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Thermal Management and Diving Safety

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Abstract

Diving is conducted in a broad range of thermal environments, many of them involving some degree of cold stress. Coldwater diving can magnify many hazards, including compromises in physical performance, decision-making, and decompression safety. Appropriate thermal protection is important for divers, with hazards created by both inadequate protection and overprotection. Divers are best served by prioritizing safety over absolute comfort and being mindful of the total potential impact of any practice or equipment to be used. Hypothermia is not a realistic concern for any kind of normal diving activity, and passive protection will often be sufficient to maintain physical performance and clear thinking. Active systems may be appropriate in some cases, but they can also adversely affect decompression safety. Careful consideration should be given to if and how they should be used. The best practice is to minimize unnecessary and fast heating before, during, and after diving. No dive computer effectively assesses the thermal status of divers, let alone measures the true impact of a host of related factors on decompression safety. While real-time monitoring might one day allow for dynamic decompression algorithm adjustment based on thermal state, this likely remains well in the future. At present, the obligation for safe thermal management remains with the diver.

Keywords: cold stress, decompression, health, hypothermia, physiology, thermal protection

Introduction

Diving is conducted across a broad range of thermal environments, from a peak beyond 38ºC (100ºF) to a minimum of -1.9ºC (29ºF). Water has a 3500-fold greater heat capacity than air, allowing massive transfer of heat energy to or from an unprotected body. Effectively, temperatures that may be comfortable in air may be intolerable in water for more than short periods if a diver is unprotected. While overheating is possible in the warmest water, especially for an exercising diver, the much more common issue is cooling stress, and thus will be the focus here. This report is developed as a follow up to a paper delivered in the Rebreather Forum 3 conference (Pollock 2014).

Hazards of Cold Water Diving

All diving involves hazards, but several can be magnified by cold water. The state of the hands is often the primary limiting factor, resulting from a necessary compromise between thermal protection and dexterity. Even light gloves can adversely affect performance, with the degree of impairment increasing with the bulk and flexibility. Both dexterity and sensitivity are compromised, which can affect the ability to equalize middle ear pressure and to locate and manipulate equipment. Buoyancy control is more difficult due to compromised dexterity and the additional equipment and ballast weight worn. Managing a greater gas volume requires more compensation during both descent and ascent, sometimes even manipulation of multiple systems, often a drysuit and separate buoyancy compensator. Greater control issues relate to both ballast weight retention and ballast weight release (ditchability). Many divers prioritize ballast weight retention, but the appropriate course of action may be retention or ditching depending on the situation. Once more, a compromise to allow for both should typically be found.

Vertigo can be more of a problem in cold water, not just due to the dexterity issues for equalizing, but also since hoods can increase the likelihood of external ear squeezes, and a ruptured tympanic membrane that introduces colder water into the middle ear can produce a greater effect. Practically, the likelihood and magnitude of both alternobaric and caloric vertigo may be increased. Cold water and the restrictive suits worn to protect against it are also two of the multiple risk factors for immersion pulmonary edema.

The thermal state of divers can have complex effects on performance, decompression stress, and decision-making. In addition to the acute effects, repeated coldwater exposure is also a primary risk factor for the development of exostoses (surfer's ear), expressed as an overgrowth of bony tissue in the outer ear canal.

The primary focus of this discussion is on the physiological hazards of cold stress, practices that can influence them, and strategies to manage them.

The Importance of Thermal Protection for Diving

Divers frequently ask what thermal protection is appropriate for a given set of conditions. The only simple answer is that it should be sufficient for impairment to not be a problem. Thermal stability is increased with larger body sizes, lower surface area to body mass ratios, greater subcutaneous fat thickness (natural passive insulation), and greater muscle mass (increasing metabolic heat production through non-shivering thermogenesis, shivering thermogenesis, and exercise). The thermal state is influenced by activity levels, and even by limb movement that can alter the surface exposed to the ambient environment.

