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# Human Factors in High-Altitude Mountaineering

Christopher D. Wickens, John W. Keller, and Christopher Shaw

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## Abstract

We describe the human performance and cognitive challenges of high altitude mountaineering. The physical (environmental) and internal (health) stresses are first described, followed by the motivational factors that lead people to climb. The statistics of mountaineering accidents in the Himalayas and Alaska are then described. We then present a detailed discussion of the role of decision-making biases in mountaineering mishaps. We conclude by discussing interpersonal factors, adaptation, and training issues.

*Keywords:* mountaineering, decision-making, altitude

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## Introduction

In 1996, in a now well-documented disaster (Boukreev, 1997a; Krakauer, 1997), eight fatalities were recorded in a single 12-hour period near the summit of Mt. Everest in conditions of horrible weather. Although cold and storm were obvious causes of the disaster, so too was poor judgment, particularly in pursuing the climb beyond the obvious “turnaround time,” after which a descent was pushing the limits of daylight and deteriorating weather.

In 1978, a team of four climbers reached the summit of K2 on the first American ascent of the world’s second highest mountain. Prolonged stay on the summit forced an unplanned bivouac (a benighting at high altitude with neither tent nor sleeping bag) for one of the climbers, and lethargy from high-altitude exhaustion led all four to experience additional nights at the highest camp, seriously imperiling their safety on the descent (Ridgeway, 1980). Fortunately, no lives were lost but frostbite and serious illness resulted.

In 1953 Herman Buhl chose to climb on toward the summit of Nanga Parbat, the world’s ninth highest mountain, on a solo climb so lengthy that he was forced to spend an open night above 26,000 ft (8,000 m) on his descent (Herrligkoffer, 1954). In this case he “lucked out,” and survived on an extraordinarily warm night. But more typical weather conditions that night would probably have had a fatal effect.

These three examples of questionable judgment have joined with many others to produce the relatively high fatality rate of high-altitude mountaineering, discussed below. However, of course, there are myriad decisions that have been made “correctly,” but are far less well documented. In this regard, it is valuable to consider at least one example of a judgment or decision that was clearly “right.” In 1938, the American Fritz Weisner and the sherpa Pasang Dawa Lama were within 500 ft (150 m) of the summit of K2, on the threshold of making the highest ascent ever. However, despite Weisner’s strong urge to continue, Pasang Dawa Lama assertively (and perhaps literally) “put his foot down,” refusing to continue the ascent because of the late hour. Defying pressure of the leader and his strong goal motivation for summiting, Pasang’s decision probably saved both of their lives (Kauffman & Putnam, 1993).

As co-authors, we can personally contrast the litany of decisions we have made in the mountains that have been “good” with a minority that were probably “poor,” but produced luckily successful outcomes (we are all alive, and have all of our fingers and toes). Co-author CDW, for example, pushed on during a climb on Mt. Eolus in southern Colorado, despite the deteriorating weather. Reaching the summit in lightning and sleet, he and his colleague compounded the error by fleeing down an unfamiliar face of unexpected steepness and ice, rather than retracing the known ridge route. This case of “getdown-itis” (to use the aviation term) nearly caused a serious fall. Co-author JK once started and rode a 6 in. deep, 30 ft wide (15 cm × 9 m) mini-avalanche for 75 ft (20 m) down a steep slope. Expecting the spring wet avalanche conditions that were present, he missed the clues that indicated a more winter-like slab also existed. Although such a small slide is not generally dangerous, it was lucky there were no trees, rocks or cliff bands in the immediate slide path. Co-author CS spent half an hour

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sitting on a snow patch at 13,000 ft (3,960 m) while a thunderstorm moved overhead, striking repeatedly on neighboring peaks. The effort required getting that far and the nearness of the 13,400 ft (4,085 m) summit that was the goal of the day somehow made the idea of waiting (rather than running down the slope away from the storm) seem more reasonable than it does in retrospect.

In addition to providing an overview of the environmental factors associated with human activities at high altitudes, the ultimate goal of this article is to identify the nature and sources of poor (versus good) decision making in mountaineering, particularly at high altitude. This somewhat restricted focus on decision making within the much broader realm of human performance is intended for three reasons. First, many other non-cognitive dangers of high-altitude climbing have been exhaustively covered elsewhere, particularly physiology- and health-related ones (Houston, 1998; Wilkerson, 2001), although we review these briefly in the following section. Second, as we note above, and not unlike aviation (Wiegmann & Shappell, 2003), many of the most severe mishaps and accidents can be traced to poor decision making, and these examples of problematic cognition are often caused by instances of breakdowns in other information processing functions, as we discuss below. Third, whereas decision analysis can often focus on what went wrong in hindsight, it is not easy to forecast the relative frequency and danger of causal variables in foresight (Woods, Johannesen, Cook, & Sarter, 1994), and so in this article we hope to provide a framework for doing so, drawing upon a reasonable database from aviation and other high-risk decision areas.

In the following sections, we first describe the environment of high-altitude mountaineering, and its adverse influences on safety. We report statistics that document the magnitude of and effects on these safety hazards, and then present a cognitive model of information processing and decision making where the sources of cognitive biases on mountaineering decisions can be represented. Finally we discuss some of the remedies or mitigations of the dangers and further research needs. In the text we periodically introduce *italicized* anecdotes experienced directly or indirectly by one of us, to illustrate general points, with concrete examples.

## Environmental Factors

In this section, we represent “the environment” in which high-altitude mountaineering takes place very broadly, considering not only the physical environment in which the climber functions, but also the “biological environment” of his/her own health, and the social environment within which s/he climbs.

### Physical Factors

#### Altitude

The atmosphere thins with increasing altitude, creating hypoxia, a condition in which there is decreased supply of

oxygen to the body. The partial pressure of oxygen declines roughly linearly with altitude above 16,400 ft (5,000 m), and the air at the summit of Mt. Everest (29,028 ft/8,850 m) contains approximately 32% of the oxygen available at sea level. Some describe the feeling of reduced oxygen by suggesting you try to run a mile while breathing through a drinking straw. To illustrate further, consider the following:

Start at the base of a staircase. Place one foot on the next stair, stop and take five long deep breaths with the understanding that you will not be able to take that next step until you’ve taken the breaths. Place your next foot on the next stair and again stop to take five long deep breaths. After ten steps like this, stop for a five-minute break during which you are dizzy, your vision occasionally blurry and you’re barely able to catch your breath. Repeat this sequence for 500 ft (150 m) of stairs and you may begin to understand what it felt like to reach the 20,000 ft (6,100 m) summit ridge of Denali.

#### Cold

Temperature generally drops 3 °F (1.67 °C) for every 1,000 ft (300 m) in elevation gain. From Everest base camp at ~17,500 ft (5,300 m) (already a very cold place) the mountaineer wishing to reach the summit will endure increasingly colder temperatures as they near the summit. During the usual climbing seasons (April through early June, and September–October), the average temperatures in Everest base camp (since 2002, measured at 6:00 p.m.) vary between 25 °F (−4 °C) and 14 °F (−10 °C). On the summit, the variation is between −2 °F (−19 °C) and −24 °F (−31 °C) ([www.mounteverest.net](http://www.mounteverest.net)). The effects of cold on human performance are well documented (Hancock, Ross, & Szalma, 2007).

#### Wind

The effects of wind are never far from the mind of a mountaineer. While cold temperatures make life difficult, the addition of high wind can make even the most basic movement or task nearly impossible, and consume far more precious calories than in still air. Likewise, the effect of wind chill on any exposed skin can quickly lead to cold injuries. At the highest camp of the standard route on Mt. Everest, the wind typically blows at around 50 mph (80 kph).

We note that the combination of the above three factors, altitude, cold, and wind, is often multiplicative on their negative influence on human physiology (just as the well-known “wind chill” combines the latter two in an over-additive fashion). For example, hypoxia, leading to more rapid breathing, increases the intake of very cold air, thus speeding the loss of core body temperature. It is this combination of factors that has led to the colloquial definition of “the death zone,” altitudes above 26,000 ft (8,000 m), where the body generally cannot replenish itself.

### *Visibility*

High wind, blowing snow, and low clouds can create environments where the visibility is reduced to just a few feet. Furthermore, snow surfaces, often devoid of texture and landmarks, can exacerbate such low visibility, leading to rapid spatial and geographic disorientation.

### *Verticality*

The very nature of mountains involves a non-horizontal environment ranging in angles from less than vertical to beyond vertical (overhanging). While this seems obvious, it is important to understand that this truth affects every activity, thought, and decision in the mountain environment. Essentially, the goal is to move both up and down the mountain without losing the tenuous hold to snow, ice, or rock resulting in even a small fall. In general, this usually means that the movement both up and down must be relatively slow, hence amplifying the effects of the above stressors. It is also apparent that increased verticality will increase the likelihood of both snow avalanches and rock fall.

