summit during which they endured horrific weather[41]. Currently such a route is expected to take two to five days by an average party[42] and has been climbed by Colin Haley in a blazing 8 hours and 7 minutes[43]. These shorter timelines allow climbers to thread weather windows, allowing themselves to summit and return to well fortified camps before a storm hits and subjects them to unnecessary risks on route[44].

Equipment too has improved. Famously, the first mountain bike race, 1976's Repack Race was so named because the coaster brakes in use at the time would overheat and need to be repacked with grease after every five minute run[45]. The coaster brakes, overheating and devoid of grease, could lose their braking power[46]. It is not hard to imagine what might happen if participants completely lost their brakes as they careened downhill on rigid 1970's era cruiser bikes. Currently, mountain bike disc brakes can be expected to easily last about 3,000 miles[47], a far cry from the 2.1 miles that the Repack Race covered. The better equipment available to mountain bikers today has allowed participants to push the sport in unimaginable directions[48].

Finally, training has improved and formalized as well. SCUBA diving is a relatively recently devised sport and so its creation and training history are well documented, at least in the United States. The first safe and successful open-circuit SCUBA system, the Aqua-Lung, was developed in France in 1942[49]. By 1948 the device had made it to America and the next year,

37. Contemporaneously, the editor of the UK's Alpine Club wrote of Mountain Craft that "The book is magnificent ... It will be standard for so long as mankind is interested in mountaineering." Alan Hankinson, Geoffrey Winthrop Young: Poet, Educator, Mountaineer (London: Hodder & Stoughton, 1995).
38. Geoffrey Winthrop Young, Mountain Craft (Charles Scribner's Sons, 1920), https://www.gutenberg.org/ebooks/67729.
39. Lou Dawson, "Training for the New Alpinism - Book Review," Wild Snow (blog), December 16, 2014, https://wildsnow.com/15227/training-new-alpinism-book-review/.
40. House, Steve, and Scott M. Johnston. Training for the New Alpinism: A Manual for the Climber as Athlete. First edition. Ventura, California: Patagonia, 2014.
41. Steve Roper and Allen Steck, Fifty Classic Climbs of North America (San Francisco: Sierra Club Books, 1979).
42. Joseph Puryear, Alaska Climbing (Mill Valley, CA: SuperTopo, 2006).
43. Colin Haley, "Cassin Ridge Speed Solo," September 10, 2018, https://colinhaley.com/cassin-ridge-speed-solo/.
44. The Mountaineers Books, Mountaineering Freedom of the Hills 8th Edition. ; 50th Anniversary 1960-2010 (Mountaineers Books, The, 2010). 469.
45. Joe Breeze, "Repack History" (Marin Museum of Bicycling, January 10, 2024), https://mmbhof.org/mtn-bike-hall-of-fame/history/repack-history/.
46. Sheldon Brown and John Allen, "Bicycle Coaster Brakes," June 3, 2024, https://www.sheldonbrown.com/coaster-brakes.html.
47. Lennard Zinn, "Technical FAQ: Durability of Disc Brake Pads," VeloNews, June 1, 2023, https://velo.outsideonline.com/road/road-racing/technical-faq-durability-of-disc-brake-pads/.
48. Though the academic literature is sparse on these improvements, it should be obvious that safely riding down rock climbs would not be possible with early mountain bikes: "Mountain Biking Down Steep Squamish Slabs," Gripped, December 1, 2022, https://gripped.com/video/mountain-biking-down-steep-squamish-slabs/.
49. Jacques Cousteau and Frédéric Dumas, The Silent World (Washington, D.C.: National Geographic Society, 2004).

Jaques Cousteau, one of its inventors traveled to America to conduct training[50]. By 1953, the first modern diving manual, *Underwater Safety*, was written[51]. In 1954, the first organized training program was organized by the LA Department of Parks and Recreation and five years later the Young Men's Christian Association (YMCA) began the first national training program[52]. A year later in 1970, the National Association of Underwater Instructors (NAUI) began the first instructor training[53]. This marks the end of the creation of a complete training infrastructure, transitioning from classes by a sports originator and books to formalized training for both participants and instructors. This is not to say that improvement of training ceased, 1981 brought less intense training pedagogy, making diving available to families and others with hectic schedules while the mid 1980's saw the introduction of new diving tables aimed at recreational divers and dive computers that could calculate these tables on the fly[54]. These improved training efforts have been effective, from 1970 to 1993 diving fatalities have slightly decreased, even as the sport has grown in popularity[55].

Beyond these three avenues of improvement, what more is there to explore? Other traditions of safety exist, notably in the worlds of workplace safety, aviation and medicine. These worlds will be discussed in more depth later on, but will be touched on briefly here to examine what they may have to offer. Aviation safety is a close analog to high risk sports, there is no way to make airplanes completely safe[56]. However, beyond improved equipment and training, aviation safety makes use of extensive protocols during flight as well as reliable automatic backup systems[57]. Medical safety is based on peer-reviewed studies and rigorous testing of procedures and medicines before they are released to the general public[58]. Finally, workplace safety generally revolves around the principle of removing people from the location of hazards or failing that, using appropriate protective equipment between people and workplace hazards[59].

Comparing these approaches to safety to the current practice in high-risk sport is interesting, but reveals little new area for exploration. While many high-risk sports use

50. Drew Richardson, "A Brief History of Scuba Diving in the United States," SPUMS JOURNAL 29, no. 3 (September 1999): 173–76.
51. Richardson, "A Brief History of Scuba Diving in the United States."
52. Richardson, "A Brief History of Scuba Diving in the United States."
53. Richardson, "A Brief History of Scuba Diving in the United States."
54. Richardson, "A Brief History of Scuba Diving in the United States."
55. N. Smith, "Scuba Diving: How High the Risk?," Journal of Insurance Medicine (New York, N.Y.) 27, no. 1 (1995): 15–24.
56. However, commercial aviation is, per mile, one of the safest forms of transportation. Ian Savage, "Comparing the Fatality Risks in United States Transportation across Modes and over Time," Research in Transportation Economics 43, no. 1 (July 2013): 9–22, https://doi.org/10.1016/j.retrec.2012.12.011.
57. Douglas D. Boyd, "A Review of General Aviation Safety (1984–2017)," Aerospace Medicine and Human Performance 88, no. 7 (July 1, 2017): 657–64, https://doi.org/10.3357/AMHP.4862.2017.
58. Lucian L. Leape, Donald M. Berwick, and David W. Bates, "What Practices Will Most Improve Safety?: Evidence-Based Medicine Meets Patient Safety," JAMA 288, no. 4 (July 24, 2002): 501, https://doi.org/10.1001/jama.288.4.501.
59. A.B. (Butch) de Castro, PhD, MSN-MPH, RN, "'Hierarchy of Controls': Providing a Framework for Addressing Workplace Hazards," AJN, American Journal of Nursing 103, no. 12 (December 2003): 104.

some simplified versions of the protocols that pilots use[60], the equipment that high-risk sports use is often analog or of relatively basic computing power compared to an airliner, leaving few new avenues to implement automatic backup systems[61]. High-risk sports tend to occupy small worlds, without the economic power or population to enable the kinds of studies that modern medicine is based on. Finally, in contrast to the principles of workplace safety, removing participants from the dangerous aspects of high-risk sports destroys their essential character. High-risk sports gain much of their emotional power from the potential danger that they expose participants to[62]. The aspects of skydiving that make it fulfilling are the very same aspects that make it dangerous. High-risk sports cannot be entirely stripped of all their dangers, without losing their essential character.

With these ideas in mind, the problem space is laid out before us. High-risk sports represent an emotionally fulfilling, though occasionally injurious or deadly, avenue for self-actualization for many people[63]. The danger they present is inherent, in fact, its existence is the cause of much of participants' fulfillment[64], but participants do not wish to be injured in pursuit of their chosen avocation[65]. Improvements in equipment, training and fitness have all improved outcomes but there is still more work to be done. But what form will this work take? That question is the root of this thesis and needs more room that this introduction can provide.

Most accidents that befall practitioners of high-risk sports are what could be dismissed as accidents of choice, unfortunate but preventable if only the victim had chosen to stay home. But as research has found, participants are deeply motivated to participate in these sports, to attain the experiences and self-actualization that they offer[66]. Regardless of others actions, Colin Haley will continue to push himself on the Cassin Ridge and riders will continue to race in the Isle of Man TT. Looking at this situation through the lens of contemporary thinking on medical ethics should urge designers to develop new techniques and equipment for safety in high-risk sports.

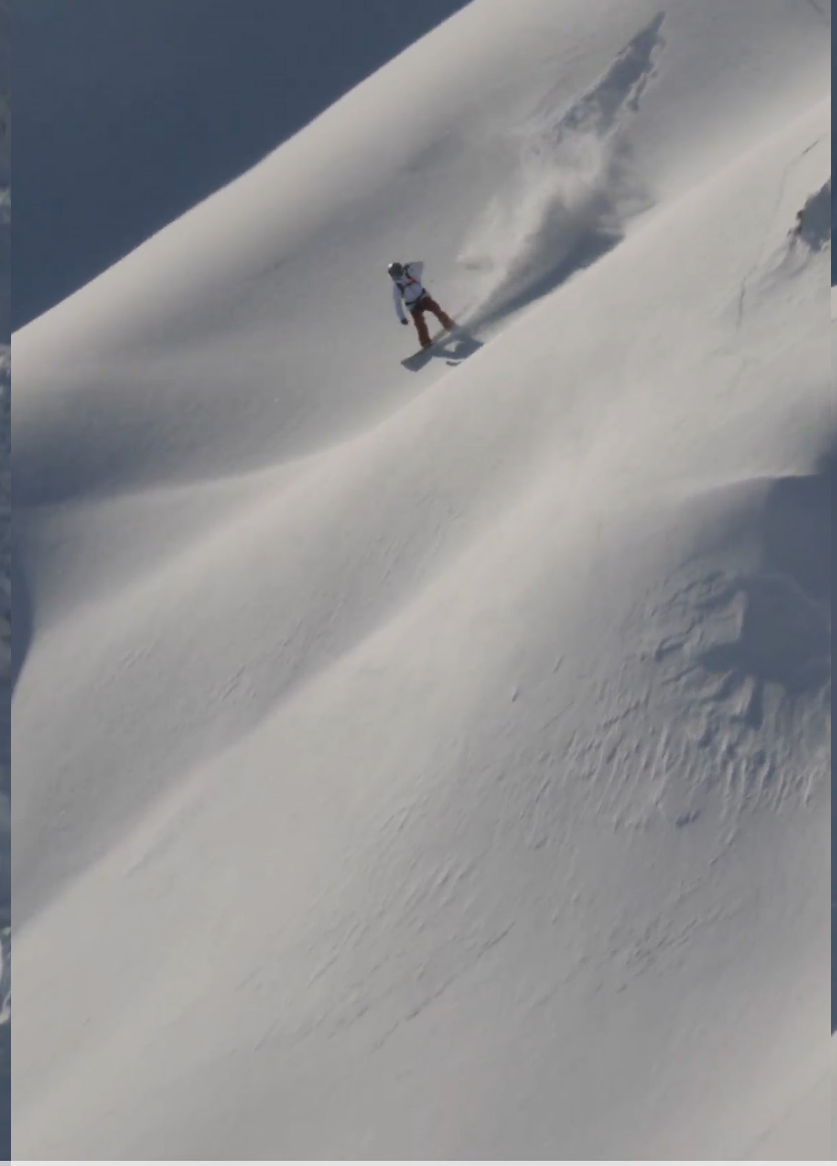
60. The Mountaineers Books, Mountaineering Freedom of the Hills 8th Edition. ; 50th Anniversary 1960-2010 (Mountaineers Books, The, 2010). p. 183
61. Some do exist, like the chemical automatic inflation mechanisms for lifejackets and parachutes have an Automatic Activation Device to open the parachute before a skydiver gets too close to the ground.
62. Dominika Kupciw and Alexandra MacGregor, "High-Risk Sport Research," The Sport and Exercise Scientist, no. 31 (Spring 2012): 28–29.
63. Immonen et al., "An Ecological Conceptualization of Extreme Sports."
64. Jones et al., "Motivational Orientation and Risk Taking in Elite Winter Climbers."
65. Frühauf et al., "A Qualitative Approach on Motives and Aspects of Risks in Freeriding."
66. Brymer and Schweitzer, "The Search for Freedom in Extreme Sports."

Contemporary thinking on medical ethics is dominated by the four principles proposed by Tom L. Beauchamp and James F. Childress in their book *Principles of Biomedical Ethics*, now in its seventh edition[67]. These four principles are autonomy, beneficence, nonmaleficence and distributive justice[68]. Autonomy, perhaps best expressed by Justice Benjamin Cardozo when he wrote "[e]very human being of adult years and sound mind has a right to determine what shall be done with his own body,"[69] means we must allow others to participate in high risk sports. Beneficence, a long-held tenant of the medical profession, holds that medical professionals should do good for their patients[70]. Beneficence is, especially in Islamic theology, an expansive concept that can include almost any act that improves the lives of others[71]. As designers, to adhere to the principles of Autonomy and Beneficence we should allow others to participate in the activities they would like to and create products to support them in these journeys.

Many factors, notably the COVID-19 pandemic, have increased participation in high-risk sports. In 2020, participation in paddlesports rose 54%, bicycling participation increased by 59% and backcountry skiing/splitboarding increased by 57%[72]. As this participation increases more individuals are exposed to the potential dangers as well as joys that high-risk sports present, the creation of new, safer, forms of equipment for these sports should be seen as an ethical imperative.

67. Kenneth V. Iserson and Carlton E. Heine, "Ethics of Wilderness Medicine," in Auerbach's Wilderness Medicine, ed. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017).
R Gillon, "Medical Ethics: Four Principles plus Attention to Scope," BMJ 309, no. 6948 (July 16, 1994): 184–184, https://doi.org/10.1136/bmj.309.6948.184.
68. Tom L. Beauchamp and James F. Childress, Principles of Biomedical Ethics, 7th ed (New York: Oxford University Press, 2013).
69. Benjamin Cardozo, Schloendorff v Society of New York Hospital, No. 211 N.Y. 125; 105 N.E. 92 (Court of Appeals of New York April 14, 1914).
70. Iserson and Heine, "Ethics of Wilderness Medicine."
71. Mohammed Ali Al-Bar and Hassan Chamsi-Pasha, "Beneficence," in Contemporary Bioethics, by Mohammed Ali Al-Bar and Hassan Chamsi-Pasha (Cham: Springer International Publishing, 2015), 129–39, https://doi.org/10.1007/978-3-319-18428-9_8.
72. Michelle Brunton, "Spike In Backcountry Participation Could Spell Danger For Skiers, Snowboarders—How To Stay Safe This Season," December 30, 2020, https://www.forbes.com/sites/michellebruton/2021/12/30/spike-in-backcountry-participation-could-spell-danger-for-skiers-snowboarders-how-to-stay-safe-this-season/?sh=710417d62f04.

0.00 Seconds
The snowboarder's impact breaks the bonds between the top snow layers and the bed surface that it rests on.



0.74 Seconds
Remotely triggered, thin cracks begin to appear at the top and sides of the slab, surrounding the snowboarder.

1.22 Seconds
The slab has detached from the surrounding snowpack and begun to move down hill. The slab remains intact.

1.84 Seconds
In motion, the slab begins to shatter under its own weight and through the variations in topography as it moves downhill.

3.36 Seconds
As it breaks apart, the slab begins to liquefy, turning into a slurry of large and small chunks of snow.

4.62 Seconds
The avalanch is in full force, escape almost impossible. Witnesses must watch victim and note direction and position.

Photos on the previous spread from: Bertil Trottet et al., “Transition from Sub-Rayleigh Anticrack to Supershear Crack Propagation in Snow Avalanches,” Nature Physics 18, no. 9 (September 2022): 1094–98, https://doi.org/10.1038/s41567-022-01662-4.

Research Questions

What training and equipment can the average backcountry skier or splitboarder be assumed to have?

How does the average backcountry skier or splitboarder perform when called upon to perform an avalanche companion rescue?

Is it possible to subconsciously influence a rescuers behavior to improve their rescue performance?

Are there universal principles to influence behavior to improve their rescue performance?

Background/Context

Why Backcountry Skiing/Splitboarding?

Given the diversity of high-risk sports and the dangers participants face, why was backcountry skiing/splitboarding, and the avalanche companion rescue protocol in particular, chosen for study in this thesis? There are a number of reasons. First, avalanches are the most deadly danger facing backcountry snow sports practitioners[1] and the procedure for rescuing someone buried in an avalanche is simple and well defined[2]. The companion rescue procedure is performed using the same procedure, regardless of environmental circumstances, and can be adequately described on a single sheet of paper[3]. This simplicity is unusual in high-risk sports, for example, when rock climbing, participants are exposed to a large number of equally likely dangers and each potential situation necessitates a unique response. Climbing Self-Rescue by Ian Nicholson, the most recent compendium of rescue responses for climbers, totals 304 pages and uses ten different example scenarios to explain potential courses of action[4].

Secondly, the time scale over which a companion rescue is performed is relatively long, allowing enough time for differentiation and study. Even the shortest time put forward for a successful avalanche rescue is 10 minutes[5], enabling even small improvements to be noticed and examined. With a sport like BASE jumping[6], where the entire activity takes seconds[7], there is no time for rescue or assistance if something goes wrong. Even a more sedate sport like SCUBA diving has a relatively short time scale, most humans can only hold their breath for a few minutes and without fresh oxygen brain damage sets in at four to five minutes[8]. The longer time scale of avalanche companion rescue allows for more granular

1. Martin Gross, Christian Jackowski, and Corinna A. Schön, "Fatalities Associated with Ski Touring and Freeriding: A Retrospective Analysis from 2001 to 2019," Forensic Science International: Reports 4 (November 2021): 100239, https://doi.org/10.1016/j.fsir.2021.100239.
2. Bruce Tremper, Staying Alive in Avalanche Terrain, 2nd ed (Seattle: Mountaineers Books, 2008).
3. Drew Nylen, "Rescue Practice: Keeping It Real," Avalanche Canada (blog), December 20, 2021, https://avalanche.ca/fr/blogs/rescue-practice-keeping-it-real.
4. Ian Nicholson, Climbing Self-Rescue: Essential Skills, Technical Tips & Improvised Solutions, First edition (Seattle, WA: Mountaineers Books, 2023).
5. P. Haegeli et al., "Comparison of Avalanche Survival Patterns in Canada and Switzerland," Canadian Medical Association Journal 183, no. 7 (April 19, 2011): 789–95, https://doi.org/10.1503/cmaj.101435.
6. BASE is an acronym that stands for Bridge, Aerial/Antenna, Span (i.e. Bridge) and Earth (i.e. Cliff). However, the acronym is traditionally not written with periods. Omer Mei-Dan et al., "Fatalities in Wingsuit BASE Jumping," Wilderness & Environmental Medicine 24, no. 4 (December 2013): 321–27, https://doi.org/10.1016/j.wem.2013.06.010.
7. A BASE jumper whose parachute fails to open while jumping from the 148 meters (486 ft) I. B. Perrine Bridge in Idaho will hit the ground in 5.6 seconds, leaving almost no time to recognize and diagnose an issue and then fix their equipment.
8. Justin Sempsrott et al., "Drowning and Submersion Injuries," in Auerbach's Wilderness Medicine, ed. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017). p. 1538

analysis and improvement.

Finally, avalanche rescue can be easily and safely simulated. During an avalanche rescue the most pressing danger to rescuers is a second avalanche from unreleased snow (known as hang fire in the snow science world) and the victim, while in danger from asphyxia and unaddressed trauma, plays no part in their rescue[9]. By replacing the living victim with a dummy, and controlling the snow above the rescuer, as is common within the bounds of ski resorts, a simulated rescue can take place safely, while keeping the terrain features that make rescues difficult (snow slopes of >30°). Compare this ease of simulation with swift water rescue. The techniques used to rescue a kayaker or rafter who has fallen into a fast moving river can not be simulated accurately and safely without putting humans in unnecessary danger[10]. Swiftwater rescue relies on an able and conscious victim who can grab ropes thrown to them or work with rescuers to re-enter a raft. An inanimate dummy cannot perform these actions and so to accurately simulate these rescues would require a human staying in the water and would expose humans to unnecessary risk. For these reasons, an avalanche companion rescue was chosen to explore this topic.

Background on High-Risk Sports

Many high-risk sports are modern inventions, enabled by new technology or equipment, however some, like surfing[11] and skiing[12], are ancient inventions. Motivations for their creation vary from a need to travel over snowy surfaces (skiing)[13], on the orders of a king to practice siege techniques (alpine climbing)[14] or simply for the joy of it (surfing)[15]. As mentioned previously, the exact definitions of what constitutes a high-risk sport are contentious, often coming more from popular perception and media hype than academic consensus[16]. However Cohen, et. al., suggest a number of factors that can be used to define a high-risk sport. The three factors they identified were individual competition of a self-evaluative or comparative nature, a natural environment or unusual physical demands and a sport

9. Tremper, Staying Alive in Avalanche Terrain.
10. Henderson D. McGinnis, "Whitewater Medicine and Rescue," in Auerbach's Wilderness Medicine, ed. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017).
11. Isaiah Helekunihi Walker, Waves of Resistance: Surfing and History in Twentieth-Century Hawai'i (Honolulu: University of Hawai'i Press, 2011). p. 16
12. Federico Formenti, Luca P Ardigò, and Alberto E Minetti, "Human Locomotion on Snow: Determinants of Economy and Speed of Skiing across the Ages," Proceedings of the Royal Society B: Biological Sciences 272, no. 1572 (August 7, 2005): 1561–69, https://doi.org/10.1098/rspb.2005.3121.
13. Formenti, Ardigò, and Minetti, "Human Locomotion on Snow."
14 John Middendorf, "In the Beginning: Subtle Means and Engines," Mechanical Advantage: Tools for the Wild Vertical (blog), May 9, 2021, https://www.bigwallgear.com/p/in-the-beginning-subtle-means-and..
15. Patrick O'Brian, Joseph Banks: A Life, University of Chicago Press ed (Chicago: University of Chicago Press, 1997). p. 98
16. Cohen, Baluch, and Duffy, "Defining Extreme Sport."

where unsuccessful outcome is likely to result in injury or death[17]. This contrasts them with traditional sports like cricket, soccer and horseback riding which sometimes share one of these attributes but not all three. In addition, they identify traditional sports as competitive in an intergroup nature, i.e. traditional sports compare points scored in a certain match whereas high-risk sports compare a participants ability to their previous ability[18].