Thermal stress can play an important role in physical performance, concentration, decision-making, and decompression safety. Consideration of thermal protection should include the pros and cons of the available options and the most appropriate prioritization. Figure 1 shows two strategies for prioritization. The comfort-focused approach is probably the natural default, with comfort as the top priority. There is certainly logic in this, since a diver who is comfortable is less likely to have issues with either physical performance or concentration, and is probably less likely to make poor decisions due to discomfort. The problem with this approach is that the potential impact of overwarming on decompression safety - which may be substantial - will often be ignored or given minimal consideration as an afterthought.

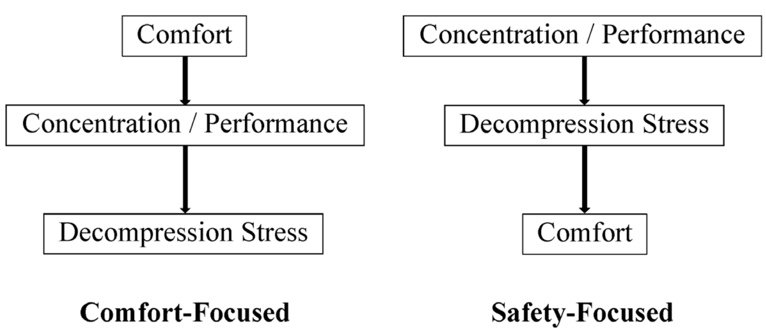

Figure 1. Comfort-focused vs safety-focused schema to prioritize planning for thermal protection.

The chief problem is that the increasing array of thermal protection strategies, particularly those involving active heating, can influence decompression stress to a degree often not appreciated by divers. It is important to remember that the availability of tools and options does not necessarily mean that they are safe. The best example of the impact of manipulating skin temperature on decompression stress was provided by a study completed by the US Navy (Gerth et al. 2007). Clamping skin temperature at warm and cool temperatures had truly dramatic effects on allowable bottom times and rates of decompression sickness. Fundamentally, inert gas uptake during the descent and bottom phase of a dive is increased when a diver is warmer, and decreased when a diver is cooler. Inert gas elimination during the ascent and stop phase is increased when a diver is warmer and decreased when a diver is cooler. Details of this work and the impressive magnitude of the effects on decompression outcome are described in another paper in these proceedings (Pollock 2024). The critical point is that the importance of the timing and intensity of both thermal state and exercise are probably second only to the dive profile in influencing decompression risk. While the Gerth et al. (2007) study is important for its control and elegance, similar patterns were seen previously in a field bubble study of coldwater divers who were either well protected or inadequately protected (Dunford and Hayward 1981), and in a more recent laboratory study of nitrogen uptake and elimination with different clamped skin temperatures (Pendergast et al. 2015).

The impact of thermal manipulation on decompression stress means that it should not be an afterthought. A safety-focused approach is likely to provide greater overall protection for divers. Ensuring sufficient protection to maintain concentration and physical performance is the top priority, with consideration of the potential impact on decompression stress right behind it. Comfort remains on the list, but definitely in last position.

The thought of downgrading the importance of comfort may be unwelcome to some divers, but the reality is that there is little concern for physical injury as long as the ability to preserve concentration and physical performance is maintained. It is important that these capabilities are preserved on all dives, so additional protections may be needed for longer dives or those likely to involve lower levels of physical activity. The critical aspect is that excessive warming, that most easily achieved through active heating systems or exercise, should be approached with great caution. Active heating may be appropriate, and even necessary, in some situations and for some divers, but the potential impact on decompression safety should be weighed carefully. This must be done by the divers and team leaders since it is a notable weakness that the influence of active heating on decompression stress is not adequately addressed by manufacturers. These are "buyer beware" tools.

One of the challenges of active heating systems is the risk of failure, which exists on any dive. A major limitation is that active heating systems tend to provide less passive protection than purely passive systems do. This means that, in the case of system failure, the diver may experience a greater degree of compromise than would otherwise be the case.