### *The gear*

While not usually considered part of the mountain environment, the gear used by the mountaineer can be as much a part of the daily difficulties as the mountain itself. Backpackers know all about carrying the necessary food, fuel, clothing, tent, and sleeping bag. Bulky, sharp, and heavy, the equipment for the high-altitude mountaineer includes more substantial versions of all these, along with extra fuel required to melt snow for water and ropes and other technical equipment required for safe movement over the high-altitude terrain. A critical decision must often be made to trade off the amount of health- and safety-preserving equipment carried (more is better) with the required speed of ascent and descent, where the weight of increased equipment is obviously counterproductive.

### *Negative Effects of the Environment*

The combination of extreme altitude and cold inherent in mountainous regions can invoke a number of ailments and dangers. Ranging from relatively mild to severe, these conditions place climbers at risk for injury and potentially death if left untreated.

### *Acute Mountain Sickness (AMS)*

AMS is the most common ailment associated with the reduced oxygen at altitude. The body's short-term response to lowered oxygen is to increase the rate of respiration. This combined with the lower humidity levels associated with colder climates results in dehydration. While most people think of dehydration associated with hot desert environment, it is one of the primary components of AMS. Anyone who has flown from their

home at a low altitude for a ski weekend or other mountain vacation will have experienced the initial headache and nausea associated with the effects of AMS. At higher altitudes, the body also begins to have difficulty digesting food properly, hence inhibiting nutrition. Furthermore injuries, even minor cuts, scrapes, and burns, heal very slowly or not at all.

### *High-Altitude Pulmonary and Cerebral Edema*

The more extensive versions of AMS include high-altitude pulmonary edema (HAPE) and high-altitude cerebral edema (HACE). In both cases, these are characterized by a buildup of excess fluid in the tissues. In the case of HAPE, the fluid builds up in the lungs resulting in reduced pulmonary capacity, and a subjective sense of drowning. The coughing can be so severe that victims can break their own ribs and the reduction in oxygen to the tissues in the already oxygen-starved environment can quickly incapacitate the sufferer. In the case of HACE, the fluid builds up in the brain causing cranial pressure. Initial cognitive effects of disorientation can quickly deteriorate into failures of bodily systems. AMS, HAPE, and HACE are all generally associated with increasing altitude too quickly. The only truly effective treatment for HAPE and HACE is rapid descent to lower altitudes.

### *Hypothermia and Frostbite*

These two conditions are a function of the cold environment. Hypothermia is a reduction in temperature of the whole body. Early stages include uncontrolled shivering as the body attempts to generate heat. As the condition worsens, motor function and cognitive abilities decrease (Hancock et al., 2007). In advanced stages, the internal organs begin to fail. Frostbite is a condition that affects the extremities; usually fingers and toes. In an attempt to protect the vital organs, the body shunts blood flow and the associated heat away from the extremities to support, instead, vital central organs and the brain. The result is that the tissues become more susceptible to the cold. The initial affects are a loss of feeling and motor function and extend to freezing from outer surfaces down through the tissue. Without proper re-warming the tissues die resulting in the eventual loss of the affected areas.

### *Snow Blindness*

Snow is a very effective reflector of solar energy. At altitude the reduced atmosphere results in high amounts of solar energy reaching the surface. Both the direct light and the reflected light impact unprotected body surfaces dramatically. Anyone who has suffered serious sunburn while snow skiing is familiar with the affect. The result of this amount of energy to unprotected eyes is snow blindness, a complete, although temporary, loss of sight accompanied by the searing pain of the sunburned cornea.

### *Falls and Impacts*

The most common causes of trauma in mountaineering are falls and impacts from falling snow, ice, or rock (Firth et al., 2008). While the mountaineer is subject to the sudden accelerations associated with losing contact with the steep mountain surfaces, likewise much of the snow and rock seems to have a tenuous connection with the mountain. The results are impact injuries either from falling or from being hit by falling material. In addition, the sharp points of crampons can suddenly catch during a fall and injure ankles and legs and the sharp points of ice tools can result in puncture injuries.

### *Blood Clots*

This is a rare but extremely dangerous malady caused by prolonged periods of little movement, coupled with, ironically, successful acclimatization, which increases the thickness of the blood; a thickness that may be amplified still by dehydration. Not generally thought of as something that can affect a mountaineer, consider being trapped in a small tent for several days without being able to do more than roll over. The malady affected the American climber Art Gilky on K2, whose deteriorating health (and eventual death) nearly cost the lives of the entire American expedition in 1953 (Houston & Bates, 1954).

It is important to note that most of these environmental influences interact, often negatively, in their effects on climber health and safety, in a manner that is often true of stressors in general (Hockey, 1986). Such an interaction is given form in the following:

Exhausted from two weeks of effort on the mountain, imagine that you and your partner have been trapped by a storm in a small tent at 17,200 ft (5,250 m) on Denali's West Buttress for the last three days. Only 3,000 ft (945 m) below your goal of the summit, you've tried to wait out the storm. You haven't slept much as the howling wind pounding against the tent and the need to help support the structure with your bodies has prevented much sleep. It's been difficult to run the stove to melt snow and prepare food so you are low on energy and dehydrated. Your partner's multi-day cough is starting to produce fluid from deep in his lungs and you've decided that you absolutely must descend. You're working down a difficult snow, ice and rock ridge with 60+ pounds (27+ kg) of gear on your back and crampons on your feet. Despite the heavy mittens you've lost feeling in your fingers and can barely handle your ice ax and you can no longer feel the toes of your right foot. The falling snow and wind is preventing you from clearly seeing or hearing your partner tied to the other end of the rope. A gust of wind catches you while you're trying to get your crampons to hold in a patch of bad ice. Overbalanced by the heavy pack and the loss of

feeling in your hands, you are unable to prevent the resulting fall. As you tumble down the steep slope you feel a sudden shock through the rope as the force of your fall pulls your partner from the wall.

### *Psychological Factors: Motivation/Goal States*

My dad was once asked why he chose to climb the highest 14,000 ft (4,268 m) mountains (14ers) in Colorado rather than the 13ers. While he agreed that the routes were often just as aesthetic and it often took just as much physical and mental effort to reach a high 13er, he pointed out that, every time I get up a 13er there's always some damn 14er blocking the view.

Charles F. Keller

It is not particularly useful to address the reasons why mountaineers choose to climb. The reasons are as varied as the winds they encounter. Mallory's famous "because it's there" is as useful as any. Rather, we focus on the range of goals within the mountaineering community. Naturally, most people think that the goal of any mountain climb is to reach the top. In fact, most mountaineers are driven by a number of goals that can compete, overlap, and vary in priority from trip to trip, or even day to day. Likewise, differing and varying goal states within mountaineering teams have been the cause of some of the most dramatic stories of team disintegration in the face of the mountain environment (Bonington, 1976; Ridgeway, 1980).

### *The Summit*

The most obvious goal of a mountaineering trip is to stand on the summit of one's objective. This goal is probably universal to all mountaineers, although in mission-oriented mountaineering, such as that of the U.S. Army's 10th Mountain Division, a goal may be instead a high mountain pass, or enemy redoubt. However, the priority that is applied to this goal has a dramatic effect on decisions, actions, and safety. At one extreme, there are those who wish to get to the summit at any cost and will make any sacrifice. Affectionately known by the phrase "summit or die," the great successes of these highly driven mountaineers are often shared with great catastrophes. At the other end of the scale are those who will take any excuse to turn back ("summit or brunch"). While often extremely safe, they rarely get to reach the summit. The majority of high-altitude mountaineers view the goal of the summit with a priority somewhere between these two extremes.

### *Summit and Get Down*

At first glance, the addition of getting down as part of the goal statement seems superfluous. However, it is amazing how often some mountaineers think only of the



ascent as a vital part of decision making and the summit as the only definition of success. The high rate of accidents and deaths during descent from the summit (Firth et al., 2008) may be attributed in part to the failure to include safely returning from the summit bid as part of the conscious goal statement.

#### *The Adventure*

Another common goal is simply that of the adventure of the mountaineering environment. Despite and perhaps because of the difficulties and dangers, some people seek time at high altitude because of how different it is from day-to-day life.

#### *Problem Solving*

Mountain climbing often imposes a fascinating intellectual challenge, involving strategic planning that balances the forces of gravity, friction, and leverage (a wonderful example of applied physics; and thermodynamics when on snow or ice), integrating these into the larger context of route finding that is at once safe and efficient.

#### *Working as Part of an Effective Team*

Common to many environments, the feeling of functioning as an affective team to overcome difficulties can be very satisfying. The memory of such an experience during a successful trip can provide a strong motivation to return.

#### *Risk/Thrill*

As with the goal of the summit, perhaps all mountaineers are thrill seekers to one extent or another. As with the adventure goal, it can be difficult to create the risks and associated thrills of a mountaineering environment anywhere else in life.

