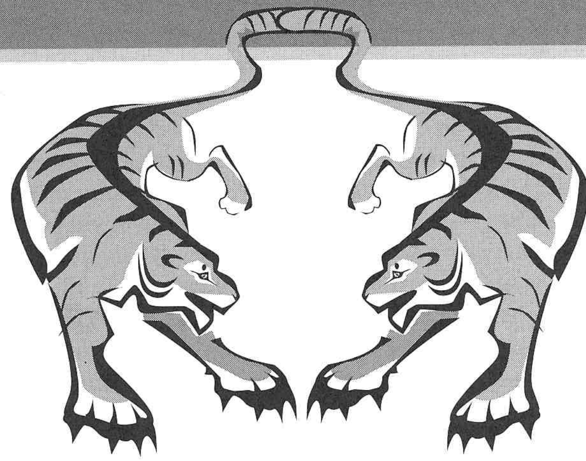
113)□Hancock, P.A. (2005). The tale of a two-faced tiger. Ergonomics in Design, 13 (3), 23-29.

THE TALE OF A TWO-FACED TIGER



BY P. A. HANCOCK

By recognizing the commonalities across apparently dissimilar accident types, designers can help reduce their frequency and impact.

FOR INDIVIDUALS IN THEIR FIRST EIGHT decades of life, the main threat of accidental death comes from road traffic crashes. Above age 78, the major cause of accidental death is slips and falls. As shown in the figure on page 24, in the United States in 1996, these two categories were the leading causes that accounted for 61.5% of more than 93,000 fatal accidents (National Safety Council, 1999). As the word *category* implies, road traffic accidents and slips and falls are considered highly disparate circumstances in which, by inference, differing causal mechanisms are involved.

An obvious outcome of this compartmentalization is that methods and designs directed to reduce the impact of these two forms of injury causation are very different, and this conclusion is buttressed by even the most cursory examination of the relevant literatures. However, I claim here that these two forms of accident exhibit fundamental similarities and that researchers involved in their reduction can take advantage of these commonalties to cross-fertilize design improvements to reduce their perennial adverse impact.

To understand the similarities between these two categories of accident, it is best to begin by examining why they are traditionally considered to be different.