The potential issues can be illustrated through an example. A diver planning a relatively long and deep coldwater dive might want to opt for battery-powered, active heating. Having the active heating on during the descent and bottom phase of the dive will increase the inert gas uptake. This can be moderated if the device is set to the lowest acceptable setting, but there will remain some uptake influence. If the system continues to operate throughout the dive the increased uptake may be partially met by augmented elimination, However, if the system fails late in the bottom phase or during the ascent and stop phase the discomfort can be acute given the lesser passive protection common to active heating ensembles. In addition to the discomfort, this creates the warm/cool pattern of augmented inert gas uptake and impaired elimination that creates the greatest risk from a decompression perspective. If a diver gets cold it is often normal for a question to form as to whether or not accelerated decompression would be a good idea. This is where divers can get into more trouble. The reality is that the diver who is cool or cold during decompression should be increasing stop time to allow sufficient inert gas elimination since the rate is impaired. The decompression profile should be extended for safety in this scenario, not abbreviated. There is a need to control decision-making for safety purposes, not comfort purposes.

A question that often comes up at this point is whether the risk of hypothermia is important enough to justify an accelerated exit. Hypothermia is frequently discussed in relation to diving, so this may seem reasonable, but the reality is that it is much more of a fanciful hazard than a meaningful risk. The suits worn for diving, even the less than ideal and partially failed ones, provide sufficient protection to practically eliminate the risk of hypothermia. Hypothermia, by definition, requires the body core temperature to drop below 35°C (95°F), which is a substantial fall from the normal 37°C (98.6°F) reference temperature. This is not easy to achieve. A diver may be cold, and even miserable, but it is vanishingly unlikely that they will become hypothermic over the course of even a fairly extreme dive. For example, a diver in -1.9°C (29°F) polar water completed a 43 min dive in a drysuit with a failed front entry zipper that was flooded from the start, experiencing only a 0.3°C (0.5°F) drop through the dive (Pollock 2007). The diver was cold and shivering, but nowhere close to the threshold for hypothermia. Prospective studies have demonstrated similar outcomes. An evaluation of 16 oxygen rebreather divers wearing 10 mm neoprene farmer john and jacket wetsuits resting at 6 m in a 5°C (41°F) pool experienced an average core temperature drop of only a 0.7°C (1.3°F) over a six-hour dive, again not close to the threshold of hypothermia (Chapin et al. 2021). An evaluation of 13 rebreather dives wearing a similar 10 mm wetsuit configuration during resting dives at 9.1, 15.2, and 22.9 m (30, 50, and 75 ft) breathing air or heliox experienced similar modest mean core temperature drops well above the threshold for hypothermia (Kelly et al. 2023).

While hypothermia is not a realistic threat for most diving situations, cold stress is still very important. Divers need to be able to think clearly and perform effectively to do what is needed. The stress of cold hands is probably the most debilitating. This is most likely to occur in extremely cold water when a dry mitt/glove or actively heated mitt/glove fails. Water temperatures below 8°C (46°F) require careful consideration, particularly if long run times with obligatory decompression are involved. Divers must be prepared to manage adverse events with multiple priorities to avoid jeopardizing safety.

Controlling Heat Exchange

The four major avenues of heat exchange are radiation, convection, evaporation, and conduction. Radiative heat transfer, the flow of electromagnetic energy from and relatively warm body to a relatively cooler body, is often appreciated between dives on sunny days, but radiative loss in cool or cold water is generally not a major pathway. Buying suits or undergarments with "titanium" or similar linings marketed to reflect heat energy back towards the body are likely of limited value. Convective heat transfer, that mediated by currents of moving gas or liquid, is most noticeable in cold water with ill-fitting wetsuits that allow substantial introduction of water during movement. Convective heat loss can be substantially reduced with effective dams at neck, wrists, and ankles, and even more effectively eliminated in leak-free drysuits. Evaporative heat loss, resulting from vaporization of surface water, normally occurs at the skin and in the respiratory tract. Evaporation from the skin is not a problem during immersion since evaporation is not possible in a saturated environment. This is true for no-suit, wetsuits, and drysuits once the last has been sealed for a few minutes. Respiratory heat loss, on the other hand, can be important in open-circuit diving when cold, dry inspired gas must be warmed and humidified with each breath. Respiratory heat loss is substantially reduced in closed-circuit diving since the gas in the circuit is saturated with water vapor. Closed-circuit gas is also warmed by the exothermic carbon dioxide scrubber reaction. Unfortunately, the exothermic reaction warming is less of a benefit than often desired since there can be substantial cooling of gas in the inspiratory and expiratory arms of the circuit.