#### *Competition*

Many mountaineers are driven at least in part by competition, to be the first on a summit or to climb a hard route, or to set a "speed record" on some classic route. In some cases this competition embodies nationalism, such as Germany's frantic (and often disastrous) efforts to climb Nanga Parbat as the first 8,000 m peak during the 1930s.

#### *Cultural Experience*

In a strange socio-political, economic, and geographic conundrum, it is often the case that high-altitude mountaineers come from more affluent First World countries to often very poor Third World countries to find the peaks of their dreams. This necessity has resulted in many mountaineers seeking out and enjoying the cross-cultural experience as part of the whole adventure.

#### *Financial*

Finally, there is the goal of trying to make a living at mountaineering. Primarily this takes the form of either guiding

or the sponsored professional climber. While having garnered much attention as a result of the 1996 Everest tragedy, the guiding of clients has provided an ongoing financial component to mountaineering for almost two centuries. The issues associated with promoting a guiding service based on summit success feeds the competition motivation described above. The motivations of the sponsored mountaineer are similar in that in order to maintain their sponsorship they generally have to push for new and more difficult routes.

#### *Mountaineering Accident Statistics*

The above description of the hostile environment, coupled with the strong motivations to pursue climbs within that environment would suggest a high accident rate. We see this below as shown in the statistics of high-altitude climbing safety. These can be used to establish the magnitude of the safety issues and, with many constraints as we describe below, the possibility of drawing some causal inferences about events and conditions that modulate this safety. With even further caution, a few inferences can be drawn about the specific role of decision and judgment. In the following we focus exclusively on two high-altitude domains where statistics are probably most comprehensive and reliable: Denali in Alaska and the Himalayas.

#### *Denali*

At 20,320 ft (6,195 m), Denali is the highest peak in North America and is one of the most popular high-altitude peaks in the western hemisphere. The National Park Service has compiled an annual summary of climbing activities for decades and has made them available as a resource to mountaineers. The data and discussion points presented here are based on these summaries (National Park Service, 1978–2014).

For the 37-year period between 1978 and 2014:

- 38,181 people attempted to climb Denali by various routes
- 99 people died on the mountain for a 37-year death rate of 0.26%
- ~26% of the deaths occurred while ascending
- ~49% occurred while descending
- ~25% occurred while neither ascending nor descending

In 1978 there were 539 climbers registered for the mountain. The number climbed to a maximum 1,340 in 2005. The success (summitting) rate varies across different years but the average has remained steady at about 50% annually. As shown in Figure 1, the number of deaths and resulting death rate vary for the first 14 years up to 1992 with maximum annual rates of over 1%. After 1992 the annual death rate dropped and stayed at or below 0.3% for over 10 years despite the increased number of climbers, but now appears to be climbing.

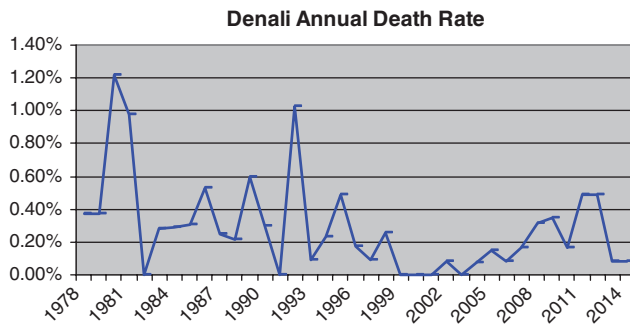


Figure 1. 1978 to 2014 annual death rates on Denali.

A number of factors seem to have helped to reduce the frequency of deaths on the mountain following 1992. In 1995 the institution of a 60-day advanced registration requirement has given park service personnel more time to provide tailored instruction and guidance prior to ascent. In addition, an informational packet was developed and progressively translated into several languages to help teams better understand the issues associated with climbing Denali.

Another factor comes in the form of decision support. Upon arrival at the 14,200 ft (4,330 m) camp, most teams walk over to the high-altitude medical research facility for a checkup. Of primary importance is the test for oxygen saturation as it provides an indication of the amount of acclimatization. The medical personnel are able to recommend, when necessary, additional rest days prior to continuing an ascent. It became a common conversation starter across teams to ask if they had had their check-up and something of a badge of honor to get a low oxygen saturation reading.

In addition, the medical facility has helped to reduce the consequences of accidents with prompt medical care of accident victims. Likewise teams of park rangers and rescue equipment stationed at various places on the most commonly used route (including bottled oxygen at the 17,200 ft [5,250 m] camp) have played vital roles in many rescues. Finally, the combination of high altitude-capable helicopters and fixed wing aircraft transportation support has clearly resulted in many lives saved through prompt evacuation, some from amazingly high on the mountain.

### Himalayas

The high-altitude statistics we report from the world's highest mountain range is derived from Salisbury and Hawley (2007; see also Firth et al., 2008). From this extensive and informative database, we have distilled a relatively small number of important conclusions that bear on our later discussion of safe and unsafe decisions.

1. Falls and avalanches contribute to the largest proportion of Himalayan deaths (about 33% each). Hired climbers (i.e., local sherpas) are somewhat less likely to fall than non-local climbers.

2. Fall rates increase the higher one is on the mountain; but avalanche deaths are most prevalent lower down (19,700–21,300 ft [6,000–6,500 m]) where, because of reduced winds, more snow remains on the slopes.
3. There are two or three times as many deaths on descent as on ascent during the summit bid (typically 1 day; see also Firth et al., 2008). This difference grows the higher the peak. From 2:1 on 19,700 ft (6,000 m) peaks it increases to 3:1 on 26,250 ft (8,000 m) peaks and to 4:1 on Everest. We note that on Denali, 20,320 ft (6,195 m), this ratio is 2:1 (see Denali statistics above), thus revealing a very consistent trend: the higher the peak, the greater the relative hazard of death upon descent. This may represent the greater exhaustion, manifest more on descent than ascent, for higher altitude peaks. It could also represent the fact that the ascent–descent vertical distance from high camp to summit is often greater for the high-altitude peaks because of the desire not to carry camping equipment too high, and not to attempt sleeping above the death zone altitude on the night before the climb.
4. Finding (3) does not mean that higher peaks are necessarily more dangerous overall. The death rate on 23,000 ft (7,000 m) peaks is higher than on 26,250 ft (8,000 m) peaks and the rate on the lower peaks Annapurna and Lhotse Shar is nearly three times that on Everest. On K2 (about 1,000 ft [300 m] lower than Everest) the rate is almost four times that of Everest (Eguskita & Huey, 2000). However, we do note that the fatality rate in the Himalayas where climbing peaks typically range between 21,000 and 29,000 ft (6,400–8,850 m)—by one estimate 1.57%—is much higher than the 0.26% figure for 20,320 ft (6,195 m) Denali.
5. Overall, there are a lot more deaths during preparation (prior to summit day: 50%) than on either ascents (9%) or descents (24%) on summit day. However, one should estimate hazard exposure, and divide by the amount of time spent in each of these three phases. Here we estimate this to be approximately 20 days for preparation (total days for successful expeditions, subtracting 4 days for descent), and 1 day each for summit ascent and descent. Based on this division, then the risk is actually 10 times greater for summit descent, and about twice as great for the summit ascent. Note that since both summit ascent and summit descent take place at the same mean altitude, pure altitude and hypoxia cannot be attributed as a cause of greater descent danger.
6. The role of supplemental oxygen provides added statistics. It has been debated whether the advantage of using such oxygen on the highest summits in mitigating hypoxia is outweighed by both the costs of carrying such oxygen to high altitudes and the overdependence on such oxygen should it run out for the less acclimatized climber (Boukreev, 1997b). This latter

event is more likely to occur on descent, and hence could in part cause the greater death rate on descent, discussed in (5) above. On this issue the accident data speak fairly clearly in favor of the advantages of such oxygen. On Everest, the death rate for individuals not using oxygen is more than doubled (8.3% vs. 3.0%) compared to those using it, and on K2 this difference is even more dramatic (18.8% vs. 0.0%) (Eguskitza & Huey, 2000).

The important point in the above description of several statistics is that there are certain trends or characteristics that make climbing in some circumstances more dangerous than in others. Furthermore, as we outline below, it is reasonable to infer that these circumstances differ in both the environmental factors described in part 2 and the resulting quality of judgments and decisions that are typically made, an issue we describe in detail in part 5. However in applying statistics such as those in order to draw inferences, it is important to consider three caveats and qualifications.

1. Obviously, when we draw inferences from differences in accident or fatality rates in existing data, strong conclusions about causality will be absent. For example, the strength of causality of increased risks due to hypoxia at higher altitude will be mitigated by the fact that higher altitude climbers are generally more skilled and experienced and better acclimatized.
2. Statistics are always heavily influenced by the base rate. The number of accidents may increase from one set of circumstances to another, but the proportion may decrease (or vice versa). However determining the proportion requires establishing a denominator, and such values are often difficult to obtain, or to gain

consensus regarding. What, for example, is the absolute number of people who climb high? Or what is the total number of decisions that are made at high altitude (and not just those that were “bad”). Such numbers are necessary in order to allow the researcher to establish a rate of bad decision making, which might be modulated by other factors.