Because high-risk sports often put their participants in some degree of danger[19], and because safety or, if need be, rescue is most readily dependent on one's companions[20], training or apprenticeship in specific rescue or safety skills is seen as culturally mandated in a way not seen in, for instance, a game of pickup basketball. An accident caused by an inexperienced player could lead to a sprained ankle and possibly a car ride to urgent care. An inexperienced party member on a multi-pitch rock climb could cause the whole party to travel slowly or get benighted as a best case scenario or the death of multiple members of the party as a worst case[21]. In addition to the importance placed on formal training or apprenticeships with a known member of the sport, high-risk sports also emphasize safety procedures. Different sports utilize different safety procedures, be it the call and response climbing commands developed by Paul Petzolt[22] or the rigorous cave diving protocol laid out by Sheck Exley in *Basic Cave Diving: A Blueprint for Survival*[23].

History of Skiing and Splitboarding

While recreational skiing is a relatively modern invention, though much older than many other high-risk sports, skiing is an ancient practice. Cave engravings depicting skiing date back to 2000 BCE, while an object often believed to be a ski found in Salla, Finland dates back to 3200 BCE[24]. Most ethnic groups living in the Arctic circle lived a nomadic lifestyle and used skis to travel for hunting, herding and foraging[25]. In the 1500's the use of skins for uphill travel was first recorded[26]. Skiing's transition to a recreational activity is more recent. During the 19th century skiing became a pursuit engaged in for pleasure rather

17. Cohen, Baluch, and Duffy, "Defining Extreme Sport."
18. Cohen, Baluch, and Duffy, "Defining Extreme Sport."
19. Eric Brymer and Robert Schweitzer, "The Search for Freedom in Extreme Sports: A Phenomenological Exploration," Psychology of Sport and Exercise 14, no. 6 (November 2013): 865–73, https://doi.org/10.1016/j.psychsport.2013.07.004.
20. Ken Zafren et al., "Technical Rescue, Self Rescue and Evacuation," in Auerbach's Wilderness Medicine, ed. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017).
21. Edward Whymper, Scrambles amongst the Alps in the Years 1860-1869 (Washington, D.C.: National Geographic Adventure Classics, 2002).
22. Derek Debruin, "Climber Communication," American Alpine Club (blog), June 20, 2023, https://americanalpineclub.org/news/2017/1/19/4xm1fcsag6b7xqf1p1w1qp7vdpp1ha.
23. Sheck Exley, Basic Cave Diving: A Blueprint For Survival, 5th ed. (Lake City, Florida: National Speleological Society Cave Diving Section, 1986).
24. Formenti, Ardigò, and Minetti, "Human Locomotion on Snow."
25. Formenti, Ardigò, and Minetti, "Human Locomotion on Snow."
26. Fabiana Martinescu-Bădălan and Robert Stănciulescu, "History and Debut of the Ski-Mountaineering," Scientific Bulletin 24, no. 1 (June 1, 2019): 46–51, https://doi.org/10.2478/bsaft-2019-0005.
27. Martinescu-Bădălan and Stănciulescu, "History and Debut of the Ski-Mountaineering."

than necessity[27]. New techniques and equipment were devised that allowed for better control and the ability to ski more difficult terrain[28]. It was around this time the disciplines we now know as downhill and cross country skiing first separated[29]. The 1930's saw the introduction first of the rope tow and then chairlift, enabling skiers to get to the top of a run by motor as opposed to their own power[30]. The onset of World War II caused the creation of a number of ski specific troops who trained in mountain warfare to fight in the mountain ranges of Europe, most famously the US Army's 10th Mountain Division[31]. Veterans of the this division were demobilized with unprecedented knowledge and experience with skiing and were instrumental in introducing and popularizing the sport to the general American public[32]. As ski resorts began to gain popularity, what is now called backcountry skiing began to be practiced or recognized as its own sport[33]. Though some similar items existed previously, modern snowboards first emerged in the mid-1970's as a way to mimic the feel of skateboarding on the snow[34]. Snowboarders are reliant on ski lifts to get uphill and early backcountry snowboarders used snowshoes, with boards strapped to their packs, to travel in the backcountry. The difficulty this posed prompted the invention, in 1990, of the split board, where a snowboard can be separated in half and attached to the feet like skis for uphill travel[35]. In 1991 the Dynafit or pin binding was introduced, dramatically lowering the weight of backcountry ski bindings[36].

With the introduction of the Dynafit binding, the modern offering of backcountry skiing and splitboarding equipment was finalized. Backcountry skiers use specialized boots that are able to loosen their ankle portion to allow them to walk or skin uphill and, when these same boots are tightened, to ski downhill. Splitboarders use the same boots as in-bounds snowboarders as the different biomechanics of snowboarding do not require a boot stiffness that precludes walking. Ski and splitboard bindings designed for backcountry use will have a walk setting that allows the heel to remain free for skinning or walking uphill as well as the ability to lock down the bindings for downhill travel. Skis and splitboards

27. Martinescu-Bădălan and Stănciulescu, "History and Debut of the Ski-Mountaineering."
28. Renee Harrington, Skiing and Snowboarding (North Carolina State University Libraries, 2023), https://doi.org/10.52750/987626.
29. Sally Guillaume, "Nordic Skiing and Cross Country Skiing - What's The Difference?," Undiscovered Mountains (blog), n.d., https://undiscoveredmountains.com/nordic-skiing-vs-cross-country-skiing.
30. Sarah Kuta, "The Invention of the Ski Chairlift," Smithstonian Magazine, February 2, 2021, https://www.smithsonianmag.com/innovation/how-railroad-engineer-from-nebraska-invented-worlds-first-ski-chairlift-180976878/.
31. McKay Jenkins, The White Death: Tragedy and Heroism in an Avalanche Zone, 1st Anchor books ed (New York: Anchor Books, 2001).
32. Jenkins, The White Death.
33. Lou Dawson, "Timeline – North American Ski Mountaineering History," April 26, 2024, https://www.loudawson.com/ski-mountaineering-history/timeline-north-american-ski-touring/.
34. Also of note is that skateboarding was created in the 1940's to mimic the feel of surfing when the waves were flat "Remembering Jake Burton Carpenter," The Burton Blog (blog), November 21, 2019, https://www.burton.com/blogs/the-burton-blog/remembering-jake-burton-carpenter/.
35. Ettore Personnettaz, "History of the Splitboard," Freeride Alliance (blog), October 29, 2020, https://www.freeridealliance.com/2020/10/29/history-of-the-splitboard/.
36. Dawson, "Timeline – North American Ski Mountaineering History."

optimized for backcountry travel are often lighter and more forgiving of ungroomed terrain than their in-bounds counterparts. Skins, a modern nylon or mohair evolution of the seal skins first observed in the 1500's allow uphill travel on skis waxed to glide over snow. Skins use thousands of tiny hairs that dig into the snowpack when rearward pressure is applied to prevent sliding backwards but when sliding forwards the hairs retract and allow the skis to move. Beyond these specialized pieces of equipment, a backcountry skier or splitboarder will have usual inbounds ski equipment; helmet, poles, warm and waterproof clothing. Because backcountry skiing/splitboarding often takes place away from established facilities, skiers and splitboarders should have a backpack to carry sufficient equipment to keep warm, hydrated, fed and comfortable in the backcountry. Sufficient emergency equipment, like first aid kits, headlamps and emergency shelters should be carried in case the unexpected happens[37]. Finally, everyone who ventures into the backcountry should be prepared for an avalanche by carrying an avalanche beacon, a collapsable probe and shovel. Without these items, rescue from an avalanche becomes almost impossible[38].

As previously discussed, high-risk sports have achieved improvements in safety through better equipment, improved fitness and standardized training. The improved equipment that enables backcountry skiing and splitboarding has just been covered. The understanding of fitness for backcountry snowsports has improved considerably[39]. Finally, training has become standardized. The techniques to ski or snowboard are applicable on groomed runs or in the backcountry, and, as inbounds ski and snowboard instruction and technique have improved, the effects have been felt in the backcountry[40]. However, training in avalanche management and rescue is unique to backcountry skiing and snowboarding.

Professional Avalanche training in the United States can be traced to 1949 when the US Forest Service Alta Avalanche School was created[41]. This program was founded to teach Forest Service employees about avalanches and how to deal with them, the curriculum was professionally focused and aimed at active control[42]. Similar programs, though aimed

37. Martin Volken, Scott Schell, and Margaret Wheeler, Backcountry Skiing: Skills for Ski Touring and Ski Mountaineering, 1st ed (Seattle: Mountaineers Books, 2009).
38. Tremper, Staying Alive in Avalanche Terrain.
39. Matthias Gilgien et al., "The Training of Olympic Alpine Ski Racers," Frontiers in Physiology 9 (December 21, 2018): 1772, https://doi.org/10.3389/fphys.2018.01772.
40. S. Loland, "Alpine Skiing Technique — Practical Knowledge and Scientific Analysis," in Science and Skiing IV, ed. Erich Müller (International Congress on Skiing and Science, Adelaide: Meyer & Meyer Sport, 2009).
41. Doug Krause, "U.S.A. vs. Canada, Avy Ed Edition," Powder, March 11, 2014, https://www.powder.com/stories/north-american-avalanche-education.
42. Jenkins, The White Death.

Ian McCammon's FACETS Acronym

F: Familiarity Something that is more familiar to us feels safer. This looks like a slope we've skied dozens of times before, with no bad consequences.

A: Acceptance This is the desire to fit in. This trap is often seen in mixed-gender groups. Mixed-gender groups are found to expose themselves to more obvious hazard indicators than single-gender groups.

C: Commitment or Consistency We've come all this way, we can't turn back now. You've committed to friends, you've spent hours, and good money to be here.

E: Expert Halo Someone in your group with high knowledge or expert skiing ability, or simply the confidence they exude can influence the entire group and dampen all other concerns. If there is a perceived expert in the group, other group members might not speak up if they have alternative opinions, thinking that the "expert" must know what they're doing.

T: Tracks/Scarcity The race for first tracks can cloud our judgment. In addition, the thought that the resource (fresh powder) is quite limited and you must go now while the getting is good.

S: Social Proof or Social Facilitation Previous tracks on a ski slope will give you a false sense of security and therefore does not mean it is safe. Just because other people are in the same zone, does not mean that zone is safe.

43. David W. Lovejoy, "Avalanche Education in the United States: The Good, the Bad and the Ugly," in Proceedings, 2012 International Snow Science Workshop, (Interntaional Snow Science Workshow, Anchorage, Alaska, 2012).
44. Krause, "U.S.A. vs. Canada, Avy Ed Edition."
45. Krause, "U.S.A. vs. Canada, Avy Ed Edition."
46. Ian McCammon, "The Role of Training in Recreational Avalanche Accidents in the United States," in M: Proceedings of the International Snow Science Workshop, (International Snow Science Workshop, Big Sky Montana, 2000), 37–45.
47. McCammon, Ian. "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications." Avalanche News 22, no. 2 & 3 (Spring 2004).
48. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."
49. Lundy, Chris. "The Evolution of Avalanche Education: Pro/Rec Split." Sawtooth Mountian Guides (blog), October 26, 2016. https://sawtoothguides.com/2016/10/26/evolution-of-avalanche-education/.

at ski instructors instead of forest managers, were created by the National Ski Patrol for use by their members[43]. Recreational training, aimed at backcountry skiers, began to be offered in the 1970s, but coursework was non-standardized[44]. It was not until the 1990s that a more formal curriculum was developed by the American Institute of Avalanche Research and Education (AIARE) and the National Outdoor Leadership School (NOLS). In 1999 the American Avalanche Association (AAA), founded to establish national avalanche education standards, published its first educational guidelines[45]. These classes taught students how to recognize avalanche terrain and understand the snowpack to manage risk through travel choices as well as rescue techniques.

As avalanche education became more common, avalanche professionals noted a perplexing trend. While avalanche education had at first reduced the number of avalanche fatalities, the effect had petered out[46]. Attempting to find a solution to this problem in 2002, Ian McCammon wrote his seminal paper *Evidence of heuristic traps in recreational avalanche accidents*, further refined in 2004. To explain this effect, McCannon proposes that a number of what he terms *human factors* influence decision making in avalanche terrain and lead backcountry users to make poor decisions they might not have in other circumstances[47]. He organized the main human factors he noticed into the acronym FACETS[48]. The impact of McCammon on avalanche education cannot be overstated, introducing to the avalanche world the understanding that humans are fallible decision makers and that steps should be taken to account for this.

One effect of this research was the overhaul of avalanche education curricula that the AAA launched in 2017. In addition to splitting courses into a professional and recreational track, snow science and avalanche forecasting was de-emphasized in the recreational level 1 course while focusing more on the skills to make rational and informed decisions in avalanche terrain and to repeat this process every trip[49].

Dangers of Skiing

As with most high-risk sports, backcountry skiing and splitboarding exposes its participants to dangers not found in everyday life. Taking place in the outdoor environments, during the winter and early spring, skiers and splitboarders are exposed to snow, cold and rain. These factors, if not managed, can lead to hypothermia and nonfreezing cold-induced injury (NFCI)[50]. As a physical activity, musculoskeletal injuries are always possible[51]. When the sky is clear, the extremely high albedo[52] of snow can cause sunburns[53]. These environmental dangers are rarely fatal but can contribute to other accidents.

While skiing can sometimes be described as controlled falling[54], uncontrolled falls present one of the most temporally immediate dangers of skiing[55]. Skiers travel at an average speed of 34.9 km/h (21.7 mph)[56] and easily skiable snow has a density of 530-550 kg/m^3 [57] making impacts dangerous. Even skiers who manage to stay upright speed may cause them to impact trees, fall off unseen cliffs or hit other skiers[58].

Even when a skier does not hit a tree at speed, trees can remain dangerous due to the wells they create in the snowpack. A tree well forms when tree branches prevent the space under a tree from filling completely with snow[59]. The branches prevent most snow from filling the space under the tree and what snow does accumulate is much less compacted than the surrounding snow[60]. Tree branches can hide the wells and if a skier or snowboarder falls in, snow can fall on top of them, camouflaging the skier's/snowboarder's location. Most often, skier's/snowboarder's fall in head first and if their body is angled down more than 30°, they will not be able to extricate themselves and must be recovered by another person[61]. Loose powdery snow in the well can block a trapped skiers airway, causing non-avalanche-related snow immersion death (NARSID)[62]. Treewells are notable in that they are equally present in the backcountry as well as in ski resorts where many dangers are controlled for customers. However, while many of these dangers are controlled in ski resorts, in the backcountry the

50. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, eds., Auerbach's Wilderness Medicine, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017).
51. John Hurt et al., "Winter Sport Musculoskeletal Injuries: Epidemiology and Factors Predicting Hospital Admission," European Journal of Orthopaedic Surgery & Traumatology 33, no. 5 (August 9, 2022): 1735–43, https://doi.org/10.1007/s00590-022-03322-y.
52. Chad W. Thackeray and Christopher G. Fletcher, "Snow Albedo Feedback: Current Knowledge, Importance, Outstanding Issues and Future Directions," Progress in Physical Geography: Earth and Environment 40, no. 3 (June 2016): 392–408, https://doi.org/10.1177/0309133315620999.
53. Andrew C. Krakowski and Alina Goldenberg, "Exposure to Radiation from the Sun," in Auerbach's Wilderness Medicine, ed. Paul S. Auerbach, Tracy A. Cushing, and N. Stuart Harris, Seventh edition (Philadelphia, PA: Elsevier/Mosby, 2017).
54. Todd Whitcombe, "Skiing the Art of Controlled Falling," Prince George Citizen, January 15, 2015.
55. T. M. Davidson and A. T. Laliotis, "Alpine Skiing Injuries. A Nine-Year Study," The Western Journal of Medicine 164, no. 4 (April 1996): 310–14.
56. Lenka L. Stepan et al., "Skier and Snowboarder Speeds at US Ski Areas," JSAMS Plus 2 (2023): 100033, https://doi.org/10.1016/j.jsampl.2023.100033.
57. Greg West and Rosie Howard, "Density of Newly-Fallen Snow" (University of British Columbia, December 2018), https://www.eoas.ubc.ca/courses/atsc113/snow/met_concepts/07-met_concepts/07b-newly-fallen-snow-density/.
58. Davidson and Laliotis, "Alpine Skiing Injuries. A Nine-Year Study."
59. Christopher Van Tilburg, "Non–Avalanche-Related Snow Immersion Deaths: Tree Well and Deep Snow Immersion Asphyxiation," Wilderness & Environmental Medicine 21, no. 3 (September 2010): 257–61, https://doi.org/10.1016/j.wem.2010.04.004.
60. Van Tilburg, "Non–Avalanche-Related Snow Immersion Deaths."
61. Paul Baugher, "Risk Trends at U.S. and British Columbia Ski Areas: An Evaluation of the Risk of Snow Immersion Versus Avalanche Burrials," 2006.
62. Van Tilburg, "Non–Avalanche-Related Snow Immersion Deaths."

Size	Destructive potential	Typical length	Typical deposit volume
D1	Rel. harmless to people	Bus	Avg apartment ≤ 1 m deep
D2	Injure/bury/kill a person	Football field	Floor large house ~2 m deep
D3	Bury/destroy a car or house	1 km	Hockey rink 2-3 m deep
D4	Destroy a large truck or 4 ha forest	2 km	4 hockey rinks 4 m deep
D5	Destroy a village or 40 ha forest	3 km	5+ football fields 8 m deep

Destructive Force Scale (D-Scale)

63. Jürg Schweizer, Christoph Mitterer, and Lukas Stoffel, "On Forecasting Large and Infrequent Snow Avalanches," Cold Regions Science and Technology 59, no. 2–3 (November 2009): 234–41, https://doi.org/10.1016/j.coldregions.2009.01.006.
64. Simon Rauch, Giacomo Strapazzon, and Hermann Brugger, "On-Site Medical Management of Avalanche Victims—A Narrative Review," International Journal of Environmental Research and Public Health 18, no. 19 (September 29, 2021): 10234, https://doi.org/10.3390/ijerph181910234.
65. Hermann Brugger et al., "Resuscitation of Avalanche Victims: Evidence-Based Guidelines of the International Commission for Mountain Emergency Medicine (ICAR MEDCOM)," Resuscitation 84, no. 5 (May 2013): 539–46, https://doi.org/10.1016/j.resuscitation.2012.10.020.
66. Reuters, "109 Reported Killed in Avalanches in Turkey," The New York Times, February 2, 1992, sec. 1.
67. Jerry Johnson et al., "Rethinking the Heuristic Traps Paradigm in Avalanche Education: Past, Present and Future," ed. Pier Luigi Sacco, Cogent Social Sciences 6, no. 1 (January 2020): 1807111, https://doi.org/10.1080/23311886.2020.1807111.
68. "Cryosphere Glossary" (National Snow and Ice Data Center, n.d.), https://nsidc.org/learn/cryosphere-glossary.
69. "Avalanche Encyclopedia" (Avalanche.org, n.d.).
70. "Avalanche Encyclopedia."
71. Guye Lacell, one of the most experienced ice climbers of his day, was killed while climbing in Montana when a small, loose avalanch knocked him over a cliff. Jodi Hausen and Karin Ronnow, "World-Class Ice Climber Dies in Hyalite Avalanche," Bozeman Daily Chronicle, December 11, 2009, https://www.bozemandailychronicle.com/news/world-class-ice-climber-dies-in-hyalite-avalanche/article_d2ca5bc3-bde1-5553-ac55-15b3421c81cb.html.
72. "Avalanche Encyclopedia."
73. "Avalanche Encyclopedia."
74. "Avalanche Encyclopedia."
75. "Avalanche Encyclopedia."
76. "Avalanche Encyclopedia."
77. "Avalanche Encyclopedia."

most dramatic of these dangers is that presented by avalanches.

Avalanches

An average of approximately 250 people die in avalanches every year[63]. Beyond those killed, an unknown number of people are caught by avalanches and survive, or are non-fatally injured[64]. In developing countries these death tolls can reach extreme numbers (284 lives in South East Anatolia in 1992, 135 lives in Kashmir in 2012)[65], and primarily claim soldiers, herders or those whose homes are located in the slide path[66]. However, most are recreationists: skiers, snowboarders, climbers and snowmobilers, what Johson et. al., call victims of choice[67]. By necessity, these sports require travel in terrain where avalanches are possible or even probable.

An avalanche is caused when a mass of snow loses its structural integrity and begins to slide downhill[68]. While popularly discussed monolithically, two main types of avalanches exist. Slab avalanches, where a cohesive mass of snow loses its tensile bonds to the surrounding snowpack and begins to slide downhill as one piece[69]. The other type, the loose avalanche, occurs when snow loses its internal structure and begins to slide downhill as a loose mass of snow[70]. Loose avalanches are generally only dangerous when they knock a recreationalist into another danger such as off a cliff[71] or small terrain trap[72].

Within these two categories, avalanches are further categorized by the mechanism by which they formed, the surface on which they slide or the mechanism of their release[73]. Slab avalanches can be categorized as Wind, Storm, Wet, Persistent, Deep Persistent or Glide[74]. Loose avalanches can be categorized as either Dry or Loose[75]. Once they occur, avalanches can be categorized by their size and destructive force on the D-Scale the describes the destructive potential of an avalanche on a scale from 1-5[76]. Furthermore, the size of the avalanche can be described on the R-Scale by its relation to the size of the slope on which the avalanche released and traveled[77].

These categorizations describe how an avalanche behaves once it is triggered. Though avalanches can be triggered in a number of different ways, the ultimate mechanism of triggering is universal[78]. An avalanche is triggered when the snow's structure can no longer support its own weight[79]. Avalanches that occur during storms are often triggered because the weight of new snow overwhelms the structural capability of the snowpack underlying it[80]. Solar radiation or rain can change the crystalline structure of the snow, weakening its inter-crystalline bonds until it can no longer support the snow above it[81]. External forces can also trigger avalanches, earthquakes, rockfall and artillery can all cause inter-crystalline brakes that propagate and cause a slide to begin[82]. Finally skiers, snowmobilers and even deer can trigger avalanches both by adding to the weight that the snowpack must support as well as by breaking bonds between snow crystals with their legs or tracks[83]. Approximately 94% of avalanches that catch skiers or splitboarders are human triggered[84]. Once triggered, an avalanche can be a self-sustaining cycle. The mass of the moving snow slams into stationary snow below, breaking its bonds and adding snow to the moving mass. Moving avalanches continue to grow and entrain more snow until they reach a shallow enough incline that the moving snow's momentum is no longer enough to push the snow downhill. Aside from wet avalanches which slide on noticeably shallower slopes[85], avalanches are generally triggered on slopes from 30° to 45°[86], and are less common on steeper or shallower slopes[87], though the size and volume of the avalanche can alter this.

