Checklists Save Lives

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Abstract

Critical processes that depend on active human input are at risk for catastrophic failure due to the limits of human memory, as well as cultural background issues that may impair performance. In order to make complex activities safer – such as aviation, surgery and scuba diving –evolutionary changes from traditional practices have been necessary. This article explores the use of checklists in general and proposes some innovations to further their incorporation into recreational rebreather diving.

Introduction

In complex human activity, the risk of failure is often traced to human factors. Specifically, it can be traced to failures of the human brain to perform reliably and consistently, especially in stressful situations. Omitting key steps, or overlooking signs of incipient risks and flaws, can result in the creation of an accident chain with catastrophic results.

As human beings attempt ever bigger, more complex and more dangerous endeavors, the risks of failure increase. No matter how sophisticated our engineering solutions become, any process that depends at any point on the timely and accurate action of a human brain will always have a weak link that no amount of skill or training can eliminate.

To address this problem, a number of solutions have evolved in recent decades that seek to formally codify the critical steps in many of the processes that make up these endeavors. Moving these standard operating procedures from human memory to written text helps maintain accuracy when external stressors or routinization threaten to sabotage the whole system. Furthermore, by making these procedures delivered by an inanimate object – a written list – rather than an authority figure, many of the cultural and political overtones that interfere with safety and efficiency can be eliminated. Physical, written checklists can do a lot to support the safe execution of these processes by formalizing standard procedures, encouraging communication, and backing up human memory at a time when it is needed the most.

This paper explores these potentially lifesaving documents in a number of ways, looking at three activities: aviation, surgery and scuba (focusing on recreational diving). We will review the history of their development, the desiderata for good design, and the limits and common obstacles to adoption of checklists. Hopefully, this material will be especially useful to recreational rebreather divers, a sport where they have been implemented on a very limited basis, and with no external regulatory enforcement or oversight.

Discussion

Aviation, surgery and scuba diving have much in common. They are all highly technical endeavors with the potential for lethal harm following the failure of any of a number of critical processes. They each take place within the context of a well established culture, which has a significant impact on the way that these processes are carried out. They are all relatively new human activities, none of which existed (at least not in modern form) a century ago.

Furthermore, their traditional practitioners were usually people of great skill and training, but also of great ego and confidence. In many cases, this confidence crossed the line into overconfidence. This could lead to poor communication with less exalted but still critical team members, with tragic consequences[1,2]. Making critical steps dependent on human memory clearly has its limits, seen as complexity grows and the demands become more numerous.

The modern checklist was developed following the crash of the prototype of the Boeing model 299 bomber in 1935. Helmed by one of the finest test pilots in the US Army Air Corps, who was himself under the observation of Boeing's chief test pilot, the aircraft was lost soon after takeoff because the gust locks used to secure control surfaces (e.g. rudders and flaps) on the ground were not released prior to flight.

The Army staff who studied this tragedy made a great leap in understanding. They had the crucial insight that failure (in this case, of human memory) *would* happen, and the way to limit harm was to *plan* for it. They realized that as the complexity of any endeavor grew – in this case, a new and very complicated airplane – relying on a single human brain for critical processes wasn't wise, no matter how well trained and experienced that person was. They came up with a written checklist, and model 299 went on to become the celebrated B-17 bomber with 13,000 units in operation and an excellent safety record.

Modern aviation still relies heavily on written lists, both in pre-flight checks and emergencies. While a few of the latter are "memory items" - things that must be done very quickly with no time to run a list - others are either short single page cue sheets (quick reference checklists, or QRC), or longer manual-style instructions (quick reference handbooks, or QRH), that are pulled out and worked through when dealing with in-flight failures.

In aviation, checklists have been adopted widely, and for many decades - from single engine propeller planes to jumbo jets and sophisticated military aircraft. They are enforced by government agencies and corporate policy, and for the most part accepted unquestioningly by the crew.

The surgical checklist is of much more recent origin. While some degree of formalization of operating procedures has been around for years, the current surgical "timeout" checklist stems from the 2007 World Health Organization "Safe Surgery Saves Lives" project. They have been accepted for the most part by health care workers, some enthusiastically, some grudgingly. Checklists seem to have significantly reduced some of the more common causes of excess surgical morbidity and mortality[3], but they do have their limitations and downsides[4,5,6]. These are also generated and enforced by external authority; a more regional process than with aviation. However, a national non-governmental organization that offers voluntary hospital certification (JCHAO) does confirm implementation[7].

Checklists work not only by eliminating missed steps due to memory lapses or normalization of deviance[8], but by changing culture[9], promoting communication and stressing that ALL team members have an important role to play in ensuring safety, acting as checks on each other. And they share common features – a pause point is a natural or triggered point in a process when a checklist must be run. A forcing function is an aspect of design that deliberately interferes with user activity to minimize bad outcomes. Figure 1. shows an example of these features embedded into the software of a rebreather controller.