3. Paralleling challenges in interpreting aviation incidents from the Aviation Safety Reporting Systems (available at <http://asrs.arc.nasa.gov/overview/summary.html>) (Wickens, 1995), the vast majority of those accidents in climbing are based upon self-report. Such reports can be biased in content, and in fact in absolute number, as climbers may be reluctant to call attention to their own poor judgments. There appears to be no parallel to the ASRS within the climbing community.

### Decision Making

Decision making, both good and bad, is supported by human information processing. Figure 2 presents an overall information processing/decision making model for high-altitude mountaineering. At the core of the model is represented the four stages of information processing adapted and slightly modified from Wickens and Carswell (2006) (Wickens, Hollands, Banbury, & Parasuraman, 2013). These stages support the climber to:

1. **Sense and perceive** environmental events, conditions, or cues (e.g., weather patterns, snow conditions, time of day, health of self and companions). Given the number of such cues, particularly when time is critical, many of these may be filtered by the process of selective attention, and/or given differential weighting (e.g., more

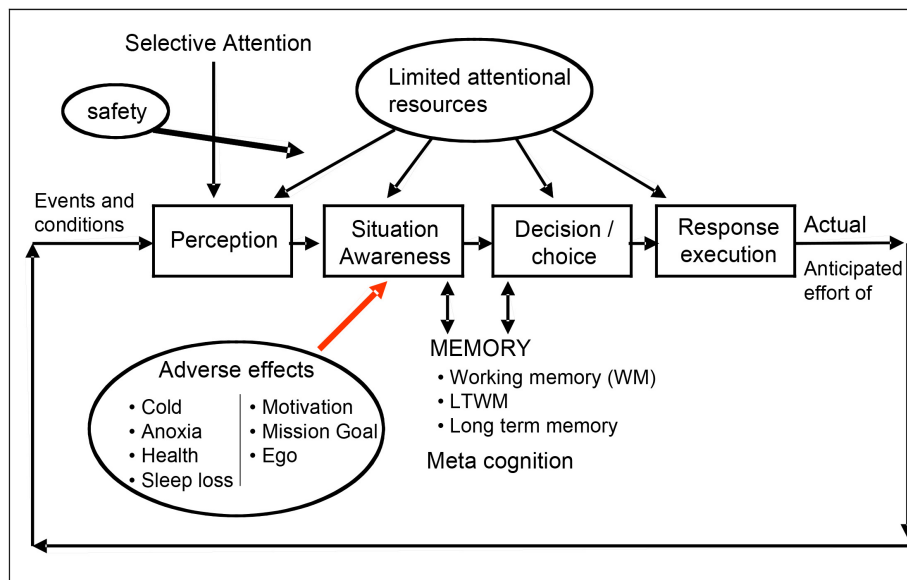


Figure 2. An information processing model of climbing decision making.



weight to salient self-health than to less salient cues of a companion's health; more attention by the guide to the complaining client than to the stoic silent one).

2. **Integrate the cues to maintain overall situation awareness (SA)** (Durso, Rawson, & Giroto, 2007; Endsley, 2006). Sometimes this may involve a specific assessment of the situation, as when making a go/no-go decision, or a decision to turn around. At other times, an ongoing awareness will be **maintained**, even in the absence of a specific goal-directed assessment (e.g., awareness of the passage of time, of changing weather patterns, of clients' developing hypoxia, or of numbness of the climbers' own fingers and toes). The process of maintaining SA and forming a particular situation assessment is quite intensive in its demands for memory (Durso et al., 2007; Wickens, 2015).
3. **Chose different decision alternatives**; for example where and when to set up camp, to set up a protective belay, which route to take, or whether to continue or turn back. Ideally this process should be preceded by an accurate situation assessment. However, good SA will not guarantee good choices, since the latter are also governed by knowledge of risks associated with different choices and their outcomes, as well as values and goals, in a way that SA is not (Endsley, 1995; Wickens, 2015).
4. **Execute the chosen course of action**. Here we can distinguish between two influences. On the one hand, the quality of action execution may be directly influenced by a host of environmental factors: for example manual coordination and rope work will be severely degraded by cold hands; as will be climbing on icy rock. On the other hand, the **anticipated effort** of response execution can substantially influence the decision paths that are chosen (Wickens, 2014). For example the knowledge that one has cold hands may lead to a decision to take an avalanche-prone snow ascent up a snow couloir (deep gorge or gully on the side of a mountain), rather than the safer rock climb up the adjoining ridge because of the effort required of cold hands on cold rock; or the anticipated physical effort of brewing lots of water may shortchange the exhausted climber's need to hydrate. In climbing, anticipated effort plays a major role in balance against risk because the extreme exhaustion and rarity of oxygen leads to depletion of both physical and mental effort. The following from Curran (1995) illustrates a disastrous choice, based on the conservation of anticipated effort.

In 1978 a British climber was killed while ascending from C1 to C2 on K2. He was engulfed in ...a slab avalanche five hundred feet wide, three hundred feet high. Thousands of tons of snow. The figure in the middle struggled and was overwhelmed and disappeared

from view. Three thousand feet to the glacier.... When first establishing this part of the route, there had been a choice: Either an easy traverse across a snow basin below the crest of the ridge or the more difficult ridge itself. The basin was chosen to conserve energy—...we were moving horizontally—it was little more than walking.... Yet the consequence of the effort-preserving choice, proved fatal.

As shown in Figure 2, two additional components of the information processing model lie outside of the direct "flow" of information from sensation and perception to action: memory and attention. First, as shown below the stages, many aspects are supported by memory. This memory system has traditionally been defined by its time constant, with **long-term memory** or knowledge characterizing the stored set of facts, skills, and procedures acquired slowly through learning, training, and practice, and which are forgotten equally slowly. Here, critically, knowledge of risks is an important variable for climbing decisions; however so also are learned perceptual skills, such as appreciating the avalanche conditions of a snow slope from a quick glance, as well as motor skills such as those involved in rapidly setting up protection at a belay spot, or self-arresting after a fall on steep ice.

In contrast, **short-term memory** or **working memory** is resource intensive and loses information within a matter of seconds if it is not rehearsed. Such might underlie the following climber (second on the rope) forgetting a series of route instructions shouted down from a lead climber above; or forgetting that a particular safety action had not yet been carried out when the climber is interrupted during a series of procedures (e.g., the double back of a harness; or tightening crampon straps). Data indicate that working memory is degraded by cold (Van Orden, Benoit, & Ogsa, 1996) and by high altitude (Kramer, Coyne, & Strayer, 1993).

In between working and long-term memory lies what Ericsson and Kintch (1995) have referred to as **long-term working memory**, that which critically underlies situation awareness (Durso et al., 2007). That is, while certain elements may not be actively rehearsed in a continuous fashion as would be necessary to retain in working memory, they can be rapidly retrieved or brought to mind if necessary, like remembering the dynamic situation of the weather when it was most recently evaluated; or keeping track of how far above a protection point one has climbed as a lead climber. Importantly, both long-term and long-term working memory lie at the core of a critical element for climber decision making: that of **meta-cognition** or knowledge about one's own knowledge. On the one hand, this may refer to knowledge stored in long-term memory. For example a climber may decide that he or she simply does not possess the skills to attempt a particularly challenging route. Meta-cognition, on the other hand, may refer to knowledge about his or her own situation

awareness; a climber may or may not be aware of her lack of information about the difficulties of an upcoming section which she is to climb; or may have failed to attend to, and hence notice the onset of symptoms of HACE or AMS.

In addition, the second component, shown at the top of Figure 2, is that of the limited attentional resources necessary to carry out many of the information processing steps, as well as to rehearse information in working memory. This limitation challenges the multitasking abilities in mountaineering (Wickens, 2008; Wickens & McCarley, 2008). Most stages and cognitive operations are resource-limited, implying that if other concurrent tasks compete for those resources, those operations will be degraded, particularly if those competing concurrent tasks are perceived to be of higher priority, or are triggered by events of considerable salience (Wickens & McCarley, 2008; Wickens, Gutzwiller, & Santamaria, 2015). We have already discussed how an interruption can divert attention away from following a series of safety procedures. We could, as well, consider the distraction from careful rope management, imposed by threatening weather concerns, or by internally directing attention to one's physical health. According to such a model, adequate multitask performance will depend not only upon the **demand** for resources by concurrent tasks (e.g., their difficulty or cognitive/motor complexity), but also upon the **supply** of resources available (i.e., the size of the resource "tank"), a supply that can diminish with fatigue, and upon the appropriate allocation of resources to more important (safety-critical) tasks.