Like all natural forces, avalanches have been with humanity throughout time. In The White Death McKay Jenkins recounts the multiple supernatural explanations that were believed about avalanches. Some explained the fearsome, unexplained forces by arguing that dragons dwelt in mountain passes, a belief that continued into the eighteenth century, alternatively a 1652 Swiss witch trial concluded that "witches are the causes of avalanches."[88]

Though the causes and avoidance of avalanches were little understood at the time[89], the first recorded attempts at organized avalanche rescue date back to the late 1600's when the

Relative Size Scale (R-Scale)

78. "Avalanche Encyclopedia."
79. Tremper, Staying Alive in Avalanche Terrain.
80. Tremper, Staying Alive in Avalanche Terrain.
81. Tremper, Staying Alive in Avalanche Terrain.
82. Tremper, Staying Alive in Avalanche Terrain.
83. Tremper, Staying Alive in Avalanche Terrain.
84. Tremper, Staying Alive in Avalanche Terrain.
85. "Glossary" (Avalanche Canada, n.d.), https://avalanche.ca/glossary.
86. "Glossary."
87. "Glossary."
88. Jenkins, The White Death.
89. Jenkins, The White Death.

monks of the Great St. Bernard Hospice began to use their guard dogs, the progenitors of the St. Bernard breed, to rescue avalanche victims. The Hospice, which sits at St. Bernard Pass, a difficult, snowy pass that many pilgrims crossed on their way to Rome, was founded in 1050 by St. Bernard de Menthon[90] to assist those pilgrims. In the mid 1700's the guard dogs of the monastery began to be used to find and warm those buried in avalanches while alerting the monks at the monastery that a traveler was in need of rescue, having been lost in the snow drifts on the way over the pass[91].

Aside from dogs, which are still in use today[92], other workable methods of locating a buried avalanche victim eluded rescuers until the creation of the avalanche cord. The avalanche cord is a red cord, tied around the waist of someone traveling or working in avalanche terrain and left to drag behind them as they move. The cord is marked with metal rings every meter stamped with the distance and direction to the victim. When searching avalanche debris, a rescuer would look for the red cord in the snow and then pull on it to find which end led to the victim. They would then dig along the path of the cord to locate the victim[93]. It is unclear if any successful rescues were ever facilitated by an avalanche cord[94].

The beginning of modern avalanche rescue can be traced back to creation in 1968 of the first avalanche beacon[95]. The Skadi, as the unit was known, emitted a radio pulse that could be picked up by a corresponding unit. Users would search the area where a buried victim might be and hone in on where the signal was loudest. All subsequent analog beacons are based on this search methodology[96].

While analog beacons work, the learning curve to perform a search is steep and the procedure difficult. Digital beacons significantly improved the search experience and streamlined the procedure. The Backcountry Access DTS Tracker, first introduced in 1997, was the first beacon to use digital signal processing to locate the direction of the buried signal and use an easy to read user interface to communicate this with a rescuer[97].

The introduction of the digital avalanche beacon simplified the avalanche search

90. Today, St. Bernard is the patron saint of hikers, skiers, snowboarders and climbers. Kevin Shea, "Patron Saint of Hikers: St. Bernard's Catholic Church Celebrates 11th-Century Namesake," Adirondack Daily Enterprise, June 17, 2019, https://www.adirondackdailyenterprise.com/news/local-news/2019/06/patron-saint-of-hikers/.
91. Jess Blumberg, "A Brief History of the St. Bernard Rescue Dog," Smithstonian Magazine, March 1, 2016, https://www.smithsonianmag.com/travel/a-brief-history-of-the-st-bernard-rescue-dog-13787665/.
92. Matthias Hohlrieder et al., "Rescue Missions for Totally Buried Avalanche Victims: Conclusions from 12 Years of Experience," High Altitude Medicine & Biology 9, no. 3 (September 2008): 229–33, https://doi.org/10.1089/ham.2007.1061.
93. Exhibit at the Washington State Ski & Snowboard Museum at Snoqualmie Pass, Washington
94. Lou Dawson, "Avalanche Cord — String of Life or Placebo of Sad Demise?," Wild Snow (blog), September 14, 2017, https://wildsnow.com/23132/avalanche-cord-history-safety-rescue/.
95, Lou Dawson, "Skadi — First Avalanche Rescue Transceiver 'Beacon,'" Wild Snow (blog), August 9, 2013, https://wildsnow.com/10527/skadi-history-avalanche-rescue-beacon-transceiver/.
96. Dawson, "Skadi — First Avalanche Rescue Transceiver 'Beacon.'"
97. Lou Dawson, "The Antenna That Changed Everything - BCA Tracker Overview," Wild Snow (blog), December 27, 2019, https://wildsnow.com/26774/bca-tracker-avalanche-beacon-transceivers-safety/.

procedure to what is taught in all modern avalanche classes. This procedure is performed as follows[98]: As soon as an avalanche occurs, all members of the party must stop what they are doing and watch the victim who has been caught. Knowing the direction that the victim traveled in as well as their last seen location can give important clues to a rescuer. When the avalanche has stopped moving, the remaining members of the party must examine the scene to determine if there is any remaining danger. Potentially, unreleased but unstable snow, known as hangfire, may still threaten the slide path, however this is rare[99]. If hangfire is present, or other dangers preclude rescuers entering the avalanche path, the rescue must be abandoned.

Once the scene is determined to be safe, all members of the party who remain unburied must turn their beacons into a search mode. Now, instead of sending out an electronic ping, the beacons will search for this ping and use their circuitry to pinpoint the location the signal is coming from. However, beacons have limited range, approximately 40 meters for older models up to 90 meters for the latest beacons[100], and so rescuers must first perform a signal acquisition search. To pick up a signal, rescuers must ski a zig zag pattern ensuring that they are covering the terrain in 40 meter wide swaths. Once a signal is acquired, the rescuers beacon will start to beep and indicate a direction and distance to the buried beacon. A rescuer must travel in the direction indicated by the beacon, travel paths are slightly curved because avalanche beacons follow the flux lines of the electromagnetic signal. At 10 meters, the rescuer should remove their skis or splitboard and continue on foot. As they get closer to the signal the rescuer should slow down as the signal reaches around 2.5 meters, they should almost crawl while pressing the beacon against the snow. Once the lowest distance number is identified, the rescuer should bracket the location, sweeping the left and right then forward and backward to identify the location with the lowest distance displayed on the beacon. This spot should be marked, commonly by punching a hole in the snow.

Once the center of the bracket is marked the rescuer will retrieve and assemble their

98. The description of an avalanche rescue is compiled from the following sources:
Tremper, Staying Alive in Avalanche Terrain.
Grissom et al., "Avalanches."
Colin Zacharias and Liz Riggs Meder, eds., Decision Making in Avalanche Terrain: Avalanche Rescue Student Handbook, 2019.
99. "Glossary" (Avalog.co, n.d.), https://avalog.co/glossary.
100. Dom Rickicki and Ian Nicholson, "The 5 Best Avalanche Beacons of 2024" (Gear Lab, May 13, 2024), https://www.outdoorgearlab.com/topics/snow-sports/best-avalanche-beacon.

avalanche probe. To probe, the rescuer will start by inserting the probe into the spot where the beacon returned the lowest number. The rescuer should press the probe fully into the snow, perpendicular to the surface, feeling for any resistance that would suggest a buried body. If none is felt, the probe is removed and reinserted 25 cm (10”) away from the first probe, again feeling for a buried body. Probing continues in a spiral pattern outwards, every 25 cm (10”), until the buried victim is positively located. The probe should be left in the snow to mark the location of the victim.

At this point all rescuers should assemble their shovels so they can assist with the rescue. Shoveling should begin downhill of the victim so that excess snow can be shoved down hill as well as to create a bench to easily extricate the victim onto and on which to render medical aid if needed. A rule of thumb is for the rescuer to step back one step for burials under a meter and two steps for burials over a meter, and then begin digging into the snow aiming at a point slightly under the tip of the probe. Shoveling is difficult work, an average rescue requires moving over 907 kg (2000 lbs) of snow and is physically taxing for a solo rescuer. When multiple rescuers are available, current scholarship advocates for a conveyor belt system where a lead shoveler digs into the snow and shovelers behind move the loosened snow out of the way of the primary shoveler. Sources differ but advocate rotating the lead shoveler to the back of the conveyor every 90 seconds or every four minutes to allow the lead shoveler time to recover.

Once first contact with a victim is made, if multiple rescuers are present, the shoveler who first sees the body should yell “Contact!” or something similar to communicate to others that the victim’s location has been identified. Diggind should continue, attempting to locate and clear the victim’s airway as soon as possible. If needed, mouth to mouth resuscitation can be performed while the victim is still entombed. Extricating a fully buried skier or splitboarder, especially one still attached to their skis or board is difficult, but as soon as an airway is cleared and breathing restored the work is less urgent. Beyond rescue, appropriate

medical care should be provided as soon as is practical focusing on restoring breathing or reversing hypoxia induced cardiac arrest. Spinal trauma must always be considered but is of secondary importance to restoring respiration and circulation. Once extracted and stabilized, evacuation is the final piece of the puzzle. If a victim can move under their own power, skiing out is always the quickest option. If not, an improvised sled may have to be assembled or in the worst case a helicopter or snowmobile called to evacuate the victim. Finally, most medical guidelines advise transporting the victim to a hospital for observation.

Avalanche companion rescues are a matter of time. The most aggressive guidance suggests that victims have the best chance at survival if their airway is re-established within 10 minutes[101]. This chart, printed on the next page, shows that survival chances fall precipitously over the course of the initial phase, what is termed the *survival phase*, continue to drop during the *asphyxia phase*, during which the the effects of hypoxia and hypercapnia begin to become fatal. The final long tail of the graph, known as the *latent phase*, represents only victims who were not injured in the initial slide, were buried in a snowpack with a patent airway to the surface and had quick access to definitive medical care after they were unburied[102].

Trauma is also a concern. The incidence of trauma varies dramatically by overall location. European avalanche victims have about an 6% chance of dying from trauma when caught in an avalanche[103]. Canadian avalanche victims have about a 50% chance of dying while Americans roughly split the difference at 25%[104]. This dichotomy is explained by the intense tree cover of Canadian backcountry skiing venues compared the the relatively bare backcountry of most of Europe[105]. While trauma is a concern for avalanche victims, it is not quite as common as one might believe given the forces a body experiences when dragged downhill in a mass of snow. A study of avalanche related hospital admissions in Innsbruck, Austria found that out of total of 105 admissions the most common injury was extremity trauma with an incidence of 19%. Chest trauma was the second most common at 17% and

101. P. Haegeli et al., "Comparison of Avalanche Survival Patterns in Canada and Switzerland," Canadian Medical Association Journal 183, no. 7 (April 19, 2011): 789–95, https://doi.org/10.1503/cmaj.101435.
102. Haegeli et al., "Comparison of Avalanche Survival Patterns in Canada and Switzerland."
103. Tremper, Staying Alive in Avalanche Terrain.
104. Tremper, Staying Alive in Avalanche Terrain.
105. Tremper, Staying Alive in Avalanche Terrain.

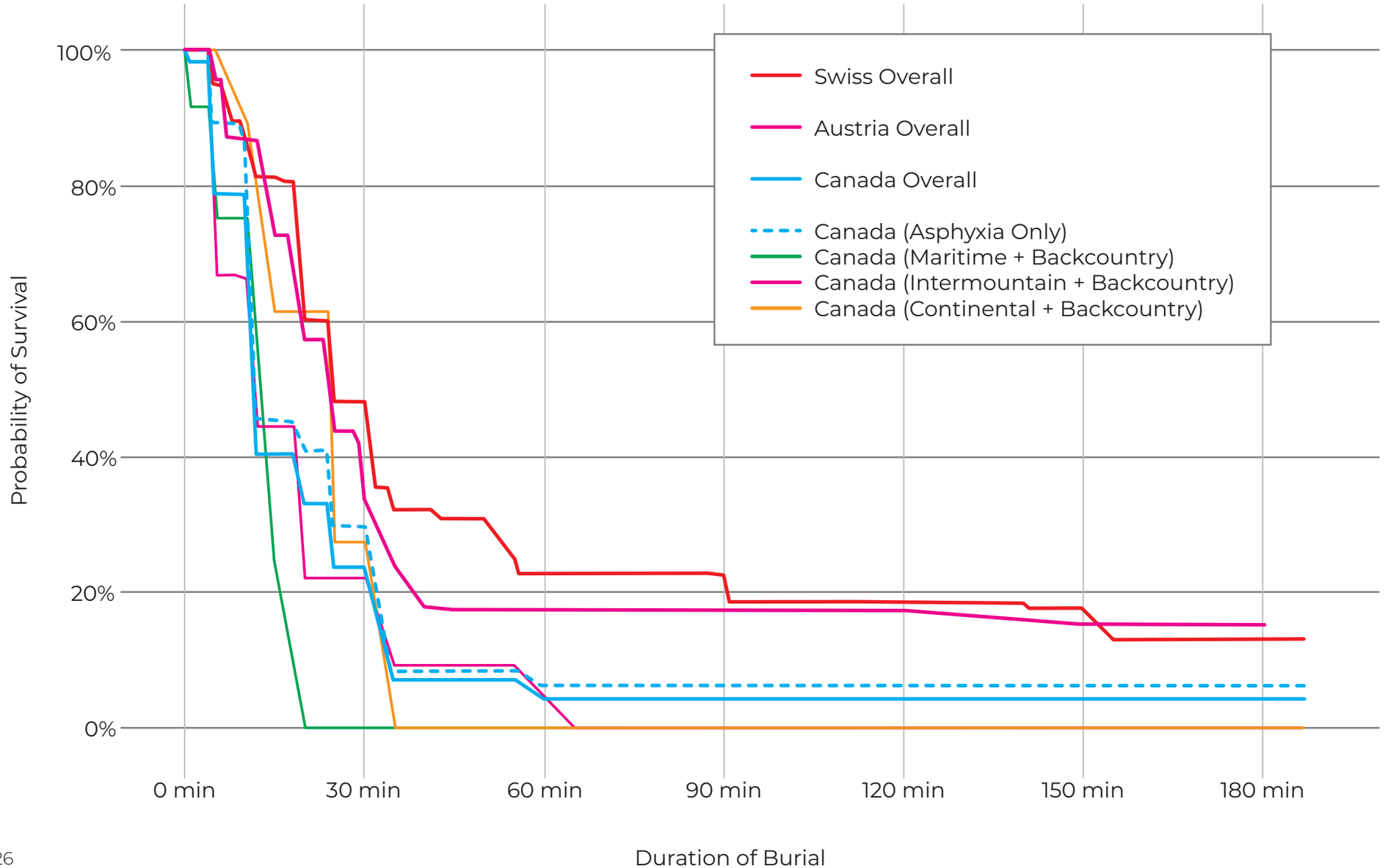


Chart adapted from Haegeli et al., "Comparison of Avalanche Survival Patterns in Canada and Switzerland." and Rauch, Strapazzon, and Brugger, "On-Site Medical Management of Avalanche Victims—A Narrative Review."

spinal fractures only affected 6% of those admitted[106].

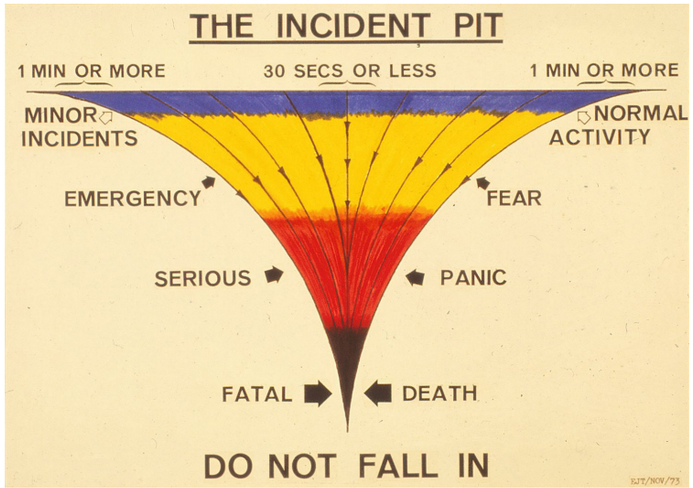
While a more recent addition to the post-avalanche care discussion, psychological concerns should not be ignored. Beyond the physical injury, getting caught in an avalanche or watching a friend get caught in an avalanche can be an intense psychologically traumatic experience[107]. Even when all parties survive, the mental weight of such an experience should not be underestimated. For those who have lost a partner to an avalanche, survivors guilt, an intense guilt that revolves around a feeling that the sufferer has done something wrong by surviving, could be easily expected[108]. While still a field in its infancy, psychological first aid, in conjunction with appropriate regular mental health care should have a place in the continuing chain of care post avalanche for all involved[109].

Because time is of the essence, outside help or outside rescue is impractical. As a rule of thumb, the best search and rescue team will be assembling in the parking lot or taking off from a distant airfield about an hour from the time the first call to 911 is placed. By the time search and rescue teams show up, avalanche rescues are generally body recoveries[110]. To have the best hope of survival, all members of a party should be prepared, with equipment and training, to rescue anyone buried in an avalanche. However, the best way to survive an avalanche is not to be caught in one. The chance that you will survive unscathed, the chance that you are rescued quickly amounts to a roll of the dice where the wager is your life. But avalanches are by definition accidents, even when human triggered, they are rarely intentional. As an accident, there are a number of ways to understand the circumstances and forces that lead up to an avalanche victim getting caught that can help us understand

What is an Accident?

Getting caught in an avalanche is an accident. Accidents are generally understood to be unwanted, unintentional event not directly caused by humans[111]. While they are not directly caused by humans, accidents tend to have a component of human involvement,

106. Matthias Hohlrieder et al., “Pattern And Severity of Injury in Avalanche Victims,” High Altitude Medicine & Biology 8, no. 1 (March 2007): 56–61, https://doi.org/10.1089/ham.2006.0815.
107. Matthias Hohlrieder et al., “Pattern And Severity of Injury in Avalanche Victims,” High Altitude Medicine & Biology 8, no. 1 (March 2007): 56–61, https://doi.org/10.1089/ham.2006.0815.
108. Karlyle Bistas and Ramneet Grewal, “The Intricacies of Survivor’s Guilt: Exploring Its Phenomenon Across Contexts,” Cureus, September 21, 2023, https://doi.org/10.7759/cureus.45703.
109. Jeffrey H. Fox et al., “The Effectiveness of Psychological First Aid as a Disaster Intervention Tool: Research Analysis of Peer-Reviewed Literature From 1990-2010,” Disaster Medicine and Public Health Preparedness 6, no. 3 (October 2012): 247–52, https://doi.org/10.1001/dmp.2012.39.
110. Michael Coyle, “Managing Expectations in SAR,” British Columbia Search and Rescue Association (blog), March 31, 2018, https://bcsara.com/2018/03/managing-expectations-in-sar/.
111. Gary C. Woodward, The Rhetoric of Intention in Human Affairs (Lanham: Lexington Books, 2013). p. 41



Towse's Illustration of the Incident Pit

for example the Great Fire of London, though made worse by human decisions and feeding on human made structures, was initially caused, as far as can be determined, by an unintentional accidental fire that started without human intervention[112]. In addition, modern understanding of accidents generally views them not as solitary incidents but as part of a larger context or sequence of events. A number of models have been proposed to analyze or understand accidents or to conceptualize their prevention. This thesis uses three accident models as guides to both for understanding avalanches and guiding solution discovery. These models are: the Incident Pit, the Causal Chain and the Reason or Swiss Cheese Model. Other models exist, but were found not to be useful for structuring the thinking for this thesis.

The Incident Pit, first described by E. John Towse at the 1973 Diving Officers Conference depicts a pit with steeply sloping walls down which a person can fall. Everyday life is imagined on the surface of the pit. A minor incident, like a fogged pair of goggles, causes one to slide down to the outer rim of the pit, where the slope is still shallow and escapable. A minor incident is easy to deal with, but if a diver encounters a second minor incident together they may drag one further down the walls into the emergency section. In an emergency the walls of the pit are steeper and harder to escape and if another minor incident or serious panic overtake the diver it is easy to be dragged further down into the serious situation or fatal death areas of the incident pit[113].

To illustrate how the Incident Pit might be used to understand an accident, it can be helpful to analyze an actual accident through its lens. An interesting and informative accident to scaffold current scholarship on is Chris McNamara's first wingsuit descent of the Grand Canyon. McNamera, a big wall climber and former wingsuit BASE jumper, was attempting to secure his place in the history books when he began to scope out the Grand Canyon for a wingsuit descent[114]. Floating the Colorado River and using trails from some of the first exploring parties, he identified all the information he needed to safely fly the

112. David Garrioch, "1666 AND LONDON'S FIRE HISTORY: A RE-EVALUATION," The Historical Journal 59, no. 2 (June 2016): 319–38, https://doi.org/10.1017/S0018246X15000382.
113. E. John Towse, "The Incident Pit," in British Sub Aqua Club Diving Officer's Conference Report, 1973.
114. Ben Adair and Chris McNamara, "My First & Last BASE Jump," First Time Last Time, n.d.

canyon: run up and take off points, flight path and landing zone. Returning to the rim of the canyon after a full day of scouting, he realized that an approaching weather window meant that he had to jump that day or wait for another opportunity, possibly allowing someone else to snag the first descent. He decided to go for it and geared up. He ran up to the lip, pushed off with his foot, jumped, opened his wings and began to fly. Early on he noticed some things were not going to plan, he almost clipped a small cliff about 15 seconds into the flight. Coming into the landing he realized he was short of the intended landing zone and was now forced to choose between landing on a boulder field or in the river. Choosing the river he landed and the nylon wingsuit that had kept him aloft became soaked with water and began to drag McNamera under the water. Struggling, he managed to escape from the suit and survive what he decided would be his last BASE jump. McNamera attributes this short landing to his exhaustion from a day of scouting, hiking up and down the Grand Canyon[115]. Small things compound and an exhausted person is less able to balance or use their musculature[116]. In addition, wingsuiting as a discipline has no automatic interventions, meaning that safety is entirely dependent on human actions with no automatic systems capable of changing the course of events[117].

This accident almost ended in tragedy, and, along with his growing realization of how many other friends he had lost to BASE jumping, led to the end of McNamera's BASE jumping career. But how would such an accident be understood and analyzed through our current academic understanding? Of the three models described earlier, we will first analyze this incident through the lens of the Incident Pit.

BASE jumping is an activity with a narrow window for correction or recovery, in this way a BASE jump could be seen as occurring in the outer rim, but below the surface of the pit. McNamera's exhaustion from a day of scouting dragged him further down the sides of the pit. In concert, these two minor incidents held him far enough down in the incident pit that an emergency landing in the Colorado River was almost fatal. In comparison, for

115. Adair and McNamara, "My First & Last BASE Jump."
116. Camila G.M. Castor et al., "Effect of Sleep Deprivation on Postural Control and Dynamic Stability in Healthy Young Adults," Neuroscience Letters 797 (February 2023): 137055, https://doi.org/10.1016/j.neulet.2023.137055.
117. Andrew Bisharat, "Has the World's Deadliest Sport Become Safer? It's Complicated.," National Geographic, August 7, 2019, https://www.nationalgeographic.com/adventure/article/wingsuit-BASE-jumping-deaths-safety-regulations.

a guest on a white water rafting trip, falling into the same river can be a fun diversion or a minor disappointment, since a whitewater rafting trip is not always that dangerous and often exists at the surface of the incident pit.