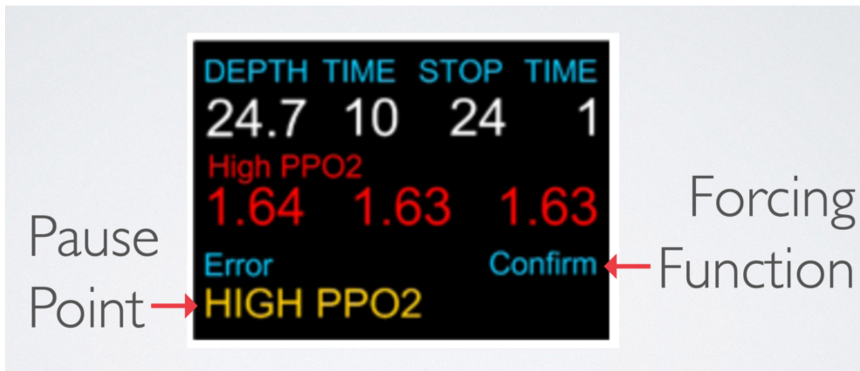

Figure 1. Pause point and forcing function on a rebreather controller. The error triggers the pause and the confirm button must be pushed to return to a normal display.

There are two main types of checklists: read-do and do-confirm. The former involves reading tasks from a list and then confirming them as completed. This would be appropriate for critical procedures that are rarely done (like restarting an engine in flight). The latter may involve tasks done from memory, and then confirmed from the list. This type would be used when the actual order or timing of the steps is not so critical, as long as they eventually get done in time (such as the use of preoperative antibiotics). An enhanced version of the read-do checklist is the challenge and response (or read-do-confirm) approach, where one team member reads an item out loud, the second team member completes the tasks, and then replies to confirm completion.

Checklists work well with relatively short processes with unvarying steps, involving highly motivated individuals, especially if there is the risk of catastrophic failure. They are less helpful in complex situations with ambiguities and day to day variances. A checklist introduced by external authority without consideration of systemic issues or workplace culture is often doomed to fail. If there is no motivation for adoption, then compliance will be low. And if the list isn't continually reviewed and updated or corrected, poor practices may become ossified as dogma.

It is important to avoid certain pitfalls in checklist design[10]. Different groups using the same checklist need to have the ability to customize it – for example, appropriate sterile technique is very different for tonsillectomy and hip replacement. Insisting on a one-size-fits-all model with no option for an "n/a" answer (not applicable) will result in the normalization of deviance, as users realize that some of the steps don't apply to them, despite the veneer of safety that a checklist may present to outside observers.

Checklists that are too long or which include non-essential items quickly fall into disuse. Ambiguous wording may prevent accurate completion of tasks. And most of all, checklists designed without input from people who actually DO the activity in question almost always are failures.

Now that we have seen what checklists can do and how they have been applied elsewhere, let's consider their use in recreational scuba diving. There are, of course, significant differences in this context between diving and aviation or surgery. Scuba – especially at the most challenging levels – is often a solitary activity. Even in team diving, the actual task performance and equipment utilization is done by the diver alone. This means that unlike many flight and operative checklists – where a key benefit is the diffusion of responsibility to team members - the responsibility for accurately completing all steps will fall on one person

The equipment is non-standardized, and in some cases, designed or built by the diver. Furthermore, while this varies from country to country, in the United States there is no regulatory agency that governs diving at all. There are organizations that set training standards and the US Department of Transportation regulates scuba tanks, but once you get your tanks filled, no one can tell you how to dive.

Finally, while there certainly have been tragedies where one dive team member's actions have cost the life of another, this is a rare exception. The victim of a scuba system failure is almost always the diver in question. In the operating room, of course, the staff generally survives, with one notable exception[11]. And while air crews risk their own lives if they fail, it's really the millions of airline passengers every year that drive the federal and corporate insistence on doing everything possible to maintain an excellent safety record.

Checklists are commonly used in scientific and commercial diving, but that is beyond the scope of this article. In recreational diving, there is some evidence that their use may reduce the occurrence of mishaps[12], and possibly injuries or fatalities, even when compared to memorized lists (e.g. mnemonics)[13].

While mnemonics are not checklists, they are more widely familiar to open circuit divers. These have problems of their own, most notably the need to force tasks to be labeled with non-intuitive names so as to make up a "clever" acronym. But they at least slow down the pre-dive process enough so that omissions and other simple mistakes are more likely to be caught. Unfortunately, even these are uncommonly used in real-world practice.

Apart from prospective research studies, the use of a physical checklist in recreational diving has been primarily a feature of rebreather training, with waning utilization after certification. The benefits of written checklists for rebreather divers have been clear for some time[14]. Despite the fact that the agencies all teach and preach the value of closed circuit rebreather (CCR) checklists, actual usage is disappointingly low. The question then arises – why is this, and what can be done about it?