Upon this information processing model may be overlaid a variety of influences on the quality of processing, and ultimately the safety of the climber. At the most general level, we portray on the left side of figure 2 two major and conflicting influences: the goal of safety, shown at the top, and a series of "adverse effects" that offset safety concerns shown below. Roughly, as partially discussed in Sections 2 and 3, the adverse effects can be divided into two categories. On the left are those physical influences related to the environment and those on the right are related to motivation and goals.

#### *The Speed–Accuracy Tradeoff*

Typically, information processing models such as that shown in Figure 2 can be characterized either by how *long* it takes to process information, or by the *quality* of that processing, producing correct or undesirable outcomes. Often these two variables are negatively correlated in the speed–accuracy tradeoff, such that, when actions are rushed, they are more likely to be in error. However in climbing, as often in aviation, the tradeoff is more complex and longer delays will not necessarily lead to better (more accurate or safer) outcomes. For example, excessive cross-checking of safety features in frigid weather can lead to increased likelihood of frostbite; and other safety-related delays with approaching severe weather can, as well, be inappropriate.

This "trade-on" (the inverse of a tradeoff) is well illustrated in the following example.

On a nice summer day, two separate teams left the trailhead at 5 a.m. for the same technical climbing route on the Colorado 14er, Crestone Needle. The Ellingwood Arete route gains about 2,000 ft up a steep ridge buttressing The Needle. The last few hundred feet of the climb get steep enough to always use a rope while most of the ridge approaching this section remains at or below the level where some people use ropes and some do not. The first team worked their way carefully up the route, hunting the easiest path through the myriad rock steps unroped until reaching the more technical climbing near the summit. The exposure during the unroped sections had been intense and a few times the chance of a big fall had seemed close at hand. They reached the summit by around 10:30 a.m. and spent an hour relaxing on the summit and enjoying the view. While the descent down the standard route is difficult to find and takes very careful work, the first team reached their car by mid-afternoon. The second team had taken a less risky approach to the ascent. They had roped the entire ridge (dozens of rope lengths) rather than just the last bit of technical climbing. In doing so they were protecting against any falls on the more moderate terrain but necessarily moving much slower. Not taking their pace into account they continued the ascent and finally reached the summit near dark. Exhausted and unable to find the descent route, they spent a very uncomfortable night huddled just off the summit exposed to lightning, rain, and cold. Luckily they survived the night and made a safe descent in the morning.

#### *Situation Assessment and Decision Making*

Figure 3 presents an alternative version of the information processing model that highlights those cognitive and motivational processes involved in choice. In the middle of the figure we consider first the decision or choice, here shown as one between two decision alternatives  $D_A$  and  $D_B$  (e.g., turn back or continue the climb). Whichever option is chosen will produce a set of outcomes ( $O$ ) shown in the matrix to the right. (Each cell of the matrix contains an entry: the value  $V$  of an outcome  $O$ , which will occur with probability  $P$ .) In the figure, these six outcomes can be characterized both by those that actually result and by those that are (or may be) anticipated at the time the choice is made. In accurate decision making, the anticipated outcomes will agree with those that actually result.

Note in the figure that two outcomes are associated with one choice ( $D_A$ ),  $D_s$  two with the other ( $D_B$ ), and two are **shared** (they will occur with either choice) between both choices, but these, like outcomes for a single option, will

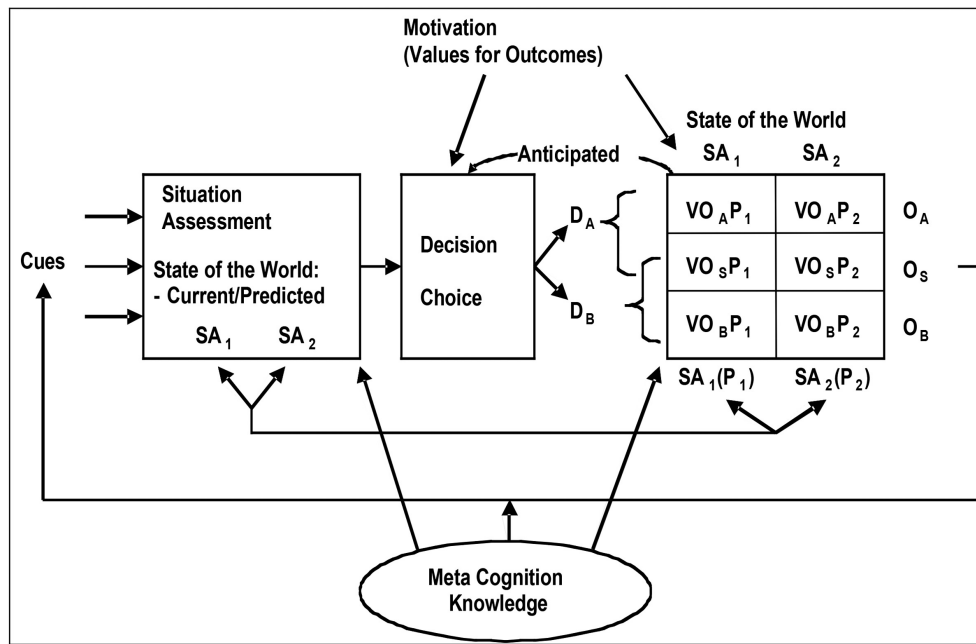


Figure 3. An information processing model of situation assessment and choice.

occur with different probabilities (P). For example the choices to continue a climb, versus turn back may both be associated with extreme cold and frostbite, but the former choice with a higher likelihood. Generally, these probabilities or likelihoods are associated with different potential **states of the world** (either existing now or predicted to occur), represented in the two columns of the matrix. As shown in the situation assessment box to the left of the figure, estimating the likelihood of these states of the world (both predicted and current), from perceived cues in the environment, is the vital role of this assessment. Thus we may speak of an “80% chance that a slope to be crossed is avalanche prone,” or of a 20% chance that “the future weather will turn bad.” As shown in the matrix, the combination of state-of-the-world and options produces a set of unique **outcomes** (here six), each of which can be associated directly with a value, positive or negative (e.g., the value of summing, the cost of frostbite). Thus the **expected value** of each decision option A and B can be represented as the sum, across all possible outcomes, of the probability X value.

Critically, this decision process is supported by three elements shown in the figure. At the top, motivation determines the costs and benefits of different outcomes. Clearly, under some states of the world, a strong motivation for summing will have a different effect on decision making than will a strong fear of frostbite. At the bottom, decision making is supported by knowledge; in particular knowledge that aids accurate situation assessment, and knowledge of the probabilities of different outcomes (risk assessment). It is also supported by **meta-cognition** (Reder, 1996): knowledge about the ongoing cognition of decision

making. Here this meta-cognition is most importantly expressed by the **confidence** in a situation assessment and by the appropriateness of the chosen course of action. A climber with extreme confidence (often overconfidence) may (a) stop assessing the situation once a decision has been made, under the belief that the original assessment is correct; or (b) stop monitoring the chosen course of action, under the strong belief that it is optimal. When this turns out not to be so, this is known as a “plan continuation error” (Orasanu, Martin, & Davison, 2001).

Whereas Figure 3 depicts this situation assessment and choice process in the abstract, Figure 4 shows the same structure, now populated by a specific critical decision that may be made by many climbers.

In the middle of the figure, the climber should make a key decision to continue or turn back based, in part on a situation assessment of what the weather will be (a probabilistic forecast). This assessment is based on perceived cues, the forecast, the current conditions, but also guiding the choice may be an assessment of physical well-being (possible frostbite in the toes). To the right, the decision matrix for the two decision alternatives is based on the perceived probability and costs or benefits of the different possible outcomes. These are shown within each cell and are also identified in the boxes to the right above and below. Thus to continue if the weather worsens will only yield a 10% possibility of summing, an outcome that nevertheless remains quite valuable (+10). Frostbite is a bad (−5) outcome. Turning back has a certain (100%) chance of failing to reach the summit. At the top, we note that the different motivations of different climbers will affect these subjective costs and values, and hence the decision choice.