The Causal Chain model imagines accidents not as a single incident or action but instead as an interlocked series of events all leading up to a final incident[118]. In the analysis of an accident each link of the chain represents an action or event that, if altered or prevented, would avert the eventual accident. Returning to our previous example, McNamara, at that point a big-wall climber, learns to BASE jump and finds wingsuit flying specifically to be intensely fulfilling. As an early participant of the sport there are a great number of first descents still to be made. He finds a first descent in the Grand Canyon, and comparing this to the early days of Yosemite climbing, wants to capture that same magic[119]. After intensive preparatory work and scouting, he finds the descent doable. He realizes that the weather is closing in and a jump must happen that day or be postponed. Believing he is capable, he suits up and prepares to jump. At this point a number of links of the chain have already been completed, if any one had been broken the accident never would have happened. But all the chains remain linked, nothing occurred to interrupt the incident chain and Chris takes that running leap into the void.

In 1990, James T. Reason proposed the Swiss Cheese Model as a way to envision the protective effect of multiple layers of safety interventions[120]. The Swiss Cheese model imagines each layer of safety system, human intervention or automatic backup as a slice of Swiss cheese with its holes randomly distributed on its surface. Each additional layer of safety blocks more holes until, with enough safety interventions, the chance of an incident approaches zero.

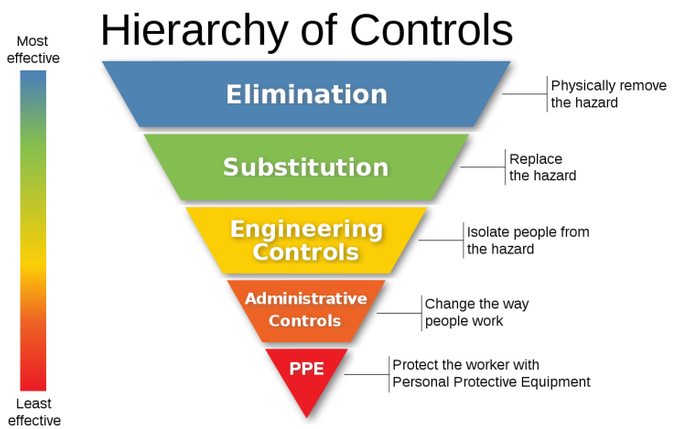
While the Incident Pit and Causal Chain are useful to describe BASE jumping incidents, BASE jumping is an activity with few automatic safety measures. A BASE jumper or wingsuit flier must release their own parachute, by hand and without automatic interventions, safety

118. N. R. Hanson, "Causal Chains," Mind 64, no. 255 (1955): 289–311.
119. Adair and McNamara, "My First & Last BASE Jump."
120. J. T. Reason, "The Contribution of Latent Human Failures to the Breakdown of Complex Systems," Philosophical Transactions of the Royal Society of London. B, Biological Sciences 327, no. 1241 (April 12, 1990): 475–84, https://doi.org/10.1098/rstb.1990.0090.

backups or, to use the metaphor, slices of Swiss cheese. Because of this another accident can be illustrative when scaffolding the Swiss cheese model. In 2005, Helios Airways Flight 522 crashed into a mountainside in Grammatiko, Greece after exhausting all fuel on board, killing all 121 passengers and crew[121]. In the investigation performed after the crash, it was found that a nearly impossible series of automatic and manual errors compounded to cause a loss of pressurization, leading to generalized hypoxia of the pilots and subsequent abandonment of control leaving the plane to be flown by its autopilot for the next three hours before fuel ran out[122]. The problem began on the runway in Crete, when a ground engineer, following up on a previous complaint, inspected the pressurization system of the airplane[123]. Once the work was completed, they forgot to change the pressurization switch from manual back to automatic[124]. During the pre-flight check, after-start check and after-takeoff check neither pilot nor co-pilot managed to notice the misconfiguration of this switch, positioned as it is above the left shoulder of the co-pilot, in a forest of other knobs and switches[125]. After takeoff, as the aircraft climbed past 12,000 ft the cabin altitude warning horn sounded[126]. This horn has an identical sound to a different alert that can only sound while the plane is on the ground and, already succumbing to the delirious effects of hypoxia, the crew ignored the warning[127]. As some systems began to fail due to the decreased air density, the crew was unable to untangle the root cause of the problem[128]. 17 minutes into the flight and with a cabin altitude equivalent to the summit of Mount Everest, the captain asked about the location of some circuit breakers and then ceased all communication[129]. At 28,000 ft the time of useful consciousness is roughly 2.5 to 3 minutes[130], and, deeply hypoxic, the cabin crew slipped into unconsciousness.

Analyzing this accident through the Swiss Cheese Model, we can see a number of layers that were either the holes happened to line up or the holes were too large. The ground crew wrapped up their inspection of the plane and forgot to return the switch to auto. Three separate checklists were completed without adequately catching the disaster in waiting.

121. Captain Akrivos D. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005" (Hellenic Public Ministry of Transport & Communications, November 2006).
122. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
123. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
124. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
125. Glyn Chadwick, "Boeing 737-300/400/500 'Classic,'" n.d., https://gchadwick.myportfolio.com/boeing-737-300400500-classic.
126. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
127. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
128. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
129. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
130. David M. Shaw, Gus Cabre, and Nicholas Gant, "Hypoxic Hypoxia and Brain Function in Military Aviation: Basic Physiology and Applied Perspectives," Frontiers in Physiology 12 (May 17, 2021): 665821, https://doi.org/10.3389/fphys.2021.665821.



131. Sally Williams, "In 2005, Helios Flight 522 Crashed into a Greek Hillside. Was It Because One Man Forgot to Flip a Switch?," The Guardian, September 19, 2020, https://www.theguardian.com/world/2020/sep/19/in-2005-helios-flight-522-crashed-into-a-greek-hillside-was-it-because-one-man-forgot-to-flip-a-switch.
132. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
133. In an incredible, though ultimately futile twist of fate, a flight attendant, Andreas Prodromou, managed to don an oxygen mask attached to a large cylinder before general hypoxia incapacitated him. Almost three hours into the flight and 50 seconds before the first engine flamed out, he managed to enter the cockpit. Though he held a UK Commercial pilot's license, he was not certified for the 737. While unable to fully take full control of the plane he managed to steer the plane away from the city of Athens and towards an empty field, preventing any ground fatalities. Tsolakis et al., "Aircraft Accident Report Helios Airways Flight HCY522 Boeing 737-31S at Grammatiko, Hellas on 14 August 2005."
134 Herbert K. Abrams, "A Short History of Occupational Health," Journal of Public Health Policy 22, no. 1 (2001): 34, https://doi.org/10.2307/3343553..
135. Abrams, "A Short History of Occupational Health."
136. "Identifying Hazard Control Options: The Hierarchy of Controls" (OSHA'S Reccomended Practices for Safety & Health Program, n.d.), https://www.osha.gov/sites/default/files/Hierarchy_of_Controls_02.01.23_form_508_2.pdf.

To extend the metaphor, four layers of Swiss cheese happened to have their holes aligned allowing the accidents' Causal Chain to continue. In an example of a hole too large to adequately contain the danger it was designed to, the sound to warn of inadequate cabin pressure was the same as a minor ground only fault. Subsequent litigation focused on Boeing's choice to use the same sound for both faults, which the families of the deceased contended would foreseeably cause confusion[131]. While oxygen supplies are provided for the flight crew, it is unclear if they were able to don oxygen masks, if the masks were properly donned or if the oxygen ran out[132]. Despite a great number of "slices" of safety, they were inadequate to catch or prevent hypoxia on the flight deck, sealing the fate of the plane[133]. As will be discussed later, aircraft contain a great number of safety systems but their complexity and inherent danger mean that there is always a possibility of slipping through the multiple layers of Emmental that stand between life and death.

Many of the incident models that have been discussed were developed from the world of industrial safety. Since at least the 1400s there has been some understanding of the dangers that one's work may present. Much of the early work focused on the fumes inhaled by miners and metalworkers, and included recommendations on how to prevent these illnesses[134]. In the 1800's, coupled with the, then nascent, labor movement, governments began mandating safer conditions for workers[135]. In the modern day industrial safety is a robust field with a great wealth of research to draw on. One of its more important concepts, and one that can be applied elsewhere, is the National Institute for Occupational Safety and Health's (NIOSH) Hierarchy of Controls. The Hierarchy of Controls lays out potential workplace safety interventions and ranges them from most to least effective[136]. While some interventions, like the elimination or substitution of the danger source, are not always applicable to high-risk sports, efforts focusing on administrative controls and personal protective equipment could bear fruit, if they have not already.

But what if the danger is inherent, if an action can never be made entirely safe? This is

a reality with Aviation safety. There is an old joke that states, “The pilot is always the first to arrive at the scene of an accident.”[137] This reality, combined with the high negative publicity of commercial aircraft accidents[138] has caused the aviation sector to adopt a number of informative and interesting safety improvements[139]. For early pilots, flying was much like a high-risk sport. Safety equipment was minimal, if present at all[140], and skill and training was of the utmost importance[141]. It was only in World War II that many of the most recognizable features of aviation safety began to be created. Though relatively simple, one of these innovations, the preflight checklist, was groundbreaking and remains a cornerstone of aviation, and increasingly other[142], safety traditions.

The B-17 was a bomber unprecedented in its size, capability and difficulty to fly. Early test planes crashed almost continuously; these crashes were usually found to be instances of “pilot error”, unthinkable for the highly-skilled test pilots who were examining the plane’s capability. The plane’s unprecedented complexity prompted a contemporary newspaper writer to say it was “too much airplane for one man to fly.”[143] The ultimate solution was not more training, but instead, a checklist. In the overwhelming cockpit, where a pilot, co-pilot and engineer had to work together to fly the plane, the checklist imposed order on the difficult procedural task of takeoff and landing. The importance of this innovation cannot be overstated, the entirety of modern piloting is run by checklist[144]. Checklists need not be physically marked to be useful, in general use they are used as a conversational guide between the pilot and co-pilot to make sure that all proper steps have been taken[145].

But the B-17 had another quirk, In 1943 a number of B-17s crashed on landing. The cause was mysterious, planes came in perfectly for a landing and then retracted their wheels and skidded to a stop on the runway. Alphonse Chapanis was assigned to examine the cause of these crashes. He discovered that the controls for the landing flaps and the landing gear looked identical and were placed next to each other, causing confusion and occasionally accidental retraction of the landing gear when a pilot meant to raise the flaps[146]. The solution

137. “Aviation Humor - Aviation Clichés” (Pilotfriend, n.d.), http://www.pilotfriend.com/humour/jokes/cliches.htm.
138. Mark L. Mitchell and Michael T. Maloney, “Crisis in the Cockpit? The Role of Market Forces in Promoting Air Travel Safety,” The Journal of Law and Economics 32, no. 2, Part 1 (October 1989): 329–55, https://doi.org/10.1086/467180.
139. “A Short History of Making Flying Safer,” Aviation Week & Space Technology, February 20, 2020.
140. Henry R. Lehrer, Flying the Beam: Navigating the Early US Airmail Airways, 1917 - 1941 (West Lafayette, Indiana: Purdue University Press, 2014).
141. Lehrer, Flying the Beam.
142. Ø. Thomassen et al., “The Effects of Safety Checklists in Medicine: A Systematic Review: Effects of Safety Checklists in Medicine,” Acta Anaesthesiologica Scandinavica 58, no. 1 (January 2014): 5–18, https://doi.org/10.1111/aas.12207.
143. Atul Gawande, The Checklist Manifesto: How to Get Things Right, First Metropolitan Paperbacks Edition (New York: Metropolitan Books, 2022).
144. Asaf Degani and Earl L. Wiener, “Cockpit Checklists: Concepts, Design, and Use,” Human Factors: The Journal of the Human Factors and Ergonomics Society 35, no. 2 (June 1993): 345–59, https://doi.org/10.1177/001872089303500209.
145. How to Read a Boeing Checklist, 2017, https://www.youtube.com/watch?v=JG7SkOQDDt0.
146. Stuart Lavietes, “Alphonse Chapanis Dies at 85; Was a Founder of Ergonomics,” The New York Times, October 15, 2002, sec. A.

settled one was the first example of shape coding, using visual indicators that connected with the action a lever performed. In this case, the landing gear levers received a wheel shaped knob and the flaps a triangle[147].

First introduced in the 1950s on the notoriously difficult to fly Convair B-58 Hustler[148], a voice warning system, colloquially known as “Bitching Betty”, among other names, allowed a new avenue of communication with pilots during high-stress scenarios[149]. This system consisted originally of 20 voice commands to communicate to the pilot in plain English malfunctions that the plane was experiencing. By assigning spoken words only to especially serious errors their gravity is communicated to pilots more effectively. In addition, there is no need for a pilot to decode the meaning of a particular chime or bell meaning that action can be taken more quickly. The system remains in wide use today for both military and civilian airplanes. This system remains in place because it reduces the time to understand what the problem is, giving pilots extra time to correct it[150].

Finally, one more aspect of aviation safety that could be useful in high-risk sports should be mentioned. Though they were not universally installed or used, some cockpits of the Mikoyan-Gurevich MiG-29, the Sukhoi Su-27 and the Mikoyan-Gurevich MiG-15 featured a stripe of white paint down the center of the instrument panel. A corresponding stripe of white was painted on top of the control stick. This was done so that if the aircraft entered a flat spin the recovery procedure, which consists in large part of pushing the stick centered all the way forward[151], could be accomplished by sight alone, connecting the white dot to white stripe[152]. While little explored, the author has termed this method *procedural anchoring* serving as it does to shorten a multi-step procedure to an almost elementary school matching game.

These improvements, coupled with increasingly reliable planes, weather forecasting and air traffic control have made commercial aviation one of the safest methods of travel[153]. This is an impressive accomplishment; as stated previously there is no fail-safe method of

147. Darwin P. Hunt, “The Coding of Aircraft Controls” (Air Force Aerospatial Medical Research Lab, August 17, 1979).
148. Robert Farley, “The B-58 Hustler: America’s Cold War Nuclear Bomber Blunder,” The National Interest, June 10, 2016, https://nationalinterest.org/feature/the-b-58-hustler-americas-cold-war-nuclear-bomber-blunder-16547.
149. David E. Thorburn, “Voice Warning Systems - A Cockpit Improvement That Should Not Be Overlooked” (Air Force Aerospatial Medical Research Lab, December 10, 1970).
150. J. Edworthy, E. Hellier, and J. Rivers, “The Use of Male or Female Voices in Warnings Systems: A Question of Acoustics,” Noise & Health 6, no. 21 (2003): 39–50.
151. “Flight Manual Mig-29” (Luftwaffenmaterialkommando, September 30, 1994).
152. Tony Doyle, Flying at the Edge: 20 Years of Front-Line and Display Flying in the Cold War Era (Barnsley: Pen & Sword Aviation, 2010).
153. Savage, “Comparing the Fatality Risks in United States Transportation across Modes and over Time.”

making airplanes safe, and general aviation still has an shockingly poor safety record[154].

Despite their rockstar aura, surgeons, like pilots, make mistakes. Early improvements to medicine focused on technique like Joseph Lister's work on sterility and infection[155]. However technique is not always followed and in recent years other solutions to improve patient outcomes have been examined. Drawing from their success in aviation, checklists have made their way to the surgical suite. Research has confirmed both checklists effectiveness and the simplicity of implementation[156]. Beyond checklists, flowcharts have also found utility. While many medical care recommendations follow a cascading series of binary choices using decision trees, perhaps one of the most interesting is the British National Health Service's Ten Second Triage Tool. Triage is difficult and involves both sensitive medical decision making as well as implicit ethical concerns. The Ten Second Triage Tool reduces decision making to a discrete set of steps that is fast and highly effective especially for the context it is used in[157].

Many of the previously discussed techniques rely on some level of skill or knowledge. All the checklists in the world will not enable an untrained person to land a plane without assistance. This raises another question, where does this knowledge lie?

Learning, the process of acquiring skills, understanding or knowledge is a massive topic, spanning a number of fields from neuropsychology to pedagogy. Thankfully a deep dive is not necessary as it appears that one small facet of learning is where our memory of how to perform an avalanche companion rescue lies - in procedural memory[158]. Procedural memory is a type of unconscious long-term memory which controls the performance of a particular task without conscious awareness of previous instances of that task's performance[159]. This means that, for instance, when one ties their shoes, they can perform that action without remembering every other instance of performing that action to guide their motions. Paul Fitts proposed a model of skill acquisition in the procedural memory with three stages, the Cognitive Phase, the Associative Phase and the Autonomous Phase[160]. To simplify, as a skill

154. Boyd, "A Review of General Aviation Safety (1984–2017)."
155. Dennis Pitt and Jean-Michel Aubin, "Joseph Lister: Father of Modern Surgery," Canadian Journal of Surgery 55, no. 5 (October 1, 2012): E8–9, https://doi.org/10.1503/cjs.007112.
156. Jonathan R Treadwell, Scott Lucas, and Amy Y Tsou, "Surgical Checklists: A Systematic Review of Impacts and Implementation," BMJ Quality & Safety 23, no. 4 (April 2014): 299–318, https://doi.org/10.1136/bmjqs-2012-001797.
157. Jamie Vassallo et al., "Ten Second Triage: A Novel and Pragmatic Approach to Major Incident Triage," Trauma 26, no. 1 (January 2024): 3–6, https://doi.org/10.1177/14604086231156219.
158. As yet there is no research directly confirming this, but based on inference this correct
159. Squire, Larry R. "Memory Systems of the Brain: A Brief History and Current Perspective." Neurobiology of Learning and Memory 82, no. 3 (November 2004): 171–77. https://doi.org/10.1016/j.nlm.2004.06.005.
160. Paul M. Fitts, "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement.," Journal of Experimental Psychology 47, no. 6 (1954): 381–91, https://doi.org/10.1037/h0055392.

is learned it becomes more and more automatic until in the Autonomous Phase the skill can be performed without conscious thought, think of the ability to tie one's shoes while carrying on a conversion with another person. Conscious effort and practice are required to acquire a skill to the Autonomous Phase[161]. Sometimes we've been told how to do something a hundred times and in the moment, we still forget.

In 2009, US Airways flight 1549 struck a flock of Canada geese approximately a minute and 20 seconds after becoming airborne from LaGuardia Airport. Both engines were rendered inoperable and the pilot, "Sully" Sullenberger, managed to glide the plane into the Hudson River, landing with no fatalities. While this incident is rightly celebrated for the quick thinking actions of the crew, the passengers performance was less than exemplary. A pre-flight safety briefing covering the use of lifejackets and other evacuation procedures are mandatory on all commercial flights, however the NTSB report found that only 17% of passengers reported watching most of the pre-flight safety demonstration, 13% reported watching some of this demonstration and 8% reported reading the safety information card. After impact only 3% of passengers retrieved a life jacket from under their seat, following the directions from the pre-flight briefing. Another 3% retrieved life jackets from a different seat, and 53% of passengers retrieved a seat cushion, however in the cold Hudson River life jackets are a far safer option for flotation[162]. This highlights the influence that compounding factors can have on recall and performance of tasks in procedural memory. In avalanche rescue especially, a number of compounding factors can be expected to interfere with a rescuer's performance.

An avalanche rescue is a stressful scenario, lives are on the line, nature's raw power has just been unleashed and we are left to pick up the pieces. Stress can have an extremely deleterious effect on performance[163]. Models like Yerkes-Dodson Law have attempted to correlate arousal with performance, positing a drop off in performance when an organism was in a highly aroused or stressful state[164]. Much criticism has been leveled against the

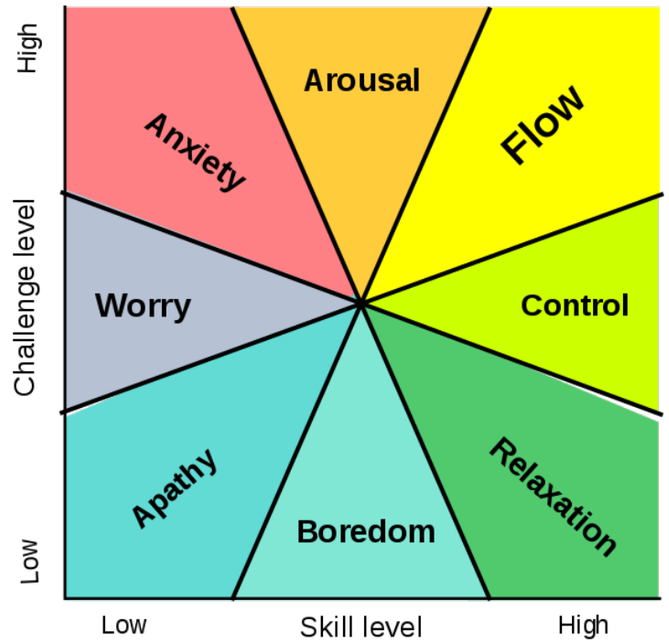
161. Fitts, "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement."
162. "Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River US Airways Flight 1549 Airbus A320-214, N106US Weehawken, New Jersey, January 15, 2009" (National Transportation Safety Board, May 4, 2010).
163. Mark A. Staal, "Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework" (National Aeronautics and Space Administration, August 2004).
164. Robert M. Yerkes and John D. Dodson, "The Relation of Strength of Stimulus to Rapidity of Habit-formation," Journal of Comparative Neurology and Psychology 18, no. 5 (November 1908): 459–82, https://doi.org/10.1002/cne.920180503.

model and it does not account for skill or practice in the performance[165]. A perhaps more descriptive model comes from Mihály Csíkszentmihályi's work on what he terms the *flow state*[166]. The eight channel model of flow model posits multiple mental states a human can occupy based on combinations of challenge and skill when accomplishing a task. A flow state describes the mental state of a skilled practitioner working at challenging task, for example a big wave surfer devoting their total mental attention to reading the wave they are on and controlling their board. While a flow state during an avalanche rescue can be seen as the ideal, other possibliiteis exist, depending on the skill level of the rescuer(s). As skill decreases a rescuer would merely feel a state of arousal or alertness and as skill decreases even further a state of anxiety[167].

Beyond the anxiety caused by low skill level, other external forces can impede performance. Thermal stress impairs both fine motor skills as well as cognitive skills, cold is noted as more impactful in this regard. Time pressure also degrades cognitive performance[168].