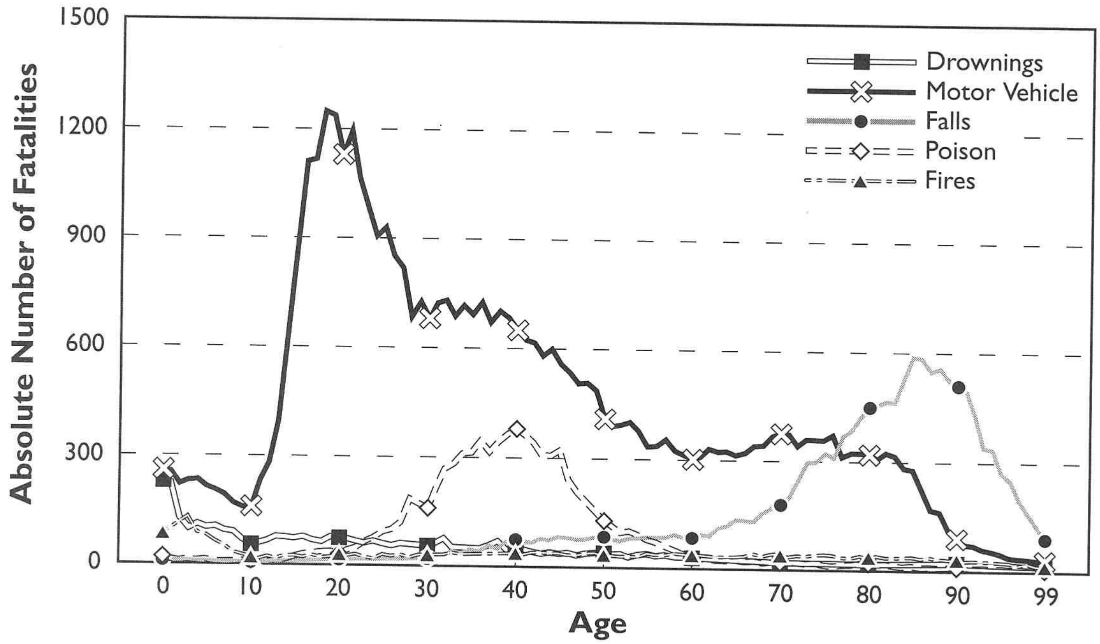
How People See the World

Categorizing the world around us is a perceptual process that demands that we unify some objects, entities, and processes under a common semantic title while excluding others that differ along any one of a number of characteristics of either rational or irrational origin. In mathematics, this formulation is known as *set theory* and is the fundamental basis of number. The language of number is our method of seeking unity in diversity, whereas the language of words is the opposite, seeking diversity in unity. These fundamental and reciprocal processes guide our observation and thinking about events and accidents, and the way we conceive of them, and subsequently frame our response. Here, I look to fracture the current categorization structure in order to illustrate how deeper commonalities lie beneath the physical framework people have come to accept as reality.

In order to function as a collective, human society requires that each person partake of a shared, common discourse. Science shares this imperative; its terms have to be open to mutual inspection and agreement. Unfortunately, this objectification of the environment is so deeply engrained, especially in the occidental world, that often that reality itself is conceived as an expression of these physical metrics. So *space* is equated with meters and miles, and *time* becomes minutes and months.

FEATURE AT A GLANCE: : In the National Safety Council's *Injury Facts*, the most prevalent cause of accidental death from birth until age 78 is motor vehicle collisions. After 78, this cause changes to slips and falls. Initially, these two categories seem obviously distinct, but here I claim they are not. I propose that because transportation is only a form of augmented locomotion, road traffic accidents are errors embedded in this locomotion process just as are slips and falls. Thus, each distinct accident form results from behavioral response. I relate this unification to Haddon's notion of accidents as encounters with uncontrolled energy (ecological "tigers"). I seek to show that traffic accidents and slips and falls are thus two faces of the same tiger.

KEYWORDS: design, accidents, vehicles, slips and falls, uncontrolled release, kinetic energy



Leading causes of accidental death by age in the Unites States, 1996. (Reprinted with permission from Injury Facts, *National Safety Council, 1999.)*

Our world is composed of behavior, and yet, paradoxically, we have come to accept the tyranny of physics somewhat in the fashion of sleepwalkers (Koestler, 1973). We cannot deny the many benefits derived from the reification of this physical perspective. However, in trying to understand events at a human level, we have to be prepared to relax the grip of these bonds, if only a little. Slips, trips, and falls and road traffic accidents are seen as different and recorded as fundamentally distinct categories because of the respective physics of each situation. One involves a vehicle, the other apparently does not. One involves postural stability, the other apparently does not. In physical terms, the kinetics involved differ by at least an order of magnitude. Under these circumstances, one appears justified in treating these events as deriving from separate realms. However, this division ignores the unifying principle of human behavior and thus obscures the fundamental advantage that a common perspective provides.

Bottom-Up and Top-Down Commonalties

In one of his many insightful works, James Gibson identified powered transportation as an artificial form of bipedal locomotion (see Gibson & Crooks, 1938). To understand the bottom-up commonalties between slipping and falling and some forms of road traffic accidents, it is important to understand that the individual involved is trying to achieve the same fundamental *goal* in each case: the safe and efficient transition from origin to destination. Although there is evidence that at least some elements of the bipedal stepping cycle are "hard-wired," most of the sequence is quickly perfected by practice. In an analogical manner, driving can also rapidly become an overlearned task that does not always require active attention in order to be achieved successfully.

Walking and driving are two of the very few skills that the average adult individual engages in on a daily basis and therefore has a sustainable degree of ongoing practice. Such is the power of this overlearning that soon we do not consider these actions to be skills at all but, rather, part of the basic fabric of behavior. However, the first faltering steps of the infant and the novice's first moments behind the wheel, which share much in common, show us that these respective activities remain skills that must be learned. Both capabilities are amenable to *automatic processing* (Schneider & Shiffrin, 1977), and they possess certain well-defined characteristics.

First, they can be performed in *parallel* with other attention-demanding tasks, so individuals can typically walk and talk and drive and talk without necessarily seeing an appreciable change in performance capability on either task. (Disputation of this assertion leads to the question of multiple tasking such as expressed in the contemporary concern for the safety of in-vehicle phone use; see Hancock, Simmons, Hashemi, Howarth, & Ranney, 1999).