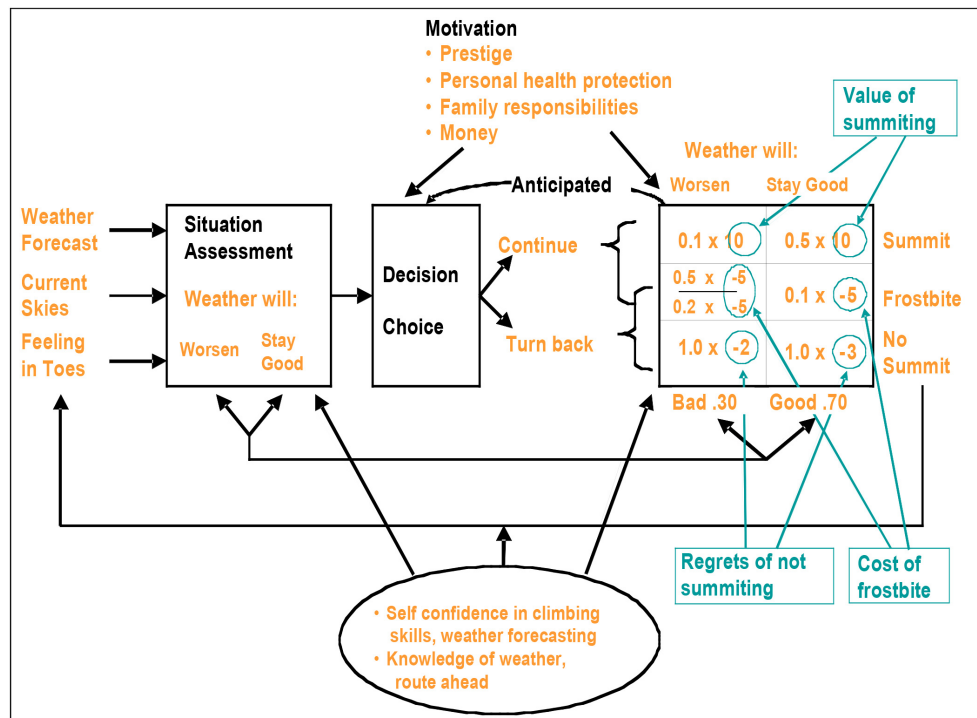


Figure 4. An example information processing model of situation assessment and choice for a specific decision.

As we zoom into the key aspects of our decision model related to situation assessment and choice, we can turn to an extensive line of research in other high-risk domains that illustrates the many biases and heuristics that characterize problematic cognition in these mental operations. By heuristics (Gigorenz & Todd, 1999; Gilovich, Griffin, & Kahneman, 2003; Kahneman, 2011; Kahneman & Tversky, 1984), we refer to mental shortcuts that are often used under time pressure or resource-scarce conditions that, nevertheless, **usually** offer a correct diagnosis of a situation, or inference of the state of the world. But because they are shortcuts, perhaps failing to consider all of the data, or optimally weight all information, they can, on occasion, be wrong. By biases, in contrast, we refer to cognitive operations that clearly influence a decision in one direction, a direction that is often “wrong” and should be corrected (Larrick, 2004). In the following, we provide examples of how these could be (and in some cases have been) expressed in a mountaineering context. However these are not directly linked to statistics revealing the degree of prevalence or influence in this context. Such data simply do not exist, in a way that parallels their existence in aviation (O’Hare, 2003; Wickens & Flach, 1988; Wickens, Stokes, Barnett, & Hyman, 1993).

#### Biases in Cue Sampling

Perhaps the most prominent bias here is that of **cue salience**. In forming any assessment of the state of the world, cues bearing on that state will vary in their information value—the likelihood that they correctly

indicate the state—as well as their physical salience or prominence (Wallsten & Barton, 1982). Unfortunately these two commodities are not always perfectly correlated, and when they are not, decision makers are often biased to process the more salient, but less informative cue, allowing it to dominate their situation assessment. One example might be clear blue skies, close to the climber, and perhaps stretching off to the eastern horizon in a visible direction which is away from the bad approaching weather, with the symptoms to the west barely visible because they are mostly hidden by the bulk of a mountain or behind the climber. Another example is the guide who makes a diagnosis of the collective health of the party, paying most attention to the more vocal client; whether that client is positively voicing how great they feel, or loudly complaining about how terrible they feel.

A second bias in cue sampling is related to **stress-induced attentional tunneling**, the well-documented phenomenon whereby, under stress, we tend to pay attention to that information which is directly visible in or near our forward field of vision and which we consider most important to the task at hand, while often ignoring that to the periphery (Wickens et al., 2013). As the rock climber ascends a rock wall (particularly the novice), and begins to feel the stress of major fatigue in the arms, or the imminent danger of “coming off” the rock, the tendency is to continue to look for hand holds directly in front of or just above the face, while ignoring the search for those off to the side, or for better footholds, as these require a much wider scan pattern. We can also apply this tunneling to more abstract



task-related goals, positing that a climber with a very strong motivation to summit might, as stress increases, focus attention more exclusively only on the path ahead, while ignoring information (such as bad weather cues toward the horizon behind) which might support a predictive assessment that summiting is ill advised.

#### *Heuristics and Biases in Situation Assessment or Diagnostic Inference*

Most notorious from the work of Tversky and Kahneman (who won a Nobel prize in economics for this work; Kahneman, 2003) are a set of heuristics, used to diagnose a state of affairs (assess a situation) that either exists now, or is likely to exist in the future (prediction; Kahneman, 2011; Gilovich et al., 2003; Kahneman, Slovic, & Tversky, 1982; Tversky & Kahneman, 1974). The first of these heuristics is **anchoring** (Hogarth & Einhorn, 1992): the tendency to settle on an initial belief (e.g., that it will be a fair day, or that snow conditions will be favorable), and then “anchor” on this belief, well after subsequent evidence arrives that the belief may not be accurate. This is labeled a heuristic, in that it conserves cognitive effort that might otherwise be needed to constantly revise beliefs on the basis of newly arriving information. The anchoring heuristic is closely related to the **confirmation bias** (Cook & Smallman, 2008; Nickerson, 1998) by which the held belief or assessment leads the climber to only seek or pay attention to cues (environmental conditions and events) that confirm that belief to be true, while ignoring those that may disconfirm it. For example, a common occurrence in the world of avalanche accidents is for a group to start out the day having been informed by the local avalanche report center that the danger is only moderate. The skier or climber anchored to this belief then either fails to notice evidence of unstable conditions in their area of travel or only attends to those signs that support belief in the stability of the snow pack (e.g., the climbers ahead who ascended it).

**Availability** is another heuristic that helps the climber establish how **likely** a given event, condition, or state of affairs might be (Tversky & Kahneman, 1974). As we saw in Figure 3, this is a necessary operation to obtaining an accurate situation assessment. While it is quite plausible to assert that, in the absence of hard visible cues, one should adopt a hypothesis that represents a state that has been most frequently observed in the past, the problem lies in the fact that climbers will estimate how frequently things occur by how available they are to be retrieved in their memory. And here, availability will be based on **personal experience**, which may not accurately reflect the actuarial statistics of frequency. For example if one has climbed on a mountain in the Cascade mountains in Washington, for several days in exceptionally good weather, using the availability heuristic to estimate weather likelihood the climber will be more prone than they should be to assume that favorable weather is the norm (despite the fact that long-term weather statistics

in the Cascades provide a gloomier forecast). Consider the following description by one of the co-authors:

At 20,320 feet, Denali’s summit is relatively low by Himalayan standards. Expectations of conditions based purely on an altitude comparison may account for how often teams seem to overestimate their abilities and underestimate Denali (Waterman, 1983). At only a few degrees south of the Arctic Circle, mountaineers on Denali experience weather similar to the severity found on the highest Himalayan peaks. Likewise, because the atmosphere is thinner at the poles, experienced mountaineers agree that Denali feels physiologically more like 23,000–24,000 ft (7,000–7,300 m). Thus the climber may assess his or her belief on the risks of Denali based purely on the availability of prior experience of, or reading about, climbs in the Himalayas or South America.

Not surprisingly, some of the best determinants of availability are salient personal events. The climber who may believe that their rock climbing leader skills are well honed despite some evidence to the contrary (e.g., mild criticism from colleagues) may only substantially change that belief upon suffering a serious leader fall from too far above a protection point, perhaps coupled with an injury. Such an event will now be **very well** represented in their memory, in a way that will help signal that their leading skills are not as good as they thought they were.

It is possible to see the combined influences of anchoring, the confirmation bias, and availability in the following example:

Avalanches are so common in the high Himalaya that one becomes inured to them. After repeated use of a particular route, climbers often don’t give that particular spot much (if any) thought throughout the rest of the expedition. Although it is considered foolish to venture out the day after a large snowfall, most will climb on the second day, and by the third day of good weather, only the sick or injured will remain in their tents.

In October of 1999 on Dhaulagiri (26,788 ft/8,167 m), two members of a combined team perished when six of the seven were caught in an avalanche above camp 2. Set early in the season, the route had been deemed safe perhaps anchoring their assessment and repeated movement through the area may have created a confirmation bias that the original diagnosis was correct. Late in the season with only one shot left to try for the summit, the team moved out from camp 2 on a clear morning after a very windy night. At one point a bit off the ridge while pulling the fixed ropes up through the wind-packed snow the whole slope released under their feet. Weeks of repeated use had left the team with the available



information that the area was safe resulting in a textbook avalanche trap without any of them even asking the first question—Is it safe?—a question that would have been automatic in a similar situation closer to home.