But it is not just external factors that can affect human cognition, the human mind uses a number of processing shortcuts to comprehend the data it takes in. These heuristics, as the shortcuts are called, can sometimes create strange side effects in both decision making and actions[169]. There are two main areas of research into heuristics, the first is the "fast and frugal" school that examines the lightweight and precise decision making tools that heuristics can be[170]. The other, the "heuristics and biases" school examines the systematic biases that color our judgment and decision making[171]. It is from this second school that McCammon draws the scholarly basis of his human factors. But there are other biases that affect our behavior in the backcountry.

Some of these biases currently affect skiers and split-boarders behavior. Two major biases not already talked about currently affect decision making in the backcountry. Risk compensation or risk homeostasis, is a known cognitive bias, though hard to repurpose for positive outcomes. The risk compensation hypothesis posits that participants will take



The Eight Channel Model of Flow

165. Staal, "Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework."
166. Mihaly Csikszentmihalyi, Flow: The Psychology of Optimal Experience, 1. HarperPerennial ed (New York: HarperPerennial, 1991).
167. Mihaly Csikszentmihalyi, Flow: The Psychology of Optimal Experience, 1. HarperPerennial ed (New York: HarperPerennial, 1991).
168. Staal, "Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework."
169. H. A. Simon, "Rational Choice and the Structure of the Environment.," Psychological Review 63, no. 2 (1956): 129–38, https://doi.org/10.1037/h0042769.
170. Daniel Kahneman, "Maps of Bounded Rationality: Psychology for Behavioral Economics," American Economic Review 93, no. 5 (November 1, 2003): 1449–75, https://doi.org/10.1257/000282803322655392.
171. Kahneman, "Maps of Bounded Rationality."

riskier choices when wearing safety gear[172]. Of concern with risk compensation is that, in some instances, the riskier choices participants make could overcome the protective effect that safety gear provides, leading to a net increase in injuries and death. With skiing and snowboarding specifically, research by suggests that helmet use was a predictor of risk taking when other factors were taken into account, however the rise was moderate and not likely to outweigh the benefit of helmet wearing[173]. Research has not yet been conducted on the risk taking behavior prompted by wearing avalanche airbags or using other safety devices. However, when designing novel safety interventions, their perceived safety value and potential risk taking they may promote should be taken into account.

The survivorship bias is another cognitive bias that needs special attention. The survivorship bias occurs when data is collected from a subgroup of a larger population and its experiences extrapolated to the whole[174]. For avalanches this bias can seriously affect decision making in the backcountry. Avalanches are an all or nothing proposition, so parties can never know how close they were to triggering an avalanche if one is not triggered and observed, potentially a skier could tour for years without truly understanding how reckless they were being if their actions always fell just a millimeter or two short of triggering an avalanche.

Research into the ways that human cognition is fallible to biases prompted another question, could these biases be harnessed to affect human behavior? Work trying to accomplish this tends to fall into two camps. The first examines *nudges*, that attempts to positively alter human behavior for the better[175]. The second camp uses what are called *dark patterns* to induce a user to do something they would not otherwise do[176]. Often these two camps use the same underlying psychological principles but aim their effects in different directions.

The background for this thesis has been rangy, exploring a number of different areas that may yield solutions to the problems in avalanche rescue. With a general understanding of the landscape we're operating in, it was time to begin experimenting.

172. D C Thompson, R S Thompson, and F P Rivara, "Risk Compensation Theory Should Be Subject to Systematic Reviews of the Scientific Evidence," Injury Prevention 7, no. 2 (June 2001): 86–88, https://doi.org/10.1136/ip.7.2.86.
173. Cynthia J. Thomson and Scott R. Carlson, "Increased Patterns of Risky Behaviours among Helmet Wearers in Skiing and Snowboarding," Accident Analysis & Prevention 75 (February 2015): 179–83, https://doi.org/10.1016/j.aap.2014.11.024.
174. Michael Shermer, "How the Survivorship Bias Distorts Reality," Scientific American, September 1, 2014, https://www.scientificamerican.com/article/how-the-survivor-bias-distorts-reality/.
175. Richard H. Thaler and Cass R. Sunstein, Nudge: The Final Edition, Updated edition (New York: Penguin Books, an imprint of Penguin Random House LLC, 2021).
176. Maximilian Maier, "Dark Patterns — An End User Perspective" (Umeå University, 2019), https://umu.diva-portal.org/smash/get/diva2:1330920/FULLTEXT01.pdf.

Research/Methodology

For this thesis, research was conducted through an online survey and two field experiments to fully understand the problem space that avalanche companion rescues present. Each portion of research was targeted at uncovering insights in a specific area. An online survey was used to understand the general habits, attitudes, equipment and practices backcountry users report exhibiting when in avalanche terrain. A first field experiment was used to understand the benchmark of how trained users perform in an average rescue scenario. Finally, a second field experiment tested the utility of two potential equipment changes or interventions and what, if any, effect they had on time and quality of rescue while performing an avalanche companion rescue.

Backcountry User Survey

The online survey was used to gather baseline information about winter backcountry users. Baseline data for backcountry users is not readily available and many previous studies have only used data from those who have been part of a party caught in an avalanche, since this data is collected by federal agencies[1] in post-incident reports. This data collection methodology suffers from a sampling bias because data is generally only collected when a fatality occurs[2]. Parties or individuals who only get injured, have a close call or are not injured are not represented in the usual data set, skewing perceptions of the backcountry population. This problem is well known in the avalanche safety world[3].

The survey, which was distributed using Google Forms, asked questions about the demographics of backcountry skiers, their travel practices, the safety training and practice activities they undertake and the safety equipment they use. Participants were recruited

1. In the US data is collected by the US Forest Service, in Canada this is handled by provincial governments and in Switzerland it is the Swiss Federal Institute for Forest, Snow and Landscape Research. These three countries form the bulk of data about avalanche fatalities.
2. Johnson et al., “Rethinking the Heuristic Traps Paradigm in Avalanche Education.”
3. Johnson et al., “Rethinking the Heuristic Traps Paradigm in Avalanche Education.”

primarily via location specific Facebook groups for touring skiers and splitboarders. These groups covered participants in the Northeast of the United States, Colorado, Utah, the Pacific Northwest and Alaska. In addition, the survey was sent out via email to friends and colleagues. The survey received 217 responses. The text of this survey is included in an appendix.

Field Experiment #1: Rescue Field Experiment

This field experiment aimed to understand how users performed when attempting a single-rescuer avalanche companion rescue. Participants were not provided any additional training before the experiment and were asked to follow the previous training they had received. The field experiment attempted to mimic, as closely as possible, the realities of performing such a rescue in the natural environment.

Participants were recruited from Facebook groups covering Washington state backcountry skiing and splitboarding, ski and snowboarding clubs at the University of Washington, a Discord channel for the climbing club at the University of Washington and emails to friends and colleagues.

This experiment took place at two different ski resorts in Washington State in early February. The first instance of the experiment took place at Stevens Pass Ski Resort. The venue for the experiment was located below where the I-5, Lower Diamond and Trapper trails merge. The simulated avalanche path was a rectangle approximately 60 meters (196 feet) by 150 meters (492 feet), the approximate size of a smaller R2 sized avalanche. This size was picked as an R2 sized avalanche is the most common size of avalanche that kills recreationists[4] and is also a manageable size to simulate. The experiment venue was bounded to either side by trees while the top of the slide was marked by the position of the first experimenter and the bottom was left somewhat ambiguous but marked approximately by the position of the second experimenter at the bottom.

4. Dale Atkins, "Ten Years of Avalanche Deaths in the United States, 1999/00 to 2008/09," 2010, https://arc.lib.montana.edu/snow-science/objects/ISSW_P-089.pdf.

Participants were instructed to perform an avalanche rescue, following the protocol as they remembered it and to tell the experimenters that they were done when they felt that the dummy was stabilized and ready for evacuation. Specific directions for medical care were intentionally left vague to avoid giving participants clues as to what kinds of medical care the researchers were looking for.

The first instance of this experiment had six participants.

The second instance of this experiment took place at Crystal Mountain Ski Resort where Campbell Basin feeds into the Queens run, uphill of the loading zone of Chair 6. While a great deal of effort was made to find a venue that would match the size of the area at Stevens Pass Resort, on the ground realities, regular ski traffic, a recent patrol-triggered avalanche in Campbell Basin and the low snowpack made this impossible. Instead a course with a serpentine shape was used. The start point of the avalanche was marked by the first experimenter, the sides of the slide were marked on the left by trees and the right by avalanche debris. The approximate end of the simulated slide path was marked by the second experimenter.

The second round of this experiment had five participants.

For both of these experiments, data was gathered from an action camera attached to the participants helmet to capture the participants field of view, an action camera held by the down-hill experimenter which was used to film the participant and from contemporaneous notes taken by the researchers.

Avalanche Dummy

To simulate a buried human, a rescue dummy consisting of a head, shoulders and torso was designed and constructed for the experiment. The dummy was designed to be easily transportable by a solo skier, have a usable airway and mimic the weight and maneuvering difficulty of a real human. For a head a Prestan Ultralite Manikin Head Assembly was

modified to remove some protruding plastic and add slots for straps so that the head could be attached to the torso. Extrapolating measurements from the head, a torso was designed to mimic the measurements of a 25% male[5], so that the dummy would look proportional and not startle rescuers with an incongruity in size between head and torso. The torso consists of a bag shaped to mimic a torso and shoulders with a roll closure where the legs would join the torso. A pocket was attached to the torso allowing a beacon to be stored on the bag in approximately the position that a chest harness would carry the beacon. The roll closure allows the bag to be stuffed with snow to mimic the weight and resultant difficulty of moving a person. The bag weighs approximately 25 kg (55 lbs) when filled with snow. The fabric used was from a collection of packcloth remnants, but was chosen to be tough and durable, standing up to the rigors of being dragged, pulled and prodded with avalanche probes. The form allows a rescuer to mimic common rescue motions, such as dragging by the armpits and to provide medical care, such as clearing airways and providing rescue breaths. Most current rescue training utilizes a backpack, stuff sack or strike pad. All of these can be buried with an avalanche beacon inside to simulate a buried body, but all of them are easy to move one handed and can be retrieved much more easily and through a smaller hole than even a torso sized dummy. Future developments for this dummy could include a radio in the head so that the dummy can talk to the rescuer and more intentional fabric choice that would mimic the toughness of human skin so that overly rough probing would leave a mark or show damage on the dummy.

Dummy Setup

The dummy was dressed in a one piece ski suit and buried in a hole approximately 3.3 feet (1 meter) deep, corresponding with the average depth of an avalanche burial[6,7]. The dummy was equipped with a BCA Tracker 1 avalanche beacon stored in a pocket on its front chest. 59% of respondents in the Backcountry User Survey carried their beacons in a chest harness

5. Alvin R. Tilley, The Measure of Man and Woman: Human Factors in Design, Rev. ed., [Nachdr.] (New York: Wiley, 2002).
6. Sonia Harvey and Benjamin Zweifel, “New Trends of Recreational Avalanche Accidents in Switzerland.,” 2008.
7. Haegeli et al., “Comparison of Avalanche Survival Patterns in Canada and Switzerland.”

or in a front pocket on their bibs, so this was picked as a realistic and easy to implement location for the beacon.

In the hole, the dummy was positioned with its head down hill, face down. This position is the most common position avalanche victims are buried in[8]. As described in Kornhall et al., 2016, 65% of victims are buried with their head down hill and 45% are buried face down. Other positions (e.g. face up, facing sideways) account for 55% but face down is the most common. All told, 40% of victims are found in the head down hill, face down position, the most common of all permutations[9]. All these decisions were made to create a scenario mirroring what is most commonly found in avalanche rescues.

In the second instance of this experiment, the dummy was buried as deep as possible but due to a low snowpack, the dummy ended up being approximately 60 centimeters (24 inches) below the snow and resting directly on the dirt underneath. Aside from the differences in venue size and burial depth all other aspects of the experiment were the same.

Field Experiment #2: Equipment Intervention Experiment

After performing the first set of field experiments at Stevens and Crystal and analyzing the data, a second set of field experiments was conducted to test potential interventions and understand how they affected user behavior. Using previously defined nudge strategies to guide ideation, two pieces of intervention equipment were ultimately designed and constructed.

The first intervention was inspired by the heuristic principles of *creating friction* and *throttling mindless activity*[10]. This intervention, named the "probe quiver", consists of a quiver that can be mounted to the outside of a backpack with a blue quick release handle. When the handle is pulled the probe inside was designed to slide out due to the force of gravity. This design was settled on to force a pause in the rescue process, where after probing, a user

The Probe Quiver

8. Daniel K. Kornhall, Spencer Logan, and Thomas Dolven, "Body Positioning of Buried Avalanche Victims," Wilderness & Environmental Medicine 27, no. 2 (June 2016): 321–25, https://doi.org/10.1016/j.wem.2016.02.008.
9. Kornhall, Logan, and Dolven, "Body Positioning of Buried Avalanche Victims."
10. Ana Caraban et al., "23 Ways to Nudge: A Review of Technology-Mediated Nudging in Human-Computer Interaction," in Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19: CHI Conference on Human Factors in Computing Systems, Glasgow Scotland Uk: ACM, 2019), 1–15, https://doi.org/10.1145/3290605.3300733.

The Sled

would have to stop to retrieve the shovel from their backpack, giving them time to consider their shoveling strategy. In the process they might also take a step back due to the forces involved in taking their backpack off, setting them up for a proper shoveling position.

The second intervention, inspired by the heuristic principles of *reducing distance*, *defaults* and *positioning*[11], is a one piece tray that holds all the equipment needed for an avalanche rescue (probe, shovel and first aid kit) easily displayed and all in one place. This intervention, named the "sled", also had a handle for quick retrieval from a user's pack and informational graphics reminding users of the aspects of avalanche rescue that were frequently performed incorrectly by participants in the first field experiment. By grouping all the needed tools together, and displaying them in a way so that they were sequentially revealed, users could interact with the sled as a surgeon does with the tray that holds all the needed tools for an operation. The probe is the most visible tool, since it is used first, once that is removed and in use, a printed graphic showing proper shoveling strategy is displayed. The shovel blade and handle are the next most visible. Once the shovel blade is removed, the pouch containing the first aid kit becomes visible. The pouch containing the shovel blade displays a graphic for post avalanche medical care adapted for lay responders. These medical suggestions follow the most recent post-avalanche medical treatment recommendations made by the International Commission for Alpine Rescue's (ICAR) Medical Committee[12] as well as those advocated in Aurbach's Wilderness Medicine[13]. These treatment recommendations take the form of an algorithm or flowchart that medical practitioners can use to guide their decision making. However, both algorithms make extensive use of equipment and techniques outside the scope of what an average skier can be expected to carry or know, such as esophageal thermometers and using an ECG to diagnose heart arrhythmias. In the Backcountry User Survey only 4.4% of respondents were doctors or nurses capable of carrying out these recommendations. The recommendations of the updated algorithm removed medical care outside the scope of a lay rescuer or that required equipment not

11. Caraban et al., "23 Ways to Nudge."
12. M. Pasquier et al., "On-Site Treatment of Avalanche Victims: Scoping Review and 2023 Recommendations of the International Commission for Mountain Emergency Medicine (ICAR MedCom)," Resuscitation 184 (March 2023): 109708, https://doi.org/10.1016/j.resuscitation.2023.109708.
13. Grissom et al., "Avalanches."

commonly carried on trips in the backcountry.

Both of these interventions were tested at a small slope at Snoqualmie Pass of about 30° slope. The slope chosen was against a cliff face, to eliminate potential avalanches by minimizing the snow area over 30° above participants at any given time. Further safety concerns were addressed by inspecting the venue two days before the experiment was to occur for evidence of potential danger from above or recent avalanche activity. No visible snow of any consequence was observed and the marks left by roller balls indicated that the area of the experiment would not be hit by any snow that did fall.

Experimental Setup

An area approximately 12 meters (40 feet) by 12 meters (40 feet) was marked with flags and the dummy was buried in a hole approximately 1 meter (3 feet) deep at the lower, skier's left corner of the simulation area. In a change from the previous procedure, participants were sent a photo of the dummy dressed as it would be so that they would be able to make sense of the limited portion of the dummy that is visible when initial contact is made. In a real world rescue, a rescuer would have knowledge of the backpack and clothing their companion was wearing before they were buried, and this change was done to mirror that. Participants began at the upper, skier's right corner of the simulation area where they were briefed by one of the experiment personnel, fitted with an action camera and had the probe quiver fitted onto their backpack and turned on their avalanche beacon.

Experimental Procedure

Once a signal was acquired they began the avalanche companion rescue procedure. They were filmed by a second experimenter from the bottom. After completing the search and probe sections of the avalanche rescue the second experimenterl allowed them to assemble their shovel and begin to dig before stopping them before the participant moved their first

shovel of snow. By stopping the participant at that point it could be determined if the probe quiver had any effect on their positioning and shovel strategy without using up too much of the participants' time or exhausting them prematurely. After this portion of the experiment was stopped, the participant was quickly debriefed before the experiment continued.

The participant's avalanche equipment was transferred to the sled which was given to the participant to put in their backpack as they saw fit. The probe quiver was removed and they hiked back up to the first experimenter. The participant's camera was restarted and they were told to turn on their beacon again. Once the beacon had picked up a signal, they began a second simulated rescue. After using the beacon to locate the dummy, the participant would either partially or fully remove the sled from their backpack to access the tools according to personal preference. The participant was not told a particular way to use the sled. The participant then continued with a regular companion rescue, retrieving tools from the sled as needed. After they had unburied and provided simulated medical care to the dummy the experiment was concluded and they were debriefed.

Data/Discussion/Insights

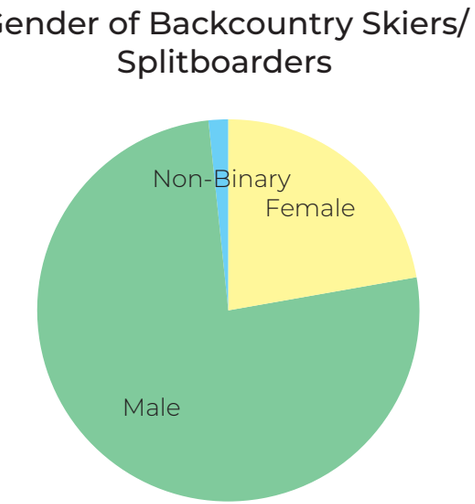
Results of each study or experiment were analyzed in a waterfall style, whereby the results of a previous experiment were used to inform the design of the next experiment. To reflect this sequentiality, results and their discussions are presented in the sequence of the experiments they were derived from.

Survey Results

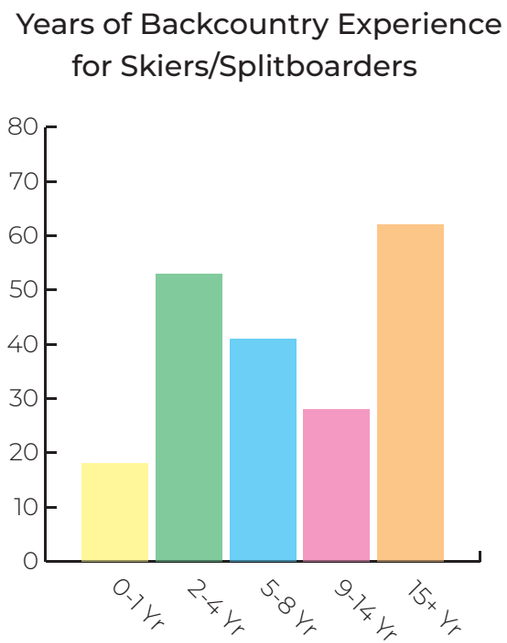
Once submissions for the survey were closed, the data was cleaned and analyzed. Firstly, although options for different modes of travel on snow (nordic skis, snowmobiles, snow shoes, skis and snowboards) were provided, only data for skis and snowboards contained enough participants to be statistically significant or informative. In total 202 participants were included in the final survey analysis.

Gender

The data on participants' gender suggests that the sport is relatively male-dominated though with a significant female participant population. This data has interesting implications for a number of aspects, but one in particular stands out. McCammon notes that women have a lower chance of getting caught in an avalanche[1]. However, as Johnson et. al., pointed out this could easily be a conclusion caused by sampling bias since McCammon's conclusions are drawn from avalanche fatality reports[2]. Since 75.7% of participants in the survey are male, it would follow that if avalanche fatalities are randomly distributed among the population approximately 75% of fatalities would also be male. However, McCammon's main conclusion that men in mixed-gender parties have a higher fatality rate[3] deserves continued exploration.



1. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."
2. Johnson et al., "Rethinking the Heuristic Traps Paradigm in Avalanche Education."
3. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."



Years of Experience in the Backcountry

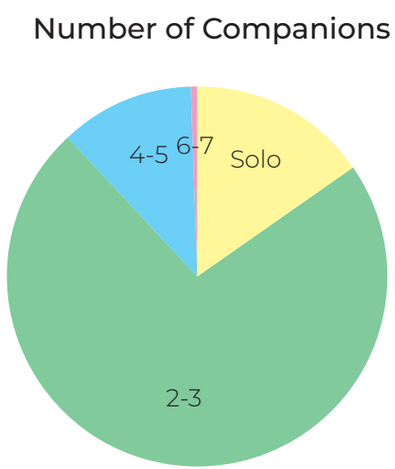
Arranged as a bar graph, the data on how many years participants had been recreating in the backcountry presents a bimodal distribution, with some interesting possible conclusions to explain what can sometimes be an indication of anomalous data. The first is that while the years of experience bands were taken from McCammon, 22 years have passed since his paper was written. It is possible that using 15+ years as an ending catch all is no longer appropriate and squishes what could be a long tail into an inappropriately large bucket. There is also potential influence from the recruitment methodology. The demographics of Facebook, and specifically backcountry skiing/splitboarding groups, could increase the number of respondents who have more than 15 years of experience in the backcountry, since older skiers or splitboarders are more able to have accumulated more years of experience. It is also possible that the influx of participants who began backcountry skiing during the pandemic are increasing the number of respondents in the 2-4 year category. Finally, while the research is slight, people do not always stick with hobbies, with one study identifying a drop off of 16 months[4]. It is possible that the data reflects this drop off over a longer scale with the spike at 15+ years capturing those for whom backcountry skiing/splitboarding "stuck". This data, combined with knowing when someones' last avalanche class was taken, can tell us interesting things about an individual's contact with continuing improvements in avalanche forecasting and rescue technique.