Second, automated processes are *effortless*, so they appear to be able to be accomplished with little conscious attention and may suffer when attention is suddenly switched back to them for some reason. Finally, automated tasks are accomplished *quickly*. Their total response time is in the order of milliseconds, barely above the perception of the instantaneous moment (see James, 1890). This means that when the specific stimuli or trigger conditions are present, the response is produced very quickly with little or no cognitive effort.

Like many forms of skill, it is marvelous to see adaptive learning capabilities transform the novice's first erratic attempts at control to the smooth execution one observes in the expert performer. This represents an accumulating process of distinguishing consistencies in the environment and then linking stimulus-response chains to these antecedent conditions. Since parts of the world (e.g., the function of the leg and its location on the body, the function of the steering wheel and its location in the vehicle) remain consistent, some stimulus-response chains can be easily identified and established, and one can recognize problems when such consistencies are interfered with (e.g., the difficulty of walking with a cast on or driving an unfamiliar rental car).

However, unlike the experimental laboratory, the world is never completely predictable, and thus purely automated real-world tasks are very exceptional – if they exist at all. Tasks that require cognitively mediated responses are labeled *controlled* to contrast them with *automatic* capabilities. Controlled responses are engaged in circumstances consisting of novel or unusual conditions. Often, we have much less practice at response in these unusual conditions, and so when they occur, we have to use innovative strategies (but strategies founded on and composed of existing capabilities) to formulate a response.

The first faltering steps of the infant and the novice's first moments behind the wheel show us that these respective activities remain skills that must be learned.

In order to mitigate the injuries and fatalities that come from errors of response in these unusual conditions, be they falls or traffic accidents, we need to know about their precursors. The first step toward their identification is a model of the normative process.

The Process of Locomotion

One of the greatest needs in the area of transportation research is a strong normative model of the driving process. Here the direct linkage to pedestrian locomotion can help extensively. Every organism that has to navigate around any environment is faced with a number of common problems. Such problems include identifying a goal as a future location in space-time and then distinguishing among possible routes by avoiding barriers in the form of intolerable energy distributions. It is these regions of "intolerable" energy that Haddon (1970) appropriately named ecological "tigers."

Typically, such tigers appear as, among others, excesses of chemical, electrical, or kinetic energy. My primary concern is with the kinetic tiger, because both slips, trips, and falls and road traffic accidents represent releases of kinetic energy concerned with object collision. To successfully accomplish the act of transportation, organisms have to decide where they are going, what method they will use to get there, and what barriers exist to achieving that goal. The goal-setting portion of the process requires the planning and distinction between possible and impossible paths.

Having begun down a chosen path, one needs to engage in a number of ongoing processes in response to dynamic challenges that the environment inevitably presents. Imagine, for example, being in a city like San Francisco. I might decide to walk from my hotel to a theater where I have booked tickets for a show. My overarching goal – attending a performance – has been set and achieved at one level of transportation, that of the electronic interaction of ticket purchase. Now I must follow this electronic avatar with the physical passage of myself.

I might well use local knowledge, asking the concierge for a preferred route, probably avoiding so-called dangerous areas. This might take the form of a sequence of turns. Nested within this level of activity is the specific form of locomotion itself. If it is late at night, I might consider the passage along dark streets excessively risky and choose a taxi even for a relatively short journey. Other forms of transport are open to me; I might fly via helicopter or go via a boat on the bay. In reality, I will probably choose to walk after all, it's only a few blocks!

Regardless of the method of locomotion selected, I must engage in the same fundamental control actions. (Of course, taxis, limos, boats, helicopters, and cable cars are usually piloted or driven by others, which alleviates me of the cognitive demands of momentary control.) In all cases, locomotion is an interweaving of open- and closed-loop control. Open-loop control (essentially using minimal external feedback) is possible because, as noted earlier, the control tasks of driving and walking are overlearned to such a degree that they can be accomplished, at least for a short while, without active monitoring. Given that vision is the dominant form of feedback used by most individuals, it is possible to try an experimental evaluation. So in an open corridor with no obstruction, you can close you eyes and walk for some period without hitting anything. You might try to use other sources of feedback, such as hearing and touch, to obtain augmented information. However, as with all interweaved open- and closed-loop control processes, eventually you will reach a point when you feel sufficiently uncomfortable with open-loop control alone. At that point you will open your eyes, sample the environment, and reestablish visual closed-loop control.