The **overconfidence bias** is one in which people often tend to be more confident than they have a right to be in the accuracy of their forecast or diagnosis (Bornstein & Zickafoos, 1999; Fischhoff & MacGregor, 1982; Kahneman, 2011; Wickens et al., 2013). This is often as true of experts as of novices (Kahneman, 2011; Taleb, 2007). For example when asked to estimate the accuracy of their predictions, stockbrokers tend to estimate these considerably higher than the actual accuracy of those predictions as the market later plays out (Taleb, 2007). For climbers, it is easy to understand how this could lead to diminished attention to bad weather cues, after a personal forecast of good weather has been made (“I am confident that my forecast will be accurate; hence there is no need for me to consider that it might not be”). Thus in a sense anchoring, confirmation bias, and overconfidence bias all intertwine in a sort of cyclic syndrome or “perfect storm” that can lead to incorrect beliefs and forecasts being held far longer than they should be in the face of either changing conditions and data, or an incorrect forecast in the first place.

The overconfidence bias also intertwines with the availability heuristic. Thus, for example, avalanche experts who get caught by slides on familiar terrain have become prone to a combination of the availability heuristic and overconfidence bias. Analysis of the mechanics of snow packs and resulting avalanches has shown that slopes are stable nearly 95% of the time (Tremper, 2001). As such, no matter how good or poor the decision of slope stability, a slope can be crossed without ripping loose most of the time. Experience gained with an absence of consequences can breed a dangerous overconfidence.

#### *Biases in Risky Choice*

As represented in Figure 3, in any high-risk decision process, whether in driving, medical care, flying, or climbing, an explicit or implicit situation assessment or diagnosis typically precedes a choice of action. Situation assessment is (or should be) “value free” in the sense that there is a ground truth against which its accuracy can be evaluated. But choice will, by definition, be value laden, because it is influenced by the subjective costs and benefits (values) of different decision outcomes, and these will vary from person to person (Figure 3). For example the decision to continue a climb could be just as optimal for the single climber who has a strong incentive to reach the summit as could be the decision to turn back for the climber who has heavy family obligations at home and is just pleased by the aesthetics of the surroundings. As shown in the matrix in Figure 3, the **expected value** of a choice option considers the probability of different outcomes weighted by the costs

and values of those outcomes. Thus the expected value of continuing a climb will be diminished by a reduced probability of success, a reduced incentive for reaching the summit, an increased probability of injury or illness on the ascent, or an increased cost of those adverse events. It is also the case that, while probabilities can be calculated objectively (or from actuarial data), they are instead most often based on *subjective* probability, as manifest in the availability heuristic.

Many of the biases and heuristics associated with such risky choices have been accounted for in other domains by **prospect theory** (Kahneman & Tversky, 1984; Kahneman, 2011) and we highlight here three of the most important, namely framing, sunk costs, and subjective probability estimation, followed by a fourth element related to the perception of risk.

#### *Framing*

When two negative outcomes, one a “sure thing” and the other a risky one, are considered by the decision maker, and both have roughly the same **negative** expected outcome, people tend to choose the risky path over the certain loss. Let us consider the decision represented in Figure 4 expressed within a negative frame: a climber facing a choice between turning back, framed as a “**sure failure to reach the summit,**” and a risky choice of continuing, framed as an “**X% possibility of suffering the mishaps of severe cold.**” Here the tendency will be to continue. In contrast, if the choice is framed as one between positives, namely turning back: “**a sure guarantee of safety,**” and continuing on: “**probably summiting, and a good likelihood of avoiding a mishap,**” people are less likely to choose the riskier path. They “take the money and run.” Decision theorists have most frequently concentrated their efforts on the negative frame where people are, so to speak, “caught between a [risky] rock and a [sure thing] hard place” (Kahneman, 2011; Kahneman & Tversky, 1984; Tversky & Kahneman, 1981).

It is but a short walk from considering the prevalence of this risky bias with the negative frame to understanding another well-known bias in decision theory, the “**sunk cost**” bias (Arkes & Blumer, 1985; Molden & Hui, 2011). This describes the well-known tendency, after suffering considerable losses from pursuing a particular course of action, to be more insistent in carrying on that action to the extent that more has been invested in that pursuit. Such a tendency can be easily shown to be irrational and less than optimal. After all, if your likelihood of winning is unchanged whether you have just started an endeavor or been engaged in it for some time, the expected costs of failure upon continuing are probably just as high (if not higher) the longer your unsuccessful effort is continued. (Consider the tendency of the gambler, down \$100 on the night, to want to continue betting to recoup the losses—a risky negative option—rather than walking away with a sure loss.) Such a

tendency can be readily applied to climbing as the more time and effort that have been sunk into an expedition or climb the greater will be the tendency to want to continue, in spite of evidence (and perhaps increasing evidence) that such an action is becoming more risky. This idea is demonstrated in the personal experience of co-author JK:

During the summer of 1998, JK and friends chose to turn back only a few hundred feet from the summit of Chopicalqui on a perfectly gorgeous day in Peru. While all members were feeling good and plenty of time remained in the day, the team had left their only rope as a fixed line to protect a difficult snow bridge further down. At the summit block of Chop, generally a moderate snow slope, the team found a mass of fallen and broken ice blocks creating a much more difficult problem. While many of the team members had the ability to make this climb, without the rope it was deemed too great a risk. A week later, the team was again turned back less than 100 feet from the summit of Tocllaraju. Again the team felt good but this time the visibility was severely limited, the weather poor, the route uncertain, and the technical difficulties much higher. While this would seem like an easier choice, having missed the summit of Chopicalqui the week before made the second decision to turn around much harder than it otherwise might have been.

Finally, the **overconfidence bias** influences decision choice, just as it influences inference and situation assessment. A well-documented research base indicates that people are more confident than they have a right to be of the success of their own actions, just as they are overconfident in the accuracy of their own inferences (Taleb, 2007; Kahneman, 2011; Wickens et al., 2013). Such a bias will have three influences: (1) it will lead people to underestimate the frequency of adverse events (and overestimate the frequency of success); (2) with that underestimation, it will lead them to under-prepare for the consequences if things do not go as anticipated; and (3) lastly it will lead people to be less vigilant than they should be, in monitoring the wisdom and appropriateness of actions already taken (no “second guessing”): thus it will influence meta-cognition.

### *Conclusions*

The above discussion does not mean to imply that all climbers (or all people for that matter) show all of the biases and heuristics in every decision they undertake. An interesting issue, beyond the scope of the current article, is the extent to which fundamental differences in personality (e.g., risk seeking, instant gratification, or temporal discounting) may underlie differences in poor choice. Furthermore, in many circumstances, these biases and heuristics may have little influence on the safety of a choice. Nevertheless, the accident and fatality rate is sufficiently high, and the environment in which even a small number of poor decisions

are made is sufficiently unforgiving, as to suggest that an understanding of these factors will benefit the safety of workers in a high-altitude and/or mountainous environment.

### *Interpersonal Factors*

#### *Teams, Team Work, and Team Decision Making*

Finally, the combination of the physiological issues of the high mountain environment and the cognitive biases and heuristics associated with decision making has a dramatic effect on the teams involved in mountaineering. Only on very rare occasions are true solo efforts made on the high peaks. Rather, nearly every mountaineering endeavor includes both the positive and negative effects of personal interactions, team work, and team decision making. Indeed, group dynamics (both good and bad) are often cited as the primary driver of mountaineering team success or failure. Consider the following:

As a veteran of numerous expeditions to 8,000 m peaks and a successful K2 summiter, CS reports that the biggest difference in the best and worst expeditions he was ever on was directly related to the teams involved.

Mountaineering teams can range from two friends tied together with a single rope, using a single tent, stove, and cooking pot (Venables, 2001) to huge expeditions involving dozens of climbers, over one hundred porters and support personnel, and literally tons of gear and food (Bonington, 1976; Hunt, 1954). Teams are created across an interpersonal range from groups of close friends who have trained together for years to disparate individuals meeting for the first time during the trip. Leadership can range from the democratic where team consensus is required for decisions (Ridgeway, 1980) to individual leaders given the power to make final decisions by the rest of the team (Hunt, 1954). It is the pressures of the mountaineering environment continuously applied over weeks and sometimes months that result in the stories of the greatest team successes and the most dramatic team disintegrations. Long-term bonds of friendship have been created and destroyed by these pressures. The success of mountaineering teams is often expressed less by having reached an objective than by whether or not their members will ever speak to each other again. Indeed, while the 1953 American expedition to K2 did not summit the peak (Houston & Bates, 1954), their camaraderie, competence, and tireless struggle during the attempt to evacuate Art Gilkey from extremely high on the peak has long been established as the shining example of a mountaineering team (Curran, 1995).