The major avenue for heat loss in cold water diving is conduction, the heat flow between objects in physical contact. The high heat capacity of water produces conductive loss rates 20-27 times greater than those found in air. The inverse of conduction is insulation, and it is insulation that is most important for diver protection.

Thermal Protection for Cold Water Diving

Passive protection

Passive warming is provided by wetsuits and by drysuit plus undergarment ensembles. As discussed above, passive protection can be substantial, even if not to the highest level of comfort. Passive insulation is provided by a range of materials and designs. Manufacturers have put a lot of effort into designing suits that are comfortable, sometimes with multiple materials to protect mobility. An unfortunate shift, however, has been away from the provision of actual test data on system performance. Independent, standardized test results are almost never made available. Divers are increasingly forced to rely on marketing material and community enthusiasm to make decisions. This may not be a problem for ensembles used in moderate conditions, but the deficiencies of even the best systems become apparent in colder water. Testing systems in water temperatures ≤4°C (39°F) may not be necessary for warm water divers, but the experience can be much more informative than the promotional claims.

Drysuits are available in thin "shell," trilaminate, traditional, "compressed" or "crushed" neoprenes, and other variants. Suit weight, flexibility, durability, and other options will differ, giving divers a lot to consider. Selections may be made for water temperature, environment, bulk, weight, or visibility.

The undergarments and trapped gas provide the majority of the insulation in a drysuit system. It is generally not the material that is most important in providing insulation, but the gas that is trapped within it. Persistent loft is most desirable, that which is maintained even when the drysuit and undergarments are affected by hydrostatic pressure. Both flexible and rigid form garments can trap gas, with weight and bulk sometimes being considerable. The hope for aerogel-encapsulated materials that could trap gas and improve insulation with very little weight and bulk has not been realized. The extremely light material that works very well in aircraft insulation applications does not work well with the forces and motion associated with diving and laundering.

Argon was proposed as an alternate to air for drysuit inflation to capitalize on its lower thermal conductivity (and therefore higher insulation value). It has been shown to be of fairly limited practical value, however, so is less often seen. One of the problems is distribution, which is not uniform when hydrostatic pressure pushes the free gas to the top of a suit space. The hint of association with argon in undergarments can now be seen, but it is unclear how it is incorporated and what if any role it plays in improving insulation. Testing has been conducted on embedding hollow microspheres into polymer plates that can be built into suits (Demers et al. 2021), but the stiffness of such plates would undoubtedly create mobility issues demanding inconsistent coverage, especially in the vicinity of joints, making the effectiveness less than clear.

Active protection

Active warming was once primarily provided in the form of hot water suits for commercial operations, but battery-powered, electrically heating garments are becoming increasingly common for all forms of diving. Improvements in battery technology have increased the amount of heat energy that can be delivered and the operational duration.

The popularity of this technology is undeniable, but thoughtful use is important. Foremost, only systems specifically designed for diving application should be used. Serious injury can result from using systems not designed for the diving environment (Johnson-Arbor 2022). In any case, the use of active heating adds complexity in terms of equipment required, power and charging needs, and duration limits. While personal comfort can be improved, the potential to adversely affect decompression safety must be borne in mind. The work described above (Gerth et al. 2007) demonstrated that decompression stress can be increased by keeping divers warm throughout dives, and that the stress will increase dramatically if warmth during the descent and bottom phase is followed by a loss of warmth during the ascent and stop phase. Use of these systems may still be appropriate, but only with a full appreciation for the implications and with appropriate strategies in the event of failure.