Days in the Backcountry per Season

Tremper, among other authors, has identified that the chance of experiencing an avalanche injury or fatality is a function of exposure[5]. Those who frequently recreate in the backcountry will likely eventually encounter an avalanche, while those who infrequently travel into the backcountry could spend their entire career without seeing one[6]. While

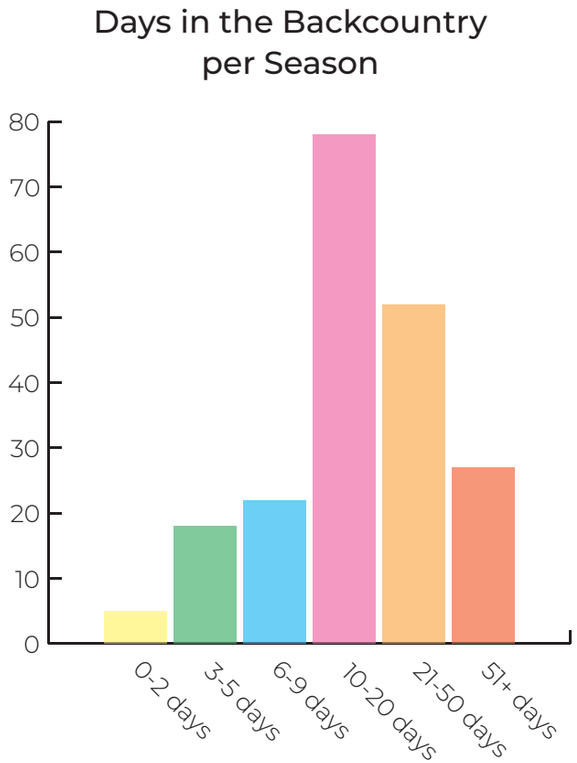
4. Jennifer Mitchell, "All the Gear, No Idea! Britain's Hobbies Have a Shelf Life of 16 Months," British Heart Foundation (blog), January 15, 2019, https://www.bhf.org.uk/what-we-do/news-from-the-bhf/news-archive/2019/january/britains-hobbies-have-a-shelf-life-of-16-months.
5. Tremper, Staying Alive in Avalanche Terrain. p. 20
6. Tremper, Staying Alive in Avalanche Terrain. p. 20

there is a possibility that the recruitment pool disproportionally reached those who recreate more in the backcountry, i.e. those who frequently recreate are more likely to join Facebook groups related to this activity, these numbers indicate that most participants spend a fair amount of time each year in the backcountry and thus expose themselves to a great deal of potential avalanche danger. This data also appears to support an initial hypothesis that the time participants spend on their chosen activities often preclude the rigorous training that are often thought necessary to practice and then carry out complex skills[7]. Making a number of back of the envelope calculations, if the average ski season lasts from December 1st to March 31st there are approximately 17 weekends for a skier or splitboarder with a normal full time job to ski. Because the majority of skiers or splitboarders are around the 20 days in the backcountry per season mark (in bounds ski days would also be in addition to this) this would indicate there is little extra time per season for additional training. Further safety solutions must be training agnostic to fit into the ski and splitboard population.

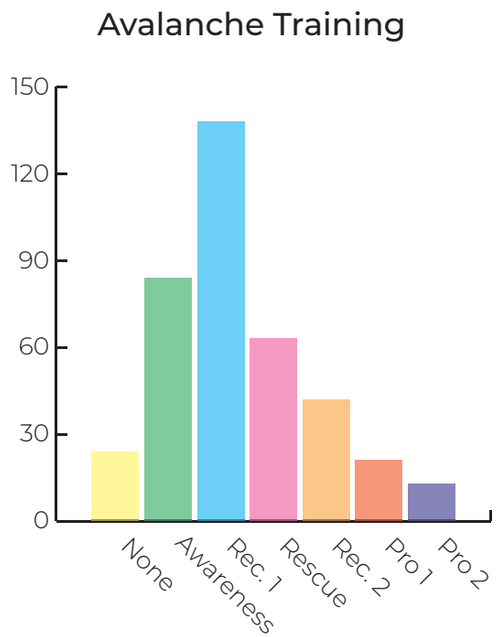


Number of Companions

Experts roundly discourage solo travel in the backcountry. If someone is buried in an avalanche, even with an arm or head exposed, it is almost impossible for them to rescue themselves. Rescue requires, at minimum, a second, unburied person who can rescue a buried victim from under the snow. However, from comments about location and the timing of survey deployment to different Facebook groups, it appears that most respondents who reported skiing solo were located in New England. Most terrain in New England, with the exception of



1. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."
2. Johnson et al., "Rethinking the Heuristic Traps Paradigm in Avalanche Education."
3. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."



a few mountains like Mt. Washington and Kahtadin, is not avalanche terrain due to slope angle and heavy tree cover. One participant reported "Vermont woods skier who is rarely in avy terrain/conditions... Biggest hazard is getting wounded by a tree or submerged branch and freezing to death in the woods."

However, except for the solo participants, it can be surmised that either one or both of the following are true. One is that McCammons finding that larger groups tend to be less safe[8] has widely disseminated, integrated into avalanche education and taken to heart and the recreationist choose to travel with smaller parties. Secondly, it could likely be difficult to organize a ski tour with large numbers of people, causing people to travel with fewer companions. Either way this is a positive development, subsequent studies have confirmed McCammon's results with different methodology[9].

While a smaller group is beneficial from a decision making and safety point of view, after an avalanche having more people to dig will speed recovery of the buried victim, increasing survival odds. There is an inherent contradiction in this, larger groups are more likely to have a member caught in an avalanche, but are better able to successfully rescue that buried member. This survey shows that most skiers or splitboarders choose to ski with a small group, further emphasizing the need for equipment that improves rescue strategy while in the backcountry.

Avalanche Training

The vast majority of respondents had taken at least some level of avalanche rescue training. Only 11.8% of respondents reported having no avalanche training. While there have been some debates about the efficacy of avalanche training[10], and few studies have examined its effectiveness with regards to rescues[11], most authors agree that some training is better than none. In addition, a wide penetration of recent training into the backcountry community allows for the dissemination of pertinent rescue techniques which cannot easily

8. McCammon, "Heuristic Traps in Recreational Avalanche Accidents: Evidence and Implications."
9. Benjamin Zweifel et al., "Risk of Avalanche Involvement in Winter Backcountry Recreation: The Advantage of Small Groups," Wilderness & Environmental Medicine 27, no. 2 (June 2016): 203–10, https://doi.org/10.1016/j.wem.2015.12.001.
10. Dave Richards, "Avalanche Education: Are We Teaching Confidence Over Competence?," August 20, 2020, https://theavalanchereview.org/avalanche-education-confidence-over-competence/.
11. Derek Bain, "The Effectiveness and Retention of Minimal Transceiver, Shovel and Probe Companion Rescue Training," in International Snow Science Workshop Proceedings 2018, Innsbruck, Austria, 2018, 1421–24.

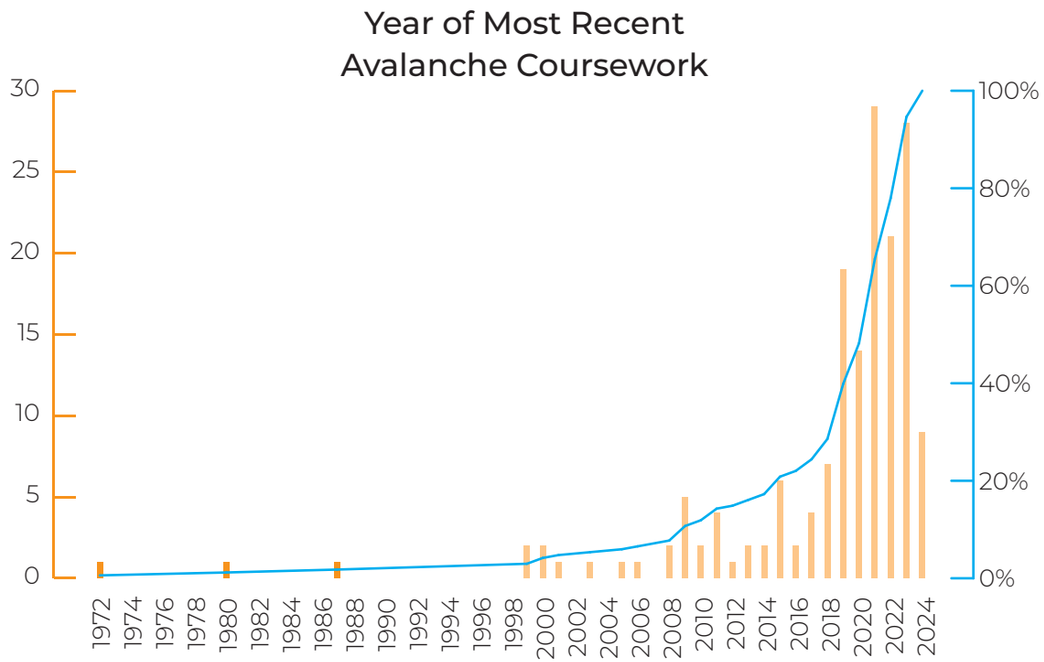
be gleaned or practiced without professional supervision. Finally, this data is interesting in that it confirms that cultural forces[12], in absence of a legal mandate, are sufficient to encourage a population to seek out sufficient training.

Year of Most Recent Avalanche Coursework

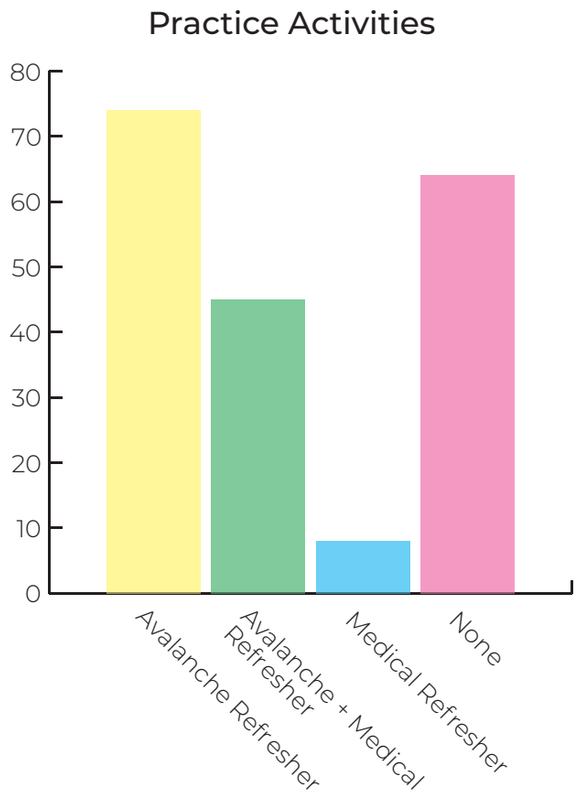
While some interesting outliers existed, e.g. one respondent noted the last avalanche course they took was in 1972, the majority of respondents had taken some form of avalanche coursework in the last 3 years. Combined with the data about how long people have been participating in backcountry sports, it can be surmised that most skiers and splitboarders take regular refresher classes or further coursework to either keep their avalanche skills sharp or continue their educational path. This data suggests that, beyond the solutions suggested in this thesis, educational curriculum changes could be effective as they will reach the majority of backcountry users relatively quickly.

Current Medical Certifications

While some respondents had Advanced Medical training, a plurality had either never had any medical training or had taken medical training that was no longer valid, many wilderness medicine classes are only valid for two years. As many authors have pointed out, an avalanche is a traumatic medical event[13]. The ability to clear an airway, assess broken limbs and start CPR are essential once a person is dug out of the snow. While it is possible that many of those



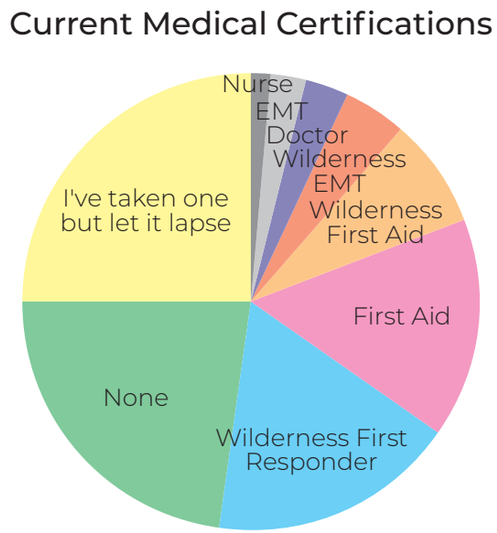
12. Abigail Barronian, "Can You Learn Avalanche Safety Online?," Outside Online, March 7, 2021, https://www.outsideonline.com/outdoor-adventure/snow-sports/online-avalanche-safety-course-mark-smiley/.
13. Michael D. Grossman et al., "Avalanche Trauma:," The Journal of Trauma: Injury, Infection, and Critical Care 29, no. 12 (December 1989): 1705–9, https://doi.org/10.1097/00005373-198912000-00021.



14. Welch, MD, "Woof(Er), Woof(Er): The Wilderness First Responder Dog and Pony Show."
15. Welch, MD, "Woof(Er), Woof(Er): The Wilderness First Responder Dog and Pony Show."

with expired medical certifications would be capable of performing these interventions, this does not seem to square with current understanding of medical pedagogy[14].

In comparing the training level and currency of medical education with the training level and currency of avalanche education a wide gulf presents itself. While most respondents possessed recent training in avalanche rescue and avoidance, this did not carry over to medical education. Perhaps in an effort to get as many people trained in avalanche education as possible, the medical side of the equation has been missed or de-emphasized in a way that leads recreationists to not seek this training.

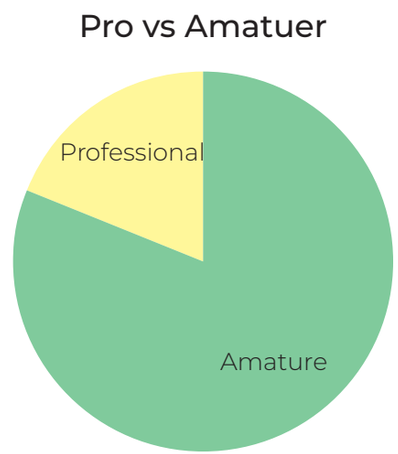


Practice Activities

Avalanche courses often emphasize the importance of repeated practice for rescue skills. and it appears that this message has been taken to heart. More than half of the respondents indicated that they do some level of avalanche skills refresher though what this entails can vary somewhat. In addition, a quarter indicated they do some level of medical skills refresher. As has been brought up before in debates about current paradigms of medical outdoor medical education, class work every two years is not generally thought of as appropriate for a perishable skill[15]. In addition, of the 38 respondents who reported working in some capacity with avalanches or travel in the backcountry, 24 of them reported taking some

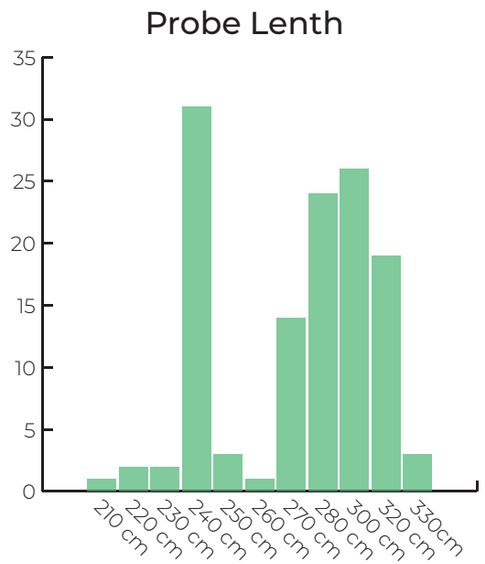
form of medical refresher, accounting for almost half of the total respondents who reported taking medical refreshers.

There is a known protocol for avalanche rescue practice that can be practiced without supervision or unique equipment. An avalanche burial can be simulated by burying a backpack with an avalanche beacon in it and having a friend search for it; many survey respondents reported doing exactly this for their avalanche practice. However, there is no standard way to practice medical skills. As should be obvious, even the abbreviated skill set of Wilderness First Aid is complex and difficult to practice without oversight, but post-avalanche medical care could be simplified and codified to the extent that it is both teachable during avalanche rescue education as well as practicable without professional oversight.



Pro vs Amatuer

About 18% of respondents indicated that they work in some capacity as a professional in the snowsport industry. This could include mountain guide, ski patroller, avalanche forecaster and could include those who work as volunteer ski patrol. While the difference in other aspects of the questionnaire between professional and amateur were not fully explored, the number of people reporting that they work in some capacity as a snow industry professional appears unusually high compared to the general population. This suggests a number of interesting possibilities. The first is that a larger percentage of the skiing population has some degree of professional experience, very believable with a large number of volunteer ski patrol who work only a few days a week (increasing their total numbers). The second is that the recruitment methodology over-recruited those with professional experience.



16. Probes shorter than this are not allowed under the new UIAA Regulations and no longer produced.

Probe Length

Probe length, while initially captured by the survey for data for the backpack design, revealed some surprising insights when the data was graphed. Manufacturers generally produce probes in 240cm[16], 270cm, 300 and 330cm lengths. As a human-powered sport where the largest share of time is spent traveling uphill, skiers and splitboarders are very cognizant of the weight they carry. While a longer probe is often seen as safer they weigh more and so represent a trade off between perceived safety and general comfort.

240cm was the most popular probe length, and once uncommon probe lengths were removed from the data set, increased lengths were increasingly unpopular. However there was some local variation due to snowpack characteristics. One respondent mentioned that they carry “ortovox longest one they had because WA”, referencing the famously thick Washington snowpack, which can bury people deeper than elsewhere in the US. On the other hand some carried very short probes writing “Various 180-220[cm]. Stats aren’t good for burials over 2m and I don’t think it’s cuz people don’t carry 3m probes”.

First Field Experiment Results

Participants

The first field experiment consisted of 11 people total. Attempts were made to replicate a representative sample of the skiing/splitboarding population though all participants were required to have completed a level one avalanche course so that a basic knowledge of avalanche rescue would be guaranteed. Of the 11 participants in this experiment, three were women and eight were men. Two were splitboarders, and nine were skiers. While all had a Recreational Level 1 avalanche certification, two had also taken Recreational Level 2 and two had taken Avalanche Rescue. Seven had taken no medical education or let their certifications lapse, one was current on Wilderness First Aid, two were current Wilderness First Responder and one was an EMT. Three participants had 2-4 years of backcountry experience, three had

5-8 years of backcountry experience, three had 9-14 years of backcountry experience and two had more than 15 years of backcountry experience. Every season, eight participants reported recreating 10-20 days in the backcountry, while one participant each reported recreating 3-5 days, 21-50 days and 51+ days in the backcountry.

Location

The experiment location at Stevens Pass Ski Resort mimicked a standard D2 avalanche path fairly accurately.The noted slide location was rectangular and pointed directly downhill, matching the approximate desired dimensions of 60 meters wide and 150 meters down slope. In addition, the depth of snow allowed for a standard burial depth of the dummy at approximately 1 meter. The results for Stevens Pass Ski Resort are displayed on the next page.

The experiment location at Crystal Mountain was less standard in layout. Due to a low snowpack, lift closures and even a recently triggered avalanche, the simulated avalanche path at Crystal Mountain Ski Resort was a serpentine shape with a low slope angle. While more unusual in shape, this simulated avalanche path could easily reflect an avalanche that swept through a gully. The results for the experiment at Crystal Mountain Ski Resort are displayed on the next page spread.

Discussion of First Field Experiment Results

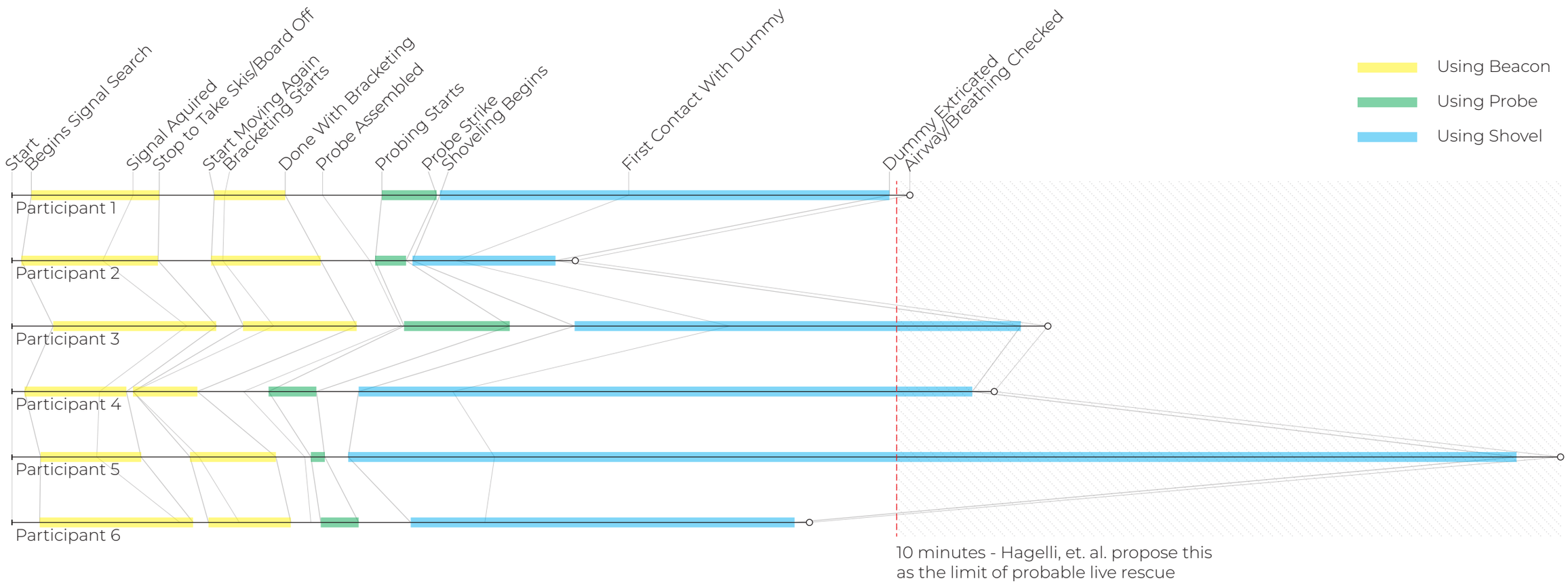
The first field experiment provided a wealth of information about participants' real world performance in a single person avalanche companion rescue. In general, participants were able to remember and accurately follow the steps of an avalanche companion rescue without pauses or appeals to experiment personnel for reminders. Portions involving an avalanche beacon went especially smoothly, most likely due to the interactive nature of the beacon and the prompts that it provides. Judging distances was consistently difficult for