The point when closed-loop control is reasserted depends on environmental contingencies. For example, in a crowded corridor or a situation where threats are probable, sampling of the environment increases proportionately. One's attention is moved around the environment contingent on the presence of novel, intense, or ambiguous stimulation. Both driving and walking are the same process of interleaved control. Often, open-loop control does not mean the total absence of attention, such as is exhibited by someone who has fainted. Rather, it means that attention is not being paid to task-relevant stimuli but can be located elsewhere, such as when one is distracted by another competing source of information.

The effect is the same in driving, whether I am closing my eyes because of fatigue, focusing on a passenger, searching for a lost item on the floor, or perusing an in-vehicle technical system. Attention is not on the primary task of vehicle control, and sudden events that occur when I am not focusing on the appropriate part of the perceptual field can be extremely dangerous. Similarly, in bipedal locomotion, when I am walking and talking to a friend, my attention may stray from the walkway, and I can miss slight irregularities in the ground, the precursor to a trip, slip, or fall. When two or more individuals in open-loop mode arrive at the same place at the same time, we have the perfect antecedent condition for a collision, and the meeting of an open-loop driver with an open-loop pedestrian promises spectacular failure.

Slipping and Crashing

There are various definitions of slipping, tripping, and falling, respectively, and although each can be related to the others, there is no necessary linkage between them. In everyday parlance, one may draw a connection between slipping and falling, or between tripping and falling; however, it remains an open empirical question as to whether a slip or trip *has* to precede a fall. That is, are falls caused exclusively by either slipping or tripping?

In a similar manner, we do not know whether loss of control or driver error *has* to precede an accident. Many accidents involve multiple vehicles, so clearly, many accidents involve blameless drivers. But are there any accidents that are not preceded by any form of human (driver) error? Each of these questions represents the same basic philosophical question of fundamental causation. The contemporary view of the source of causation is human beings and their errors, although it is important to understand that this view of causation is recent, not one that has dominated the world during the formative years of recorded history (Calasso, 1994).

We must also recognize that, in a nontrivial manner, it is collision that is the problem. Although muscular injury might follow from a slip alone (e.g., pulled muscles, soft tissue injury) and damage may result from a trip alone (e.g., a stubbed toe), it is the larger collision between self and surface that represents the essential "escape of the tiger" (Haddon, 1970). Thus driver error per se is not the problem – it is the *context* in which the error occurs that dictates whether the outcome will be benign, injurious, or fatal. Falling alone is therefore also an insufficient consideration. We have to know, for example, how far an individual fell, on to what, at what angle, etc. – after all, falling from a great height is not a kinetic problem if the air bag onto which you fall is big enough. This outcome aspect of falling is further emphasized in the transport arena; especially in motorcycle accidents, for example, it is the vertical fall from the motorcycle that is often the crucial source of the problem (see Hurt, Ouellet, & Thom, 1981). Therefore, collisions of all sorts are examples of the problem of uncontrolled kinetic forces, and the etiology of the precursory event is only one part in the whole process.

Researchers working on tire fabrication and on modern footwear are concerned with aspects of friction and methods that promote adhesion between the terrestrial surface and the tire/shoe sole.

One might define falling as the dynamic failure of stable posture, and, similarly, road traffic accidents might be defined as dynamic failures of vehicle control stability. Therefore, naturally one looks for circumstances that induce such failures. But before one proceeds down such a path, one will eventually have to return to the recognition that merely losing stability is only the onset of failure. There are also postural processes involved with protection during the fall that may well include both instinctive and strategic response. Although those who fall rarely may have rudimentary falling skills, those whose activities (e.g., judo, skateboarding, snowboarding) provide frequent experience with falling events may have advanced strategic responses to loss of stability.

The same principles apply to traffic accidents. Drivers continually make errors, and some of these lead to problematic conditions. However, if we practice at the process of recovery, we may be able to respond before suffering adverse consequences. The human movement control system is exquisitely crafted to help with this error recovery process.

Error is quintessentially an ergonomic problem. This is because to understand error, one must have a thorough knowledge of the environment in which such events occur and insights into human behaviors that create the initial sit-

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uation and the repertoire of actions used in the attempt to recover from failure (Hoffman, Hayes, Ford, & Hancock, 2002). The connection between action and environment is frequently mediated by a tool – in this case, a shoe or a tire – which itself has one interface to the environment (the shoe's sole or the tire's tread) and another interface to the human operator (the shoe inner or the steering surfaces). Finally, one has the human performer, who brings along intrinsic characteristics such as height, weight, age, sex, and experience, each of which influences the immediate situation but also influences the selection of the tool to hand.