Monitoring Thermal Status and Decompression Stress

Thermal stress is determined by the thermal protection worn and used, diver habitus, and physical activity. It is not established by water temperature, which is the only thermal measure regularly captured by dive computers. Core temperature is unlikely to be helpful since, as discussed above, it tends to change little over the course of a dive. Skin temperatures could be more informative, but measures from many sites would be needed to capture the regional differences that could play a role in altering vasomotor response and, subsequently, inert gas uptake, elimination, and tissue solubility. It is true that some dive computers capture a single skin temperature measure, typically from the anterior chest, but this does little to describe what is happening across the entire skin surface. The norm for controlled laboratory studies is to compute mean skin temperature from 10 different site measures. The number of sensors needed to capture the dynamic conditions of real-world diving would be much greater. For example, there could be vast regional differences for a drysuit diver with an intact suit, with small or large leaks in one or more limbs, with different or variably insulating layers, etc. Simply put, current decompression algorithms cannot assess the impact of thermal state in a meaningful way. Real-time monitoring might one day allow for dynamic decompression algorithm adjustment, but this will require many, many sensors and a vast collection of temperature data, high resolution inert gas uptake and elimination data, and outcome data. Collecting the necessary skin temperature data will be possible in the future with garments that can incorporate as many sensors as needed, but getting simultaneous high resolution inert gas uptake and elimination data will be more difficult. This is unlikely to be achieved for many years. And even once the necessary data are available it will be another huge hurdle to effectively model the impact of a host of subtle differences on risk and outcome. The concepts are relatively simple, but the data requirements to turn concepts into effective tools are truly daunting. Realistically, human decision-making that takes into account thermal states over the course of a dive will remain best practice for the foreseeable future.

Practical Guidance on Thermal State to Minimize Decompression Stress

Practical guidance to minimize the potentially negative impact of thermal stress through the diving timeline is summarized in Figure 2.

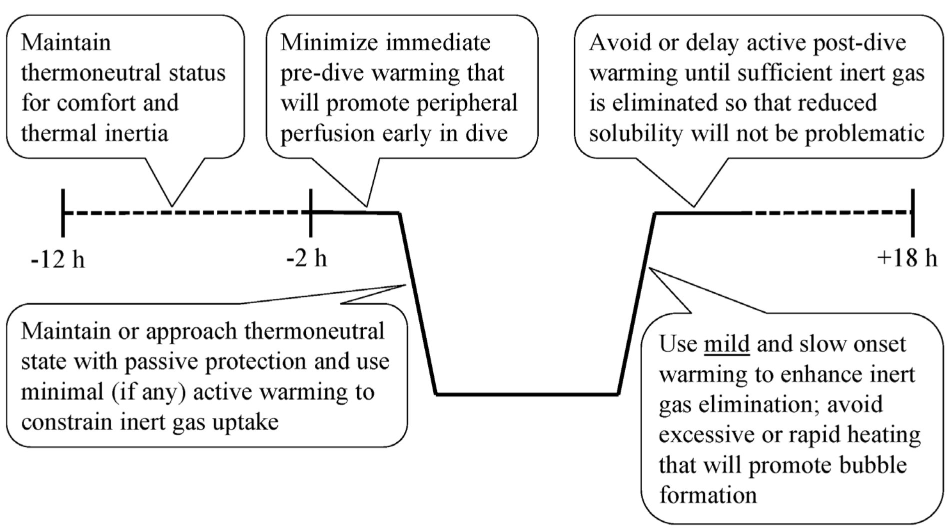

Figure 2. Guidance to minimize the negative impact of thermal state on decompression stress.

It may be desirable for divers to be cool during the descent and bottom phase, but this is likely only realistic in a limited range of conditions. The more achievable goal is to have divers avoid active warming pre-dive and to remain as close to thermoneutral as feasible during the pre-dive, descent, and bottom phases. This is more likely to be achieved by dressing for diving in a cool space and minimizing exercise and active warming throughout the descent and bottom phase. The net effect is a reduction in unnecessary inert gas uptake. Mild and slow onset warming can then be encouraged during the ascent and stop phase. The "mild" nature of warming is important to minimize complicating effects. Rapid warming will decrease the solubility of inert gas in the superficial tissues and can promote local bubble formation and "skin bends". Employing exercise to promote warming can also be problematic since anything more than very light exercise with low joint forces can promote bubble formation in any working tissue. Restricting efforts to mild warming takes discipline for a cold diver, but this is, again, the prioritization of safety over comfort. Mild warming can be achieved if the diver passes through thermoclines during the ascent, if an active heating garment is turned on to a low setting or slowly increased from a low setting to higher settings, or with very light exercise with low joint forces. Any effort to warm up beyond passive insulation during the post-dive period should be delayed to reduce the inert gas load. This means no hot showers, hot tubs, or exercise, all of which can increase bubble formation and overall decompression stress. The time required is difficult to quantify, but it must be remembered that cooling impairs inert gas elimination, so the risk window is prolonged, sometimes substantially. Practically, it is unlikely that warm drinks would have a measurable impact, so some relief is possible with them, but the focus should be firmly on minimizing unnecessary stressors in the post-dive period. Very practically, if a diver feels the need to get into a hot shower or pursue any other active warming post-dive the dive profile should be moderated to add a safety buffer. If delayed gratification is a possibility, warm thoughts about a future hot shower, hot tub, or exercise are best.