Results from Steven's Pass Ski Resort

–Participants 1 and 2 assembled shovel and probe at the same time

–Participants 3 and 4 were on splitboards

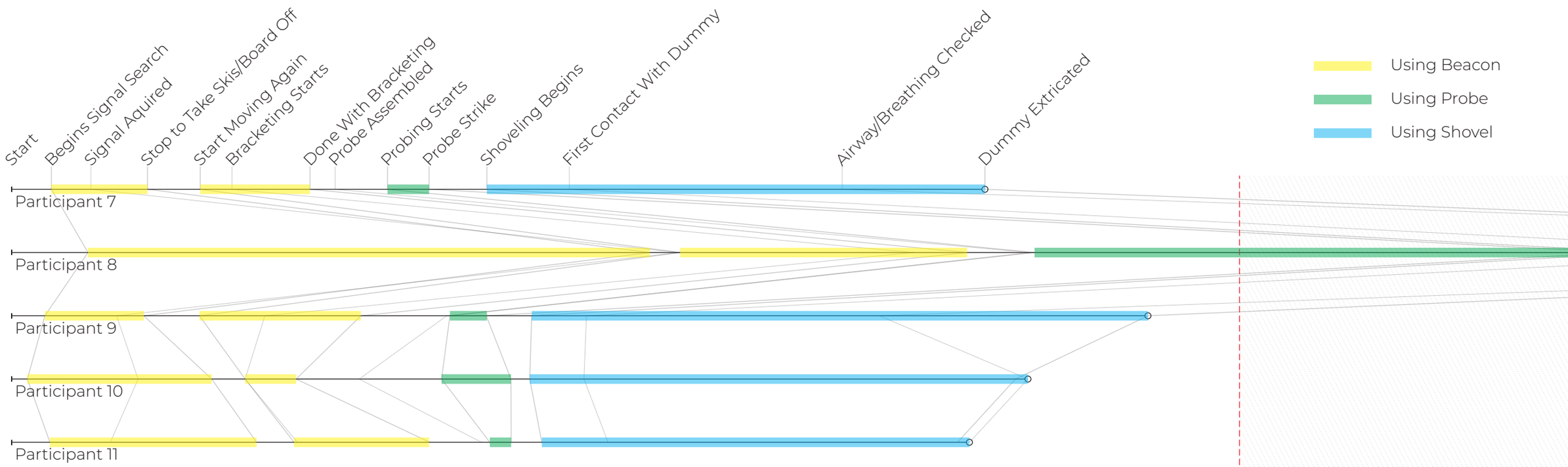
-Average probe depth was 89 cm



Results from Crystal Mountain Ski Resort

–Participants 8 was using a BCA Tracker 1 Beacon

- Average probe depth was 42.5 cm



10 minutes - Hagelli, et. al. propose this as the limit of probable live rescue

participants. Current recommendations are that during the signal acquisition portion of the search, rescuers ski almost the width of the slope leaving a buffer of 20 meters on either side as well as descending 20 meters with each traverse. In practice, either participants forgot these measurements or had difficulty judging 20 meters and so skied almost the entire width of the slope. Exact distances are difficult to ascertain without having the participants wear a GPS tracker, but it appeared from observation that traverses descended about 20 meters at Stevens Pass Ski Resort. At Crystal Mountain Ski Resort, where distances and the search area were more constrained, participants were able to effectively cover the entire search area while having to invent a coverage pattern on the fly. Lyra Perotti, the co-experimenter at Stevens Pass Ski Resort and an AIARE instructor and AMGA/IFMGA guide, mentioned that even many guides have difficulty accurately estimating larger distances like this. This difficulty was not solely restricted to large distances. Probing should follow an expanding grid or spiral system with 25 cm (10 in) between each probe strike. All participants were inconsistent with placement and distance with their probe strike, both not meeting the published standard as well as not keeping consistent distances with their rescue. In addition, participants consistently failed to keep the avalanche probe perpendicular to the slope. However, despite probe searches that did not follow published guidelines, all participants were able to quickly find the buried dummy, with the exception of a participant whose probe was not properly assembled and continually fell apart. It appears that poor performance in this area has minimal impact on the ability to locate a buried victim. Participants at Crystal Mountain had more difficulty identifying the victim than participants at Stevens, most likely because of the low snowpack. The dummy at Crystal Mountain was buried against the ground which left only a difference of about 30 cm (12 in) between a ground strike and a body strike. Participants at Crystal were able to locate the dummy but slightly slower and with less confidence than participants at Stevens Pass.

Both the act of shoveling and the strategy users employed presented major difficulty.

Shoveling itself is difficult and with only a single rescuer is exhausting. While there is no way to make moving such a large quantity of snow easy, using proper shoveling strategy makes it somewhat easier by providing a flat surface to sweep the snow backwards on. However, many participants dug holes straight to the location of the dummy which were not large enough to extract the dummy and proved more exhausting due to the need to haul snow up and out of the hole. In debrief discussions with these participants, they mentioned that digging a small direct hole had worked before during practice scenarios where the object buried was no larger than a small day pack. Perotti referred to this as “scenario-itis”, where a rescuer reverts to the strategies that were successful during their practice sessions. During practice sessions, an avalanche victim is commonly simulated by burying a small stuff sack or a backpack with a transmitting beacon inside. In scenarios like this, a small tunnel is effective at retrieving the buried objects. Backpacks, with their multitude of straps and handles, can be especially easy to retrieve through a small tunnel. This is not possible with a human. The buried victim will likely still have skis attached or limbs in a disadvantageous position and may not be easily extracted from the snow.

In addition to digging holes too small, participants dug too directly towards the point of the probe. Current best practice argues for digging towards a point slightly in front of and below the probe tip as well as digging a wide bench into the snow. The wide bench allows for victims to be slid out of the snow rather than drug up and out of a hole as well as providing a surface on which to perform CPR or other necessary medical care.

After the dummy was extricated, medical care was generally quick and substandard. For this experiment, snow was placed in the dummies mouth and a small abrasion was drawn onto the dummies cheek. Many participants vocalized that they were checking the airway, but did not actually check the airway. In addition, many participants did not fully unzip the dummies hood and so did not realize there was an abrasion on the cheek. This substandard care was not universal. Two participants, one a current EMT with a background as a ski

patroller and one with a background in college outdoor education both provided excellent medical care, conforming to the general standards of a Wilderness First Responder initial assessment.

Second Field Experiment Results

Participants

The second field experiment consisted of seven people. Attempts were made to replicate a representative sample of the skiing/splitboarding population, though significant difficulty populating the study was encountered and the participants represented more of a convenience sample than a representative sample. Of the seven participants, two were women and five were men. Two were splitboarders and five were skiers. Six of the participants had a Recreational Level 1 avalanche certification, two had also taken Recreational Level 2 and one had taken Avalanche Rescue. One participant had received avalanche education through a basic alpine climbing course. All participants had some level of current medical training, one was a Wilderness First Responder, two had taken Wilderness Medical Training, one was an EMT, two were doctors and one had taken WFR equivalent coursework through the National Ski Patrol. Five participants had 2-4 years of backcountry experience, one had 5-8 years of backcountry experience and one had more than 15 years of backcountry experience. Every season, four participants reported recreating 10-20 days in the backcountry, two participants reported recreating 6-9 days in the backcountry and one participant reported recreating 3-5 days in the backcountry.

Discussion of Second Field Experiment Results

Quiver

The probe quiver seemed to have no effect on participants' thought process or decision

making beyond annoyance when it didn't work. Most participants were able to adapt to the new component of the rescue, only one participant forgot to utilize it and took their backpack off as normal. However, once used they returned immediately to their prior rescue pattern. All participants mentioned that they did not find it useful and saw it as an impediment to the rescue process. In addition, when footage of their performance was reviewed, no pause or outward indication of strategy consideration was observed, the desired outcome of this design. While more testing is needed, this could indicate that participants are in a sort of flow state, able to adapt to circumstances in front of them but otherwise "in the zone" and impervious to attempts to change their behavior

Sled

Participants were more receptive to the sled and it was enthusiastically received by a participant who had a backpack that was not designed for Backcountry skiing and so did not have a compartment for avalanche tools. Participants mentioned that the layout of the sled mimicked the general layout of existing pockets for avalanche tools, indicating that a sort of familiarity helped with adoption. However, one participant who worked as a Volunteer Ski Patrol, disliked that the first aid kit was hidden behind the shovel. They noted, correctly, that a first aid kit has utility outside of avalanche rescues and that it should be carried in a spot where it would be accessible for other scenarios. Observations of the participants revealed two different use flows for the sled. Three of the participants left the sled in their backpack, using it almost entirely like the existing avalanche tool pockets. Four of the participants removed the sled and placed it at a convenient location for them to work from, reaching over to grab tools as needed.Shovel strategy was not affected by the sled, no participant was observed to struggle with using it nor mentioned that it was difficult to select the proper tool. Finally, participants often acted with surprise when the reminder graphics were pointed out to them. It appears that in the tunnel vision of trying to perform an avalanche rescue they had missed these nudge strategies entirely.

Overall Results and Discussion

While from the start this thesis aimed to improve equipment used in avalanche rescue, the specific understandings and takeaways from the research straddles the worlds of education, training and equipment design. The following are the most important specific takeaways from this research:

Participants with modern beacons were able to quickly and accurately search, locate and bracket the signal, with only small deviations from correct procedure. While this exemplary performance is likely due to the continually updated information that a beacon provides, non-prompted actions like removing skis at the 10 meter mark were still performed correctly.

The ability to judge distances not related to the human body or an object the user was carrying was extremely poor. For protocols like avalanche rescue, relating all pertinent distances to familiar objects such as ski or boot length would likely improve compliance.

No probe search matched the procedure, however there was no noticeable time lag compared to probe searches done by the book. Most confusion arose not in the x and y directions but in the z. Searchers were most able to accurately locate a body when the ground or other buried objects were more than about a meter below the body.

Poor shoveling strategy was most directly related to longer rescues and more difficult recoveries. Given the findings of Kornhall et. al., proper shoveling strategy is more likely to reach an airway quickly. In addition, proper shoveling preemptively preps the scene for proper medical care be it CPR or maintaining spinal considerations. Given this, refreshing on shoveling strategy is likely to have the largest impact on successful rescues if time is limited.

Even minimal formal training is effective and allows students to perform rescues quickly and accurately. In addition, reading or talking through a procedure seems to be an effective form of refresher. This takeaway should be caveated that the avalanche rescue procedure is

relatively simple and this may not be true for more complex procedures.

Once a rescue has started, rescuers appear to be in a flow state or affected by tunnel vision. Attempts to intervene or add new information will be unsuccessful. Once a rescue begins the rescuers training is essentially frozen, attempts to impart new information should happen before the rescue begins.

Derived Principles

From the results of the survey, two field experiments as well as literature review and desk research, a number of design principles were derived. These principles are designed to be used to efficiently guide the design of products used for high-risk sports as well as any similar activity where quick action must be guided by previous training. The principles are listed on the next spread:

Six Principles of Design for Skilled Procedures

Clarity then Hierarchy

If a collection of tools needs to be used in an emergency, for example an avalanche companion rescue, crevasse rescue or cricothyrotomy, these tools need to be shown together, with all unneeded or extraneous items hidden from view as a first step. Secondly, the display of these items should emphasize the order of use or place in the procedure. While extreme difficulty should not be imposed, items not needed for safety related uses should be obscured or removed from view, even if everyday actions are made slightly more difficult.

Conscious Sequencing

Every action and interaction that is part of the procedural process must be considered in light of its ease of performance and fit in the total process. Colors, touch points and closure mechanisms must be designed to support the overall process. The sequence of using the tools carried starts with accessing the tools and ends when an emergency has concluded. This whole sequence must be considered and an object designed with a view to how it assists this entire process.

Passive Reinforcement

Learning and skill mastery is a continual process. While there is no substitute for dedicated hands-on learning, objects can provide an opportunity for reinforcement or passive learning through labeling and graphics. Labels should be specific and easy to understand, graphics should be concise and directed to a real need rather than trying to cover all bases. In this way, designed objects can work in conjunction with formal training.

Unconscious Preparation

Everyday use of an item should train users in its particular quirks and vocabulary of use. Touchpoints and opening methods should be consistent between everyday usages and emergency usage. Muscle memory for how to use an object in an emergency should be developable through everyday use. If an emergency action, for whatever reason, has to be non-practice-able, it should use a similar logic and sequence as other interactions with the same object.

Low Friction

Participants in the first and second field experiments appeared to operate in a kind of flow state, focused and zoned into the process. Because of this, attempts to interrupt the process and redirect actions failed. Products designed according to these principles should get out of the way of the users, passively encouraging proper procedure but imposing no friction on the user to achieve this.

Collective Process

All actions that a user takes should be seen as either contributing to an overall safe outcome of the endeavor or preceding an accident. The design of an item should encourage every action that contributes to safety (i.e. staying hydrated and fed encourages good decision making) while preventing accidents. Providing enough room to take appropriate equipment encourages that equipment to be taken. Interrupting the causal chains that lead up to an accident should be encouraged by the design.

Ideation/Design/Prototype

As a first step in the design process, a design brief was written, using insights gained from background reading, desk research, the backcountry user survey and both field experiments. This design brief laid out the features needed, general types of fabric and rough notion needs. The design brief is included on the next page.

With the design brief finalized and design principles defined, ideation was quick and easily directed. A number of ideas were able to be “bench tested” using the design principles and found unhelpful, before time was spent on building prototypes.

To explore form factors, pattern breaks, opening methodologies and overall appearance, quick sketches were made over printouts of existing backpacks. This allowed form to be developed quickly as well as serving as almost a conversation with the existing products on the market. Using the design brief, features were explored in isolation to refine their function and utility for backcountry skiers and splitboarders. Early on it was identified that the layout of the avalanche tool pocket was core to the success of this design. A card stock and then fabric model of the pocket was trialed and test fit with different shovel handles, probes and other items.

Bernard 32 Avalanche Backpack Design Brief

Design Brief: Embodying newly defined intuitive training principles, this pack is designed for the committed ski or split-board tourer. This pack is for standard day trips, but can expand to fit rappel gear or gear for a hut trip when demanded. It can compress for spring tours and side-country rope ducking. A smooth exterior sheds snow and reaching tree branches. Avalanche tool storage is refined and intuitive, improving performance in a rescue. An opening back-panel allows quick access to the packs contents and pouches on the hip belt and running vest style shoulder straps allow for the easy carry and retrieval of everyday essentials

Size: 32L in standard config, with ability to stretch up to ~40L and compress to ~20L

Features:

-Expandable draft collar with slick closure
-Single ice axe holder, with BD style on body retrieval
-Fleece lined goggle pocket
-Full side compression straps
-Capable of A-frame and diagonal carry
-Pouches on both hip belts
-Running vest-style shoulder straps (What about insulated pouch or tunnel?)
-Ports for hydration and radio cords
-Opening zipper back panel
-Removable helmet carry
-Storage for poles while split boarding
-Snow shedding back panel
-Whistle on sternum strap

Trends/Direction:

-Appetite for “technical” fabrics while moving beyond X-Pac and Spectra, futuristic but retro ripstop
-Increasing shows of technical mastery, complex darting contributing to next-gen shaping
-No more two-tone color schemes

Authorial Materials:

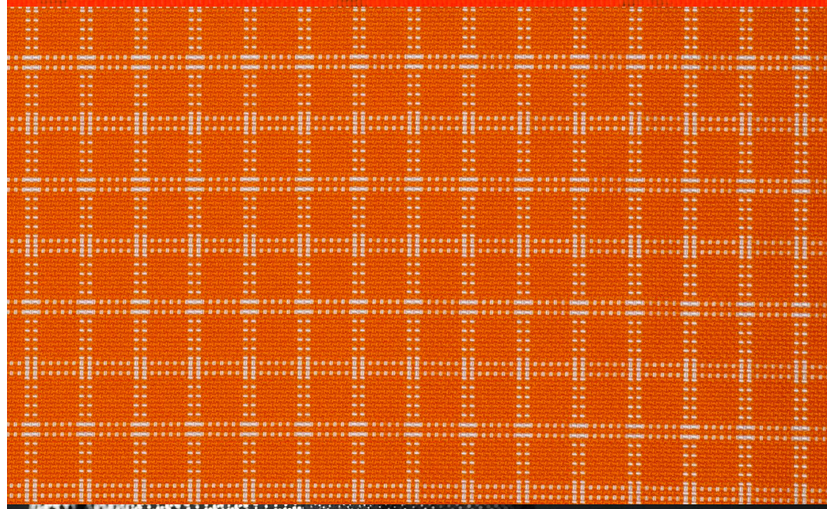
Heavy exterior fabric, laminated (~400D)
Lightweight rugged side fabric, woven (~200D)
Superlight coated for draft collar (~70D)

Authorial Notions:

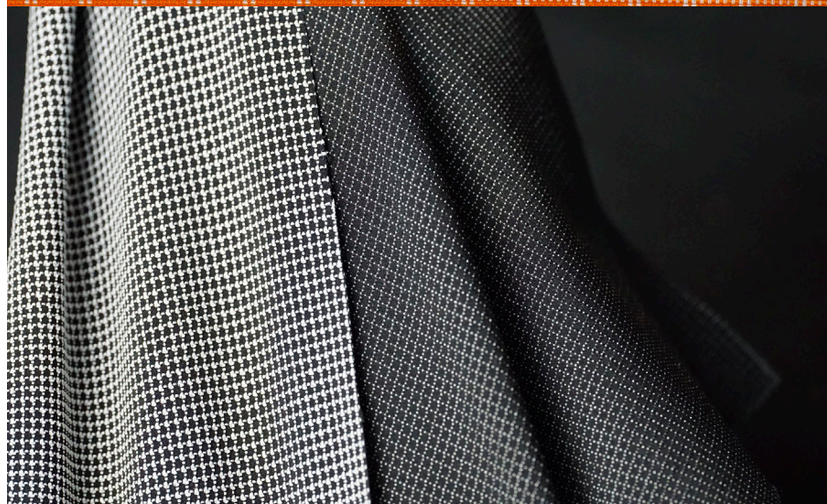
Glove friendly buckles (locking single adjust, sternum with whistle)
Low-profile double back adjusters (compression straps, load lifters, shoulder straps)

Early on in the process the fabric and notions were selected and ordered to allow for enough time for arrival. From trend analysis and conversations with industry experts some current trends with regards to fabrics were identified. These trends include a dissatisfaction with Dyneema® and X-Pac® fabrics and a wish to return to “high tech” or “futuristic” versions of traditional ripstop fabric. Many of Challenge Sailcloth’s fabrics were selected as they possessed a new twist on the traditional ripstop appearance. Buckle selection focused on utility while wearing gloves, wide selection of different types of buckles within the same style, and novelty. Duraflex GF buckles were selected, though ultimately few buckles exist on the final pack.