In our society, we are used to choosing shoes for different occasions. In addition to dress shoes, we have shoes primarily for comfort, such as slippers, and work shoes. The latter vary by at least the same degree if not more than sport shoes and can range from the steel-toed boots of heavy physical labor to the shoes of the ballerina.

Similarly, we choose transport tools for all occasions, including trucks, golf carts, skateboards, and sports cars. The dominant focus on the failure of these collective systems is more than misleading, in that for the overwhelming majority of their functional existence, they work without flaw. If we were able to capture, even in a qualitative manner, the number of human strides taken each day or uneventful miles driven each week, we would have some conception of how rare the events are that we seek to study. Unfortunately, like many proportions of baseline problems, we have no real empathic understanding of the very large numbers involved, and so the focus on exceptional events can become extreme perceptual distortions upon which phenomena like lotteries rely.

Error can be conceived in terms of a trinity of foci (see also Hancock & Warm, 1989). First, one can conceive of the problem as one of understanding *input* from the environment, such as the surface of support. This is largely an endeavor in physics to understand that the characteristics of surrounds and design solutions at the input level can be developed, such as advanced roadway reconfiguration (see Carmody, Harder, & Hancock, 2000). The second focus is on the *adaptation* of the human-tool system. This includes the resident capabilities built into the shoe or the vehicle and the manner in which the individual adapts his or her control strategies to account for variations in the input.

Thus, researchers working on tire fabrication and on modern footwear are crucially concerned with aspects of friction and methods that promote adhesion between the terrestrial surface and the tire/shoe sole. Humans provide active control in both circumstances, so we can see examples of this adaptive behavior when the environment changes. Someone traversing an icy parking lot is aware of a change in the surface of support and changes his or her stepping pattern accordingly. We often see individuals slipping under such circumstances, but their mode of locomotion is adapted so that, as far as possible, a fall is prevented. Without shoes on a hot beach we also see adaptations in gait! In the vehicle, we see similar change in accordance with weather conditions, such as drivers in the upper Midwest who are well aware of the control differences that occur in driving during a severe snowstorm.

The final form of description is the *outcome*. This may well be a locomotion pattern. However, when one chooses to use dichotomous output metrics such as fall/no-fall, collision/no-collision, one loses most of the nuances of the behavior that are needed to inform one about the process one wishes to study. In trying, therefore, to understand the control sequence and how it might lead to error, one is required to be able to measure and observe, first, the character of the surface of support; second, the interface between the surface and the tool, and the tool and the human body; and, finally, the overall goal-directed behavior.

It is crucial to understand that there are a number of feedback and feed-forward loops involved with this process. Although feedback is associated with the postural (and vehicle) stability during movement, feed-forward is associated with the perceptual evaluation of the appropriate surface of support, a capability that is instantiated very early in the human developmental process, as well as in driver training.

The Conundrum of Attention as a Causal Mechanism

One of the major categories of driver error, and an error associated frequently with slips and falls, is *inattention*. Indeed, drivers are legally culpable if not driving "with due care and attention." The problem with this imputed causal mechanism is the way in which one develops evidence for its presence. Often, "due care and attention" is defined by outcome. That is, collisions often involve failures of attention, but if nothing happened, due care and attention must have been paid. But clearly this is not so. We are all aware of moments when our attention wanders, even with the best will in the world. And which of us has not been fatigued while driving and been aware of the fact but still driven on to make the next rest stop or off-ramp?

One of the major categories of driver error, and an error associated frequently with slips and falls, is *inattention*.

Such errors of inattention are rarely punished with an untoward accident event. Thus, when they are, and attentional state is judged by outcome, we have an unfortunate circularity of reasoning that is more than dangerous. Because driver inattention (and sometimes almost synonymously "operator error") is frequently the default category of explanation, the whole notion can rapidly become a convenient fiction without any basis in fact or reality. However, this is certainly not to say that attention is not a crucial issue in the process. Rather, we must have a method of understanding attention that is independent of end state.

> The interface between the tool and the environment is as crucial as the interface between the tool and the individual.