Conclusion

Thermal state can influence physical performance, decision-making, and, directly and indirectly, decompression safety. Management of thermal stress benefits from advance planning and careful consideration of all effects of any practice or equipment to be used. Divers should, as a rule, minimize unnecessary warming in the pre-dive period and the descent and bottom phase of dives, and employ only modest and low physical strain warming during the ascent and stop phase. Post-dive warming should be delayed to allow until the inert gas load is substantially reduced.

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QUESTIONS AND DISCUSSION

JAKUB SIMANEK: I have a question about repetitive dives in cold water. Do you have recommendations for warming between dives?

NEAL POLLOCK: My recommendations would not change for repetitive diving. I favor using passive protection if function and reasonable comfort can be maintained. My goal is to maintain thermoneutrality where feasible. I would avoid active warming and exercise between (or following) dives. If active warming is needed it would be best set on the lowest level acceptable for the descent and bottom phase and then slowly increased (incrementally) during the ascent phase, avoiding excessive heating at all times. Keeping active heating at a low level between dives could minimize discomfort and reduce a desire for more aggressive warming such as in a hot shower or hot tub that would quickly reduce the solubility of dissolved gas and promote bubble formation.

JAKUB SIMANEK: You focused on the outside thermal protection. What about warm food, like hot soup and so on?

NEAL POLLOCK: It is common practice to give conscious cold victims hot fluids. While this is fine for subjective comfort the actual amount of warming provided is very modest. Picture a bathtub half full of water, about the volume of an adult body, at a temperature around 35ºC (95°F), the threshold for hypothermia. Now picture a liter of fluid as hot as you could drink it. Pour it into the bathtub. Does it do much? No. The warm fluids do not provide much warming but they may make the person feel better. Warming the gastrointestinal tract likely does not generate the same risk as warming peripheral tissues that hold more dissolved inert gas.

MARK CANEY: As rebreather divers know, it feels nicer in cold water breathing from a rebreather because you are getting warmer gas. Is there any benefit to actively heating the gas that a diver breathes?

NEAL POLLOCK: There have been cases in which additional active heating of gas has been employed in rebreathers. One manufacturer recently constructed a shroud to wrap around a scrubber canister to augment the exothermic warming of the scrubber reaction. There can be discomfort breathing gas warmed above 50ºC (122°F), but lesser temperatures are well tolerated. Actively warming breathing gas can increase comfort, possibly with less risk than warming peripheral tissues.

DAVID DOOLETTE: Can I add something to that? When you go into very deep diving, you have to heat your gas. Below 120 m (400 ft) or so you have to actively warming your gas. Otherwise, you can get hypothermia just from the heat loss. And the gas in your rebreather, depending on the design, is not particularly warm. It is warmer than open-circuit gas, but if you have an inspiratory counterlung you will be breathing gas near the water temperature. You lose most of the heat as it passes through the counterlung. So you can benefit from active heating.

NEAL POLLOCK: I mentioned the Piantadosi and Thalmann (1980) study that addressed unrecognized hypothermia. They recommended minimum inspired gas temperatures increasing beyond 107 m (350 ft). At that point the minimum inspired temperature was to be -3ºC (27°F), with step increases to 12°C (54°F) at 183 m (600 ft). So while it will be uncommon for rebreather divers to spend sufficient periods at these depths to make it a priority concern, there are certainly situations in which active warming of breathing gas may be important.