While the personalities of those involved certainly affect how well teams work together, it is often the level of variation in individual goal states and the communication of those variations that determine the quality of the interactions and resulting decisions. Those who are driven to reach the summit as their only goal will rarely agree with those who

place higher priorities on some of the other goals we have presented such as safety and aesthetics (Viesturs, 2011). It is striking how often large goal differences across team members are only realized during the time of most difficult decision making under stress.

Likewise, the interactions between team members can dramatically affect the quality of resulting decisions. In one sense, more individuals mean more information available for the decision process. In the information processing model in Figure 2, the detrimental effects of limited attentional and memory resources can be mitigated by the points of view and experience of multiple personnel. Likewise, the assessment quality of the various options and outcomes presented in the SA model in Figure 3 is often increased by input across team members.

Just as easily, however, team interactions can result in poor decisions. Sometimes referred to as “group think,” perceptions or courses of action generally agreed upon by a group are often not equally understood or supported by each member. Figure 4 also illustrates an area of potential conflict as team members with differing goal states may assign differing values and costs to different outcomes. On this point, co-author JK notes:

In the Fall of 2000 in Tibet, JK and the rest of a small group found themselves struggling to evacuate their friend, desperately ill and incapacitated with HAPE, down from their 17,600 ft (5,370 m) camp. Months before, they had planned a rather tight climbing schedule based partly on how much time each could get off from work. Weeks before, they had lost four days in Katmandu with a visa problem. While none of the members could be considered as the summit or die type, they allowed the shortened timeframe to push them to ascend too quickly with insufficient acclimatization. Even a team discussion that clearly communicated their awareness and understanding of these developing time pressures was insufficient to prevent the resulting events. Finally, one of the strongest members, partly through a desire to do their part, mistook getting ill due to altitude for feeling lousy at altitude (a nearly universal mountaineering experience). That and an insufficiently forceful recommendation of rest from other team members resulted in the very near death of their friend. In the end, only a remarkable combination of bottled oxygen, availability and willingness of local Tibetan villagers, satellite communications, and a desperate day-long drive to Lhasa averted the ultimate tragedy.

### **Adaptation**

Against this array of factors that make high-altitude mountaineering a dangerous enterprise—both the hostile environment, and the negative effects that that environment

has on decision making—there are a set of mitigating factors and variables that can offset many of these risks.

### *Acclimatization*

A common example given to express how adaptive the body can be to reduced oxygen levels is that any person flown from their sea level home to the summit of Everest would suffocate within minutes. Acclimatization is the adaptive process of the body that allows red blood cells to suffuse more oxygen to the tissues of the body thus allowing mountaineers to survive at such altitudes (Houston, 1998). This slow change is triggered by the reduced oxygen levels and requires that the mountaineer spend weeks or even months slowly moving up and down the lower slopes of a mountain. Repeatedly stressing the system in this way (the common acclimatization practice of “climb high, sleep low”) allows the body to adapt to the high-altitude environment. Increased understanding of how this adaptation occurs and decades of trial and error have resulted in acclimatization profiles, schedules, and rules of thumb that help to prevent high-altitude illnesses and the poor cognition that often accompanies these.

A common misconception is that a high level of physical condition at low altitudes translates to good acclimatization at high altitudes. This is not the case. While good physical condition may be necessary for acclimatization, it is far from sufficient, because different physiological mechanisms underlie the two phenomena. Sometimes this misconception plays into the previously noted overconfidence bias, as a climber, feeling strong from good conditioning, will push on to higher altitudes far faster than is safe, suffering AMS and even HAPE or HACE as a consequence (Seedhouse & Blaber, 2005). Hence careful monitoring for the onset of AMS symptoms is essential for each person to judge their own rate of acclimatization with higher altitude.

### *Medical*

Advances in pharmacology and medical equipment have certainly affected the mountaineering death rates. Drugs used to help acclimatization (acetazolamide) and to treat HAPE and HACE (dexamethazone) are now a common part of mountaineering medical supplies. Larger expeditions will likely include a Gamov bag. Essentially a portable hyperbaric chamber, it is used to effectively increase the air pressure, and hence oxygen intake for a patient for a short period of time (Taber, 1990). Such a pressurized facility at 13,900 ft (4,240 m) below the south route on Everest has undoubtedly saved the life of many high-altitude climbers and trekkers suffering from HAPE and HACE. As mentioned in Section 4, regarding the Denali statistics, the use of pulse oximeters to help determine acclimatization levels is increasing.

### *Gear and Technology*

Climbing gear design and realization have made enormous strides in recent decades. New fabrics for clothing and tents, new alloys for crampons and ice axes, new technologies for ropes and stoves—these have all increased the effectiveness and durability of mountaineering equipment while decreasing the weight of what needs to be carried up and down the mountains. In addition, many advances in technology have been adopted by the mountaineering community. For example it is now quite common for satellite phones to be used to get detailed, long-range weather forecasts or to call for assistance.

### *Rescue*

For decades the only rescue possibilities for high-altitude mountaineers involved one's own team or other teams nearby. Increases in communication and aviation technology have made rescue by external agents an increasing possibility. As discussed in the section on Denali, the past three decades have seen high-altitude helicopters repeatedly pluck injured or ill mountaineers from very high on the mountain. In 1996, in what may still be the highest helicopter rescue to date, a highly skilled and daring pilot was able to evacuate critical patients from above 20,000 ft (6,100 m) on Everest (Weathers, 2001).

### *Risk Homeostasis*

An interesting phenomenon, known as risk homeostasis, which has been observed in highway safety (Wilde, 1988), appears also to be manifest in mountaineering. That is, when some safety-enhancing changes are introduced—like better equipment, or greater guarantee of rescue—some climbers may exploit these “safety nets” to pursue more and more difficult (and unsafe) climbs, hence neutralizing or offsetting any benefits of these changes.

### *Oxygen*

The use of bottled oxygen on high-altitude peaks clearly mitigates the effects of anoxia and is an invaluable part of treating high-altitude illnesses. Although its use has certainly allowed a much higher number of successful ascents than would otherwise occur, controversy still exists. As previously discussed, there is a risk trade-off between relying on its availability and dramatic effect on physical capability associated with its sudden loss. In addition, it requires large numbers of extra support personnel just to stage these numerous heavy cylinders high on the peak. Finally, as the weather deteriorates late in the climbing season, the need to quickly retreat from the higher camps makes it nearly impossible to remove all the extra cylinders and other used equipment. The result has been an increasing

junk pile of old oxygen cylinders littering some of the high slopes of these magnificent peaks.

### *Education and Training*

Climbing schools have abounded around the world for decades. To this day, mountaineers returning from trips are encouraged to pass on their hard-won experience. However, unlike more structured environments such as aviation, the world of the mountaineer has little oversight or mechanisms for consistently capturing, analyzing, and disseminating information. Despite this, there is a lot of information available to the mountaineer and there are cases where some conclusions can be drawn. Myriad books exist on a huge range of mountaineering skills. One of the most widely respected texts, *Mountaineering: Freedom of the Hills* (Graydon, 2003), covers topics including basic safety skills, equipment, weather, expedition planning, and leadership. Certainly the educational program instituted by the National Park Service in the United States has helped reduce accidents on Denali. In addition, human performance research external to mountaineering in terms of decision making, group dynamics, and risk analysis is now being included in the curriculum of programs like the Leadership Seminar of the Colorado Mountain Club and the National Outdoor Leadership School. In this regard, the climbing community should consider adopting some form of “debiasing” training (Larrick, 2004).

### **Research Issues**

As alluded to above, compared to aviation (which has corresponding risks), within high-altitude mountaineering there is a major gap in controlled research, with valid studies on the relationship between combined influences of anoxia and cold on human performance. And no studies appear to have addressed the influence of these factors on high-level cognitive decisions, within the information processing framework laid about in the previous pages. Furthermore, compared to aviation, there is also a large gap between the statistics of accidents and mishaps on the one hand, and the analysis of physiological or psychological causes of these on the other; to what extent, for example, is the greater accident rate on summit descent than ascent related to depletion of oxygen and fatigue, to worsening weather as the day progresses, or to the decreased vigilance of danger, following completion of a goal? All of these are critical research issues. From a practitioner's standpoint, the greatest benefits obtained by answers to these research questions will surely be in development of evidence-based safety programs, and in guide training.

### **Conclusion**

The advances in technology and understanding of human performance in the mountains have certainly reduced the



danger of ascent and descent of high-altitude peaks. As with most pioneering endeavors, the magnificent expeditions and accomplishments of the mountaineers of the middle 1900s were clearly much more difficult and dangerous than comparable ascents of today. Despite the steady changes, most mountaineers do not want to remove all the problems or completely mitigate the risks. All the technology can sometimes take away from the experience of being in a high-altitude environment. Without the risk there is no thrill. Without the pain and suffering there is no challenge. Without the dramatic difference in environment there is no adventure. It is hard to predict how mountaineering will look in 50 or 100 years but we believe that most climbers of today strive to keep human performance in this particular extreme environment, well...human.

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