Multiple agencies and manufacturers have generated checklists on small slates that can be carried on dive gear, but they are rarely used. Why has something that has proved so worthy in the high stakes worlds of the cockpit and the operating room not gotten any traction among scuba divers? This is a hard question to answer - even the few studies that attempt to approach this scientifically cite numerous difficulties in analyzing trends with so many potential psychological and cultural variables.[15] Until a true cultural shift happens to make these aide-mémoires not only acceptable but expected practice by a wide range of divers, they won't be adopted, as new divers mirror the slack practices of their mentors[16].

In order to address this issue in one small area of scuba – checklists for recreational CCR diving – the author analyzed some of the reasons why existing versions are rarely used in hopes of providing at least a design solution to this problem (although the more challenging culture shift remains a major roadblock). It should be noted that the following is about the pre-splash checklist done just before diving, not the longer and unit-specific build checklist that is also crucial for correct assembly of the rebreather and confirmation that it is mechanically sound before use.

The checklist sticker (Figure 2) was designed to fit cleanly on the edge of the rebreather controller, strapped to the diver's wrist. It is printed with waterproof ink on waterproof paper, although it is cheap and easily replaceable should it wear. Although it is appropriate for many types of CCRs, the author has made the PDF and Word® files freely available for customization. It is similar to the Critical Control Check sticker published by the training agency GUE.

Figure 2. The author's checklist sticker project

While waiting for checklist usage to become more widely acceptable in our little tribe, some divers may prefer to be less obvious about using a checklist; the sticker only requires a glance at the wrist. Of course, the counter argument to this "benefit" is that new divers shouldn't hide their use of a checklist, especially if they want to help change rebreather culture!

Another benefit of the sticker over the printed cards is that it doesn't require a free hand to manipulate. The sticker leaves both of the diver's hands free. Furthermore, it is always going to be there, there is no question of forgetting it at home. And similarly, there is no need to stow it after use.

Finally, let us consider the use of checklists in emergency situations. This is one area where diving and surgery have yet to do what aviation has done – the creation of QRC and QRH level procedures, as mentioned above. Every emergency in diving and surgery relies on memory items. Of course, open circuit diving and surgery rarely involve "slow emergencies" that would benefit from a checklist - If you nick the aorta or blow out a low pressure hose, you don't have time for one. But rebreather diving is different, in that life threatening failures can happen over a longer period of time (as they can in aviation).

Much of rebreather training involves memorizing a series of flowcharts for failure modes[17]. The idea is that when one of these failures happens, the diver will quickly and efficiently go through these lifesaving steps. The standard pushback to the idea of in-dive checklists is that if you need one, you shouldn't be diving a CCR (that's a common response to many safety initiatives, actually). But the problem is that even the best divers often overestimate their training and familiarity with protocols that they may not have run through in years. Very few divers really drill themselves on all of these frequently enough to make them truly second nature – like the pilot's memory items – especially as time goes on.

And even if they did, these emergency procedures are often needed at times of significant neurological or psychyological stress – the diver may be panicked, hypoxic, hypercapnic, etc… All of these degrade performance in even the most skilled diver. Pilots know this, which is why they keep their complex, rarely used, emergency procedures in a book that they can refer to in flight. As Captain Sullenberger was steering flight 1549 into the Hudson river[18], his co-pilot Jeff Skiles was doing the arguably more challenging task of trying to restart the engines using a checklist (and nearly succeeding in the 3 minutes that he had!). The same sort of thing could be incorporated into our existing data displays, if there was enough financial incentive and cultural support for such a project. Figure 3 is a mockup of how a checklist could be added to rebreather electronics for an in-dive emergency.

Figure 3. Mockup of a potential in-dive emergency checklist incorporated into rebreather controller display

Conclusion

As our endeavors become more and more complex, the chance that a single human brain will always know exactly what do to and will implement critical steps without fail becomes less and less likely. One of the ways that safety can be improved and failures be made safer is by formalizing some of our most crucial processes in written form – a checklist. Well accepted as useful in aviation and surgery, the dive community has not adopted these as readily or as widely, in part due to internal cultural factors and to a lack of external authorities who ensure safe practices. We can do better by encouraging cultural shifts to make safety initiatives like checklists the sign of a good diver, and not the mark of a newbie.

Summary

Checklists can save lives by backing up human memory and encourage communication between team members in a number of increasingly complex human endeavors. While not appropriate for all types of diving, a physical, written checklist can and should be incorporated into certain complex diving activities.

Key Learning Points

Why do processes with critical steps that are dependent on human activity often fail catastrophically?

What do checklists do to limit harm?

What are desired features of a checklist?

What are features of a checklist that will limit its utility or likelihood of adoption?

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