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ALEJANDRO GARBINO: Has anyone looked at measuring either systemic vascular resistance or some derivatives of that to compare the different insulation properties other than using clothes?

NEAL POLLOCK: There is interest in Europe in flow-mediated dilation. I have never been convinced that it shows anything of particular value. But beyond that, I do not know.

I want to take the opportunity to add a comment regarding something that came up earlier today. There was a discussion about identical dives. I believe that it is rare for the experience of different divers to be truly identical. There will often be minor differences that can have meaningful impact. We have to be careful. Divers have different size, shape, body composition, garment insulation, etc. There are a lot of things that can alter responses.

SANDRA CHAPMAN: You mentioned the significance of the impact of thermal stress on cognitive performance. Could you expand a little bit about the research that is been done in that area. I know there was an ONR (Office of Naval Research) funded project at NEDU (US Naval Experimental Diving Unit), but it was a little flawed by a subjective test that had learnability factors.

NEAL POLLOCK: I do not know of well-controlled studies that have resolved the questions. Projects often include cognitive measures as an add-on.

ATTENDEE: Do the results relate to skin bends only or bends in general?

NEAL POLLOCK: Skin bends can be driven by skin warming. Active heating garments certainly have the potential to promote skin bends. Whether mild warming would precipitate whole body bends, I do not know how much data we have. When someone comes in to be treated for decompression sickness, we know little or nothing of their tissue temperatures. Temperature monitoring is not done. Even if reports having an active warming garment on high or on low, the effect on tissue temperature is unknown. We simply do not have quantifiable data. What we do know is that skin bends can develop. We also know from the Gerth et al. (2007) NEDU study that whole body warming from the outside can have remarkable impact on decompression outcomes. Twenty percent of the subjects developed symptomatic DCS in the warm/cool group with a 30-min bottom time.

ATTENDEE: Do you see a day where manufacturers are going to incorporate temperature sensors to detect our core temperature and incorporate that into the decompression software?

NEAL POLLOCK: Core temperature readings will probably not do much in most cases. There is interest in figuring out how the thermal information matters, but the presentation included demonstration of how core temperature does not change much even when a drysuit is flooded in -2ºC (29°F) water. Core temperature values are likely to be fairly uninformative. Skin temperature will ultimately be more informative, but currently not easy to collect. Mean skin temperature is classically calculated in laboratory studies with 10 sample site measures. Efforts with four sample sites have been used, but there is greater risk of missing important differences. Temperature data are difficult to interpret in any case. Temperatures will vary with surface area to body mass ratio, tissue insulation, clothing insulation, exercise, and environmental conditions. A tremendous amount of field data is needed to begin to model the impact of specific differences. We are at a point where we understand the risk concepts, but do not have sufficient data to inform decompression algorithms in a meaningful way. Current models are actually quite rudimentary. We have a long way to go before models can effectively predict physiological effects.

JANE RUCKERT: I was interested in the plots that you had with the body temperature and the hand temperature and you point out that the body temperature basically did not change with the drysuit and wetsuit, but the hand temperature showed something like a 5ºC (9°F) difference.

NEAL POLLOCK: Some of the findings were difficult to interpret in that study. The drop in hand temperature indicated that they were not adequately protected, but the subjects were described as using their own equipment and there were no details on handwear. I can say that hand discomfort is frequently the biggest limiting factor in cold water diving. A flooded dry glove can quickly prompt an abort decision in cold water. The problem is that we do not know what was worn or the amount or character of the protection provided.

Handwear is critical, at best striking a balance between warmth and dexterity. Dry mitts with ample insulation can be warm, but will severely limit dexterity. Flooded dry mitts or gloves can be so ineffective that coldwater dives must immediately end. Actively heated gloves can reduce the bulk somewhat but again can be grossly inadequate if the heating is lost. Thick wet mitts with minimal compressibility, often in the form of a three-finger mitt (thumb, index finger, and three fingers) can offer a good compromise on thermal protection and dexterity in addition to being less prone to catastrophic failure. There is no single solution, but there are a variety of options that may be fit for purpose.