Challenge Sailcloth
UltraGrid

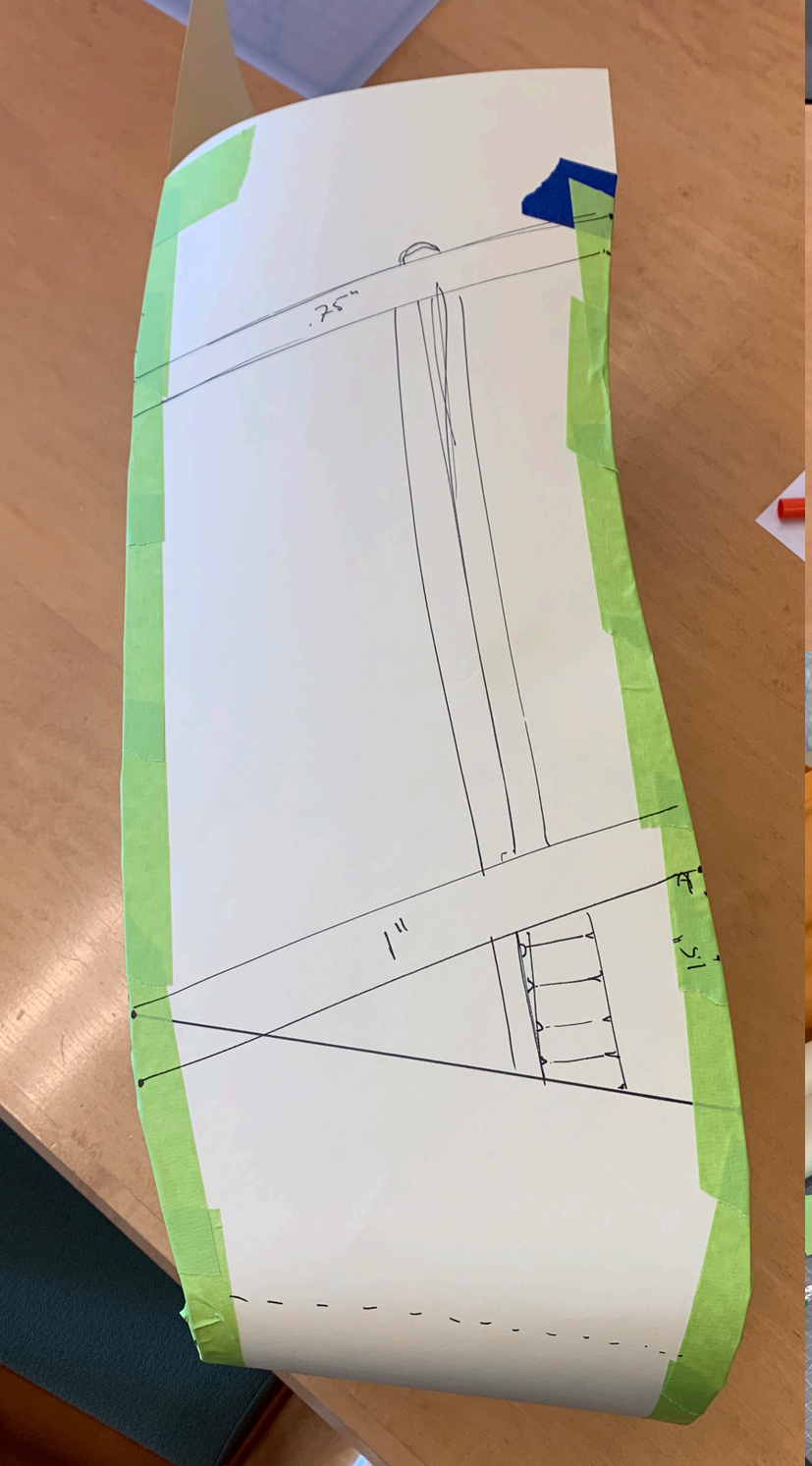


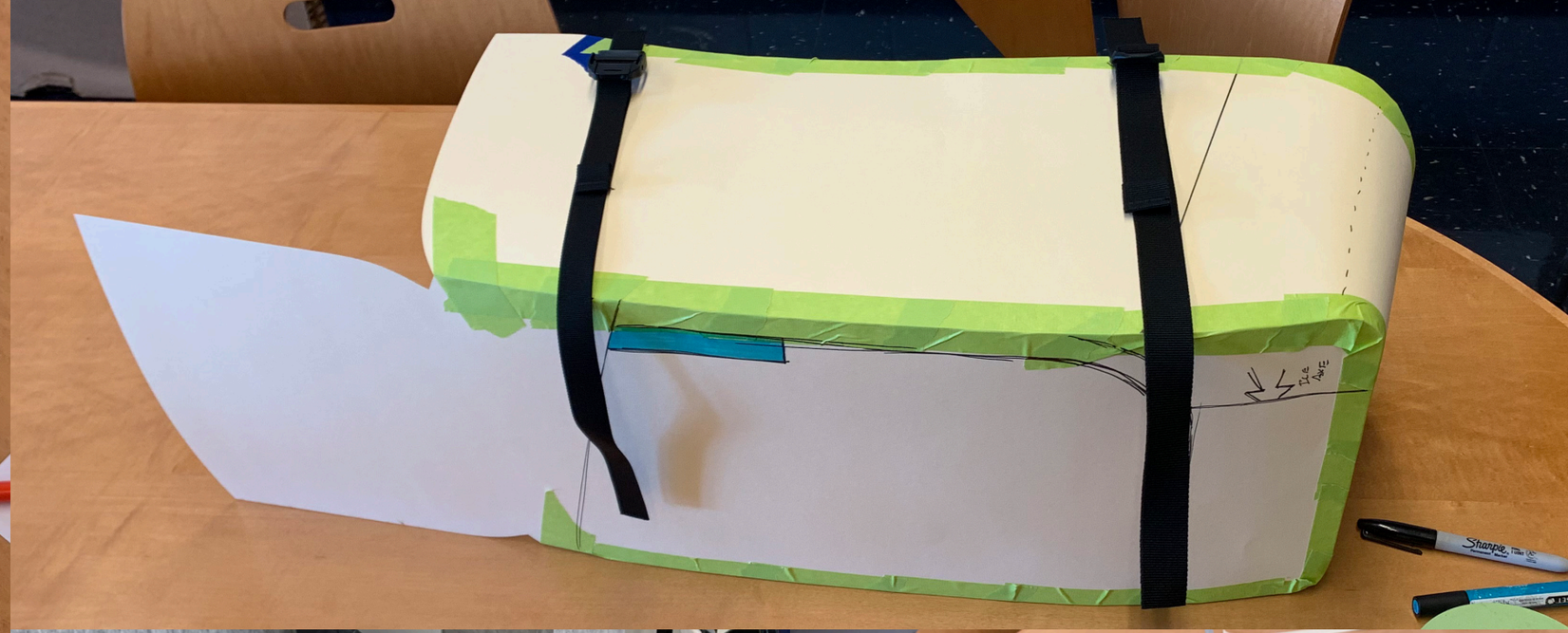
Challenge Sailcloth EPX200

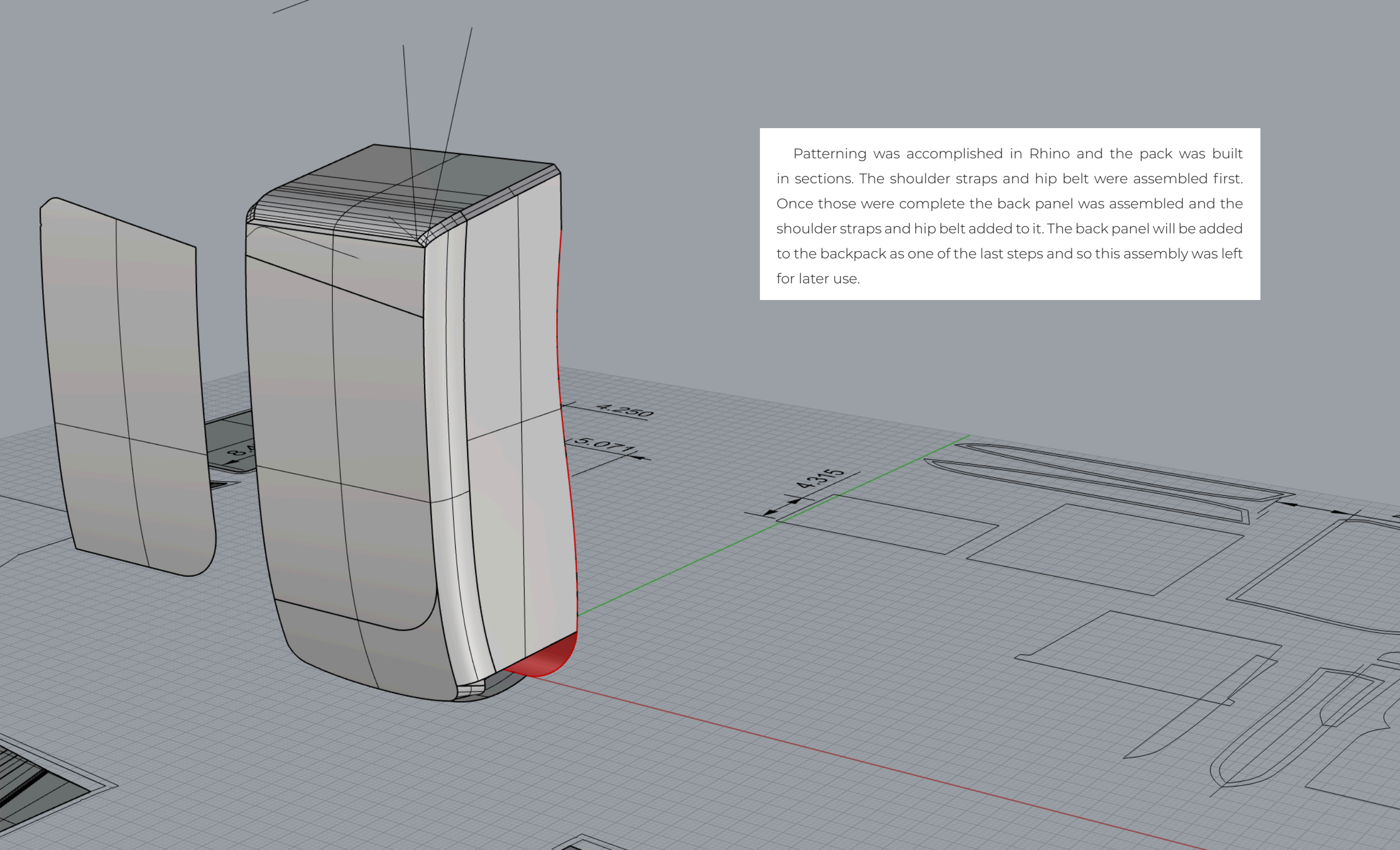


Challenge Sailcloth
UltraStretch

Once the layout of the avalanche dual pocket and details of the feature set were determined, an overall form was examined using oak tag cardboard. Early efforts focused on a pack with a rounded bottom, so shaped to avoid snagging. However patterning was difficult and the ability to fit the avalanche pocket inside was impeded, therefore this form factor was abandoned and a “ reverse tombstone” form was settled on.


.75"
1"


Sharpie

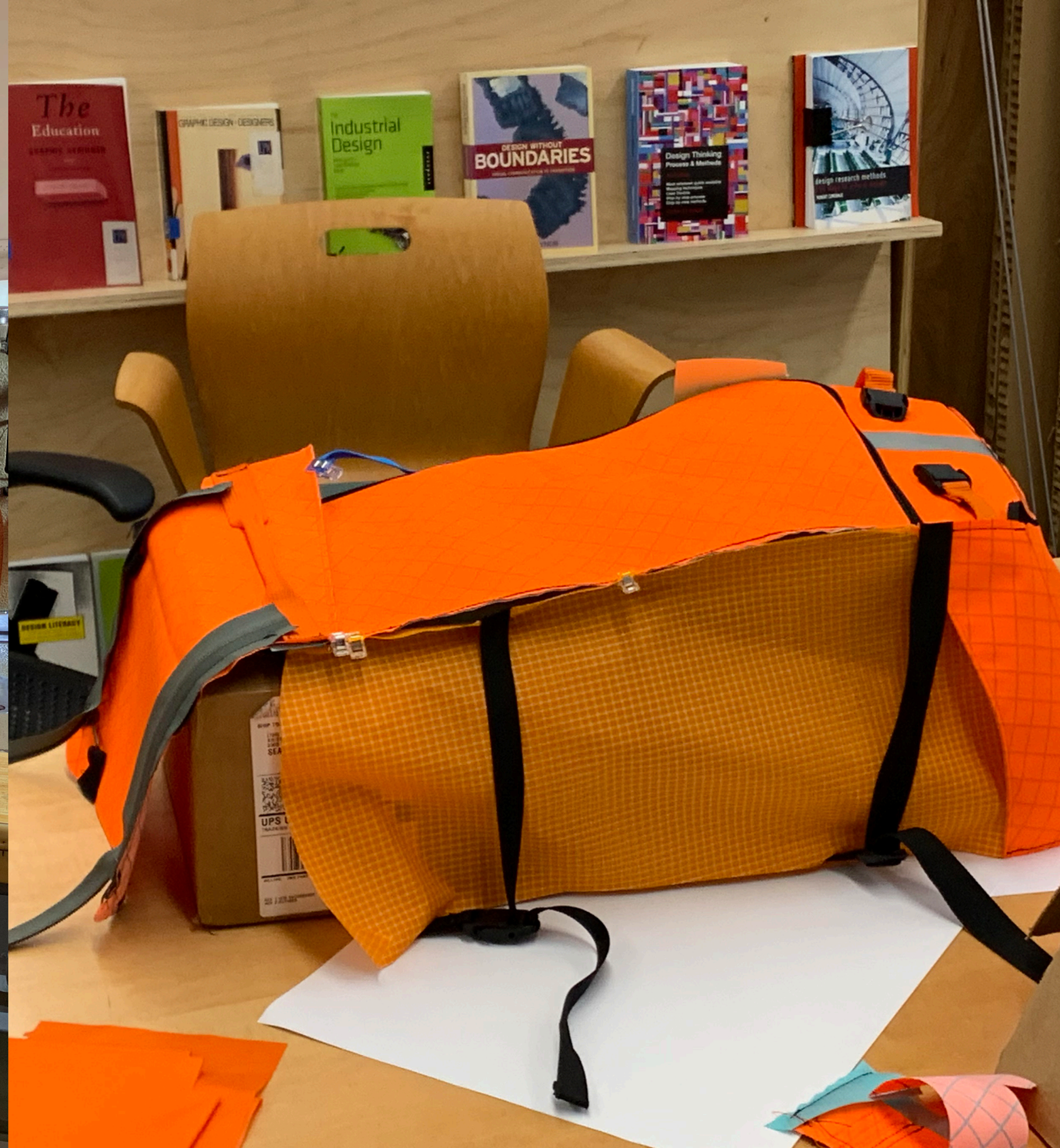


Patterning was accomplished in Rhino and the pack was built in sections. The shoulder straps and hip belt were assembled first. Once those were complete the back panel was assembled and the shoulder straps and hip belt added to it. The back panel will be added to the backpack as one of the last steps and so this assembly was left for later use.



The sides and avalanche pocket were assembled next. Then the ice tool pocket was assembled. Delays with getting printed fabric meant that the door had to be assembled slightly later, lengthening assembly. Once the proper printed fabric arrived, the door was assembled and attached to the ice tool pocket. At this point the door assembly, avalanche tool pocket assembly and sides were joined together. The third major sub assembly was the spindrift collar and lid. This was sewn together and then waited for further use. At this point the front and side assembly and the back panel were joined together and it was determined that one of the rear panels was too short. A new panel was assembled, sewn to the back and then the lid was attached. Finally the frame was inserted and sewn in place.


B


The
Education
GRAPHIC DESIGN · DESIGNERS
Industrial
Design
DESIGN WITHOUT
BOUNDARIES
Design Thinking
Process & Methods
design research methods

Final Concept

Bernard 32 backpack design combines new learnings on how users behave while performing an avalanche rescue with design choices that empower users to make safe choices and take care of themselves in extreme environments. The orange color both is attractive but also highly visible in a snowy, mountainous environment. Chartreuse is most easily visible to the human eye but often percieved as overbright or glaring. Deep red in contrast dissapears at night and in the darkness of trees, despite its color.

The pack moves with a user, a U-shaped aluminum frame and inset hipbelts allow the pack to flex and stay close to the users body during all the movements required during skiing. A svelt exterior sheds snow and reaching branches for users skiing in New England and the Pacific North West. All in all, this combines to make a backpack that is easy to use and easy to make safe decisions with.

External compression straps allow for skis to be carried in an A-frame style for sections of tours that require hiking. A loop for diagonal carry is provided, though can be removed if not needed and is not shown. A small pocket at the bottom of the side (shown but barely visible) provides storage, in concert with the compression straps, for a splitboarders poles. These poles can be retrieved without removing the backpack. Handles on the outside and against the users back are provided for handling the backpack.

Front straps provide large pockets to carry radios, snacks, phones or water flasks, keeping these tools close at hand and easy to access. the sternem strap contains a whistle so that a signaling device is always carried and accessable. Webbing on the sholder straps allows for the routing of radio cords and hydration tubing.

Accessing Avalanche Tools

A high contrast handle opens the avalanche tools pocket. Pulling on the handle starts a zipper opening. A plastic stay sewn into the pocket enables the zipper to open most of the way in one motion.

The half open avalanche tool pocket displays the avalanche probe promimenently and in a position thats easy to grab. As the probe is the first tool needed, this reinforces the procedure to the user.

When opened entirely the whole suite of avalanche tools are displayed, while a snow saw, if carried, is entirely hidden. Printed graphics allow studying while packing.

In the top of the pocket a dedicated first aid pocket both reminds users to take a first aid kit and also shows them where to locate it. Once all the avalanche tools are removed, the first aid pocket is visible, reminding users of the last, often missed, step of the rescue process.

Sholder straps pockets are postitioned to allow radios to be used without removal from the pocket, further smoothing the process of staying in communicaiton with your companions. These pockets also allow the stowage of the ends of hydration bladder tubing, protecting them from wind freezing. Webbing allows the appropriate stowage or attachment of radios, hydration tubing or other tools attached by lanyard.

Huge hip pouches hold snacks, keys, sunscreen, lib balm or anything else that must be securely held. Zippers are closed in the forward postition making them easier to close intuitively. Mirrored pockets allow for extensive storage and do away with the common, but rarely used gear loops on other packs, as these are only appropriate for glacier travel.

Keeping snacks, sunscreen and lip balm on hand reduces the friction of keeping oneself well fed and protected from sunburn. Removing annoyances like minor injuries and being well fed allows a user to make better decisions, unencumbered by distractions.

An ice ax can be retieved one handed witout taking off the pack, reducing the difficulty of retrieving and utilizing the axe when coditions dictate. By reducing the friction of utilizing the axe, users can be encoraged to use it even if it is only needed briefly

A spindrift collar allows for the backpacks volume to be expanded when neccessary. This may be needed for a trip to an overnight hut when a sleeping bag may need to be carried on the trip in only or on colder trips where a huge parka or thick gloves may be needed.

When the spindrift collar is tucked away, the zippered lid and edge bound lip form a shelf for the quick stowage of items like skins, gloves or goggles. This quick stowage allows for items to be briefly stashed if a user knows they will quickly need these items again.

Conclusion

Despite the great care and preparation that participants in high risk sports take to avoid injury and death[1], many participants feel an inevitability sense that they will loose partners and friends to the sports they love, if they have not already[2]. Chris McNamera, a big wall climber and former BASE jumper reported the increasing numbness of losing so many friends to BASE jumping accidents. He compared his outlook on BASE jumping to the viewpoint of a 90 year old, where the death of friends was expected, almost routine[3]. This is a heavy price to bear for experiences so universally cherished by their participants.

High-risk sports, through physical training, improved equipment and standardized training, have become safer over time[4]. This thesis proposes a more rigorous, evidence based method to design improved equipment that compliments existing training. However, these sports can never be completely safe, danger can only be chipped away at, like the distance walked in Zeno's Paradox[5]. The principles and results of this thesis will never make backcountry skiing or splitboarding or any other high-risk sport completely safe, instead they will, hopefully, improve the chances that these experiences remain transcendent and not fatal or injurious. No improvement can change everything, not all skiers or splitboarders will return home. But with all this effort, it is hoped that in the coming winter seasons, a few more winter recreationists will escape the forces that terrified Napoleon's army as they crossed the Alps[6]. That a few more people will escape the White Death.

1. Jamie Wheal and Steven Kotler, "The High-Tech Race to Make Deadly Adventure Sports Safe for Anyone," *Outside*, February 21, 2017, https://www.outsideonline.com/culture/books-media/high-tech-race-deadly-adventure-sports-safe-everyone/.
2. Paumgarten, Nick. "The Altitude Sickness." *The New Yorker*, March 2, 2020.
3. Adair and McNamara, "My First & Last BASE Jump."
4. Wheal and Kotler, "The High-Tech Race to Make Deadly Adventure Sports Safe for Anyone."
5. Nick Huggett, "Zeno's Paradoxes," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta and Uri Nodelman, n.d., https://plato.stanford.edu/archives/spr2024/entries/paradox-zeno/.
6. Jenkins, *The White Death*.

Appendix 1: Text for Survey Questions

Backcountry Recreation Travel, Training and Equipment

Purpose of the Survey: The purpose of this study is to understand the experience, training and equipment used during winter backcountry recreation. In conjunction with other research, this survey will be used to improve the education and equipment used in backcountry travel.

Who Can Participate: You must be at least 18 years of age and have recreated in the backcountry, when avalanches were possible, at least once to participate.

What You Will Do in this Survey: If you choose to participate, you will answer some questions about your travel in the backcountry, your training in avalanche and medical skills and the equipment you carry with you. **The survey is expected to take approximately 8-12 minutes.**

Potential Risks: It is unlikely that you will experience any risks or discomforts beyond what would be experienced in everyday life by participating.

Potential Benefits: Research participants will be contributing to the understanding of how training and equipment impact user's safety in the backcountry.

Confidentiality: The data collected in this survey is anonymous and will not be connected to your computer, identity or email address. Please do not include your name or other information that could be used to identify you in your survey responses. Information provided in this survey can only be kept as secure as any other online communication. Some data may be shared with other researchers, non-profit educational partners or presented at research conferences.

Voluntary Participation: Your participation in this survey is voluntary and you may choose to not participate or end your participation at any time without penalty.

Questions or Concerns: If you have any questions or comments about this survey, you may contact the researcher: Kristiaan Brauer at krisbra@uw.edu

Statement of Consent:

I have read this form and understood it. By selecting "Next" below, I am providing my consent by electronic means and agree to be in this study. I can print or save a copy of this consent information for future reference. If I do not want to be in this study, I can exit out of the survey.

Backcountry Experience
For the purposes of this survey, we are treating the backcountry as snow covered terrain outside the official boundaries of ski resorts or where avalanches are not controlled by ski resorts or official agencies.

What is your gender?
Male
Female
Non-Binary

About how many years have you been recreating in the backcountry?
0-1 years
2-4 years
5-8 years
9-14 years
15+ years

What is your primary form of transport in the backcountry?
Touring/Telemark Skis
Snowboard/Splitboard
Snowmobile
Snowshoes
Nordic Skis

On average, how many days a season do you recreate in the backcountry?
0-2 days
3-5 days
6-9 days
10-20 days
21-50 days
51+ days

Most commonly, how many people do you go with when you recreate in the backcountry?
Solo
2-3
4-5
6-7
8-10
11+

In the primary area you recreate in the backcountry, how would the snowpack be classified?
Please use the guide below if unsure, or note general location in the

Guide to the Three Snow Climates

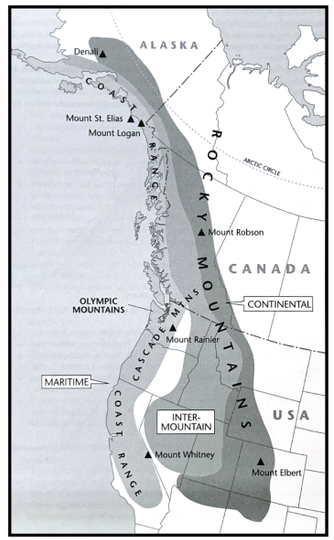


Chart adapted from Tremper, 2008

Other examples:

Maritime:
- ▸ Coastal Norwegian Range

Transitional/Inter-Mountain
- ▸ Most of the European Alps
- ▸ Northern Japanese Alps

Continental:
- ▸ The Pamirs in Tajikistan
- ▸ The Alaskan Brooks Range

"Other" box
Maritime
Transitional/Inter-Mountain
Continental
Other...

_____

Backcountry Training

Do you travel in the backcountry, ski/snowboard or deal with avalanches for work (i.e. ski patrol, mountain guide, avalanche forecaster)?
Yes
No

What avalanche courses have you taken? If you took a course before the 2017/18 split, please pick the closest equivalent course(s). Please check all that apply.
None
Avalanche Awareness
Recreation Level 1
Avalanche Rescue
Recreation Level 2
Pro Avalanche 1
Pro Avalanche Rescue
Pro Avalanche 2

What was the year you took your most recent avalanche course:
[Short answer text]

Do you have any current medical certifications:
First Aid
Wilderness First Aid
Wilderness First Responder
Wilderness EMT
I've taken one but let it lapse
None
Other...

Do you do any additional or self-initiated practice to refresh your avalanche or medical skills:
Avalanche Skills Refresher
Medical Skills Refresher
None

If you do additional or informal training, can you describe what you do?
[Long answer text]

Equipment:
For this section, please think about the equipment you would carry on a simple, single-day trip in the backcountry.
— For skiers/split-boarders, this would be a trip that does not involve rappels, ice tools or other climbing equipment nor would it be a race.
— For snowmobilers, think about the equipment you carry on your person or in your backpack, not on your sled.
— For snowshoers, think about the equipment you would carry on your most common type of trip in the backcountry.
Please be as specific as possible. Write N/A if you don't carry it or the question doesn't apply to you.

What beacon (brand and model) do you carry?
If you don't carry one write N/A
[Short answer text]

Where do you carry your beacon?
Chest Harness
Pants Pocket
Other...

What probe (brand, model and length) do you carry?
If you don't carry one write N/A
[Short answer text]

What shovel (brand and model) do you carry?
If you don't carry one write N/A
[Short answer text]

What backpack (brand and model) would you bring? If you have multiple options, please list all.
[Short answer text]

Are there any packs that you used to bring but don't any more? Why did you stop using them?
[Long answer text]

What other safety equipment do you carry? Select all that apply:
Radios
Avalanche Airbag
First Aid Kit
Separate Trauma Kit
Avalung
Satellite Communicator (InReach, PLB, etc...)
Repair Kit
Rescue Tarp
Emergency Bivy
Other...

Is there anything you would like to add?
[Long answer text]

Thank you for your time! Your responses will help shape the future of backcountry travel and education.

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