Recent research efforts have sought qualitative and quantitative approaches to this question, including eye movement research and constructs such as useful field of view. However, as I explore in the next section, errors of attention and moments of inattention are only one precursor in the accident chain. Attentional capacities are constantly probing an environment that is generally forgiving of any momentary lapses that are thus passed over without incident. It is those occasions on which initial problems begin to propagate when one sees the seeds of disaster.

How Initial Errors Propagate into Becoming Accidents

Errors may be relatively infrequent events, but how do they propagate into accidents? To capture this sequence, I employ a conception developed by Kaufman concerning the relationship between event frequency and event outcome (see Hancock, 1997). Kaufman (1993) suggested that in any complex system, there will be, as a function of the nature of the system itself, perturbing events. In the present context, this could be variation in the relation between open- and closed-loop control expressed as variation in the stepping cycle or momentary vehicle control. The vast majority of these variations are rapidly damped out in the system. That is, they result in minor perturbations that are easily and immediately compensated for.

However, in a lawful fashion (as described by the log/log relationship illustrated in Kaufman, 1993), some events become magnified in the system. A small number of these events reach sufficiently disturbing proportions that control is momentarily lost. Often, this in itself is of no great moment. Macrolevel adaptive strategies mean that the individual is often able to recover from a slip or a loss of steering control. However, these events happen in contexts that themselves are subject to the same lawful relationship. Therefore, *very infrequently*, the control error propagates in an error-receptive environment that results in a cascade effect. Now, the unfortunate minor control loss is magnified into an event that is then classified as an accident.

Even now this does not mean injury or death. It is only as the process proceeds that the untoward outcome is determined. Thus, there are literally many trillions of opportunities for disaster to occur. The overwhelming majority of these are suppressed in the system, and one can pass over these nonevents without comment or recognition because the human perceptual system is not designed to attend to and memorize such nonevents. This makes very clear that accidents are a direct result of the exploratory nature of human behavior. All living organisms are faced with the same conflict – that the price of exploration is the possibility of death. In the jungle of life, sometimes we meet the tiger.

Summary

The kinetic tiger shows its face in many guises. We have, in traditional epidemiological approaches, come to accept certain accident forms as composing discrete categories, and major publications even refer to them as such (National Safety Council, 1999). I have suggested that vehicle collisions and accidents associated with trips and falls result from the same fundamental form of failure. The reason that the tiger expresses its wrath in a different form after the age of 78 is that older individuals do not engage in driving as much and thus self-regulate their exposure. However, their *relative* exposure to falling is consequently increased, and we see this result in the pattern illustrated in the figure on page 24.

Realizing that such accidents emanate from a confluence of momentary human actions in an equally momentary, unforgiving environment provides insight into methods of mitigation. I should note that these are not necessarily fundamentally new solutions; because the underlying problem is one of uncontrolled kinetic energy, the general answer always has to be suppression or the amelioration of that uncontrolled energy in some fashion. However, it does imply that such accidents require a concatenation of circumstances in both space and time and that, when considered as a Markov process, the fundamental challenge is to break the chain at the earliest possible stage in its development. These solutions have to do with human attention and aids to that attentional process. To conclude, I present some practical design recommendations that come from the present observations.

Design Recommendations

If the design goal is to enable control in normal operational states, provide practice and technical support systems that address stable operations. However, if the goal is to provide defense against collisions, provide practice in and design support systems for incipient collision situations.

Designs must address the double interface. The interface between the tool and the environment (i.e., the tire and the road, the sole and the floor) is as crucial as the interface between the tool and the individual (i.e., the driver and the controls, the foot and the shoe interior). These two interfaces interact, and the design process should explicitly address the information intrinsic to this interaction.

The challenge of design is to lead attention to the context-contingent cues in the environment. The process of design becomes one of identifying the appropriate cues and manipulating their salience. This requires the reconception of *design itself* as a dynamic, reconfiguring process (see Hancock, 1997).

Interweaved open- and closed-loop control of highly learned skills means that error etiology may result from periods of control transition and attentional switching. That these events interlock with untoward environmental contingencies results in collisions that have outcomes dependent on the vagaries of the moment, which is why any such escape of the tiger is dangerously unpredictable.

Design can prevent propagation of the initial error, the power of the environment to harm, or the connection that links these two. Probably the easiest, most effective link to break is the first, the initial occurrence of error. Whether and how this can be done without curtailing exploratory behavior must be the focus of our next step in the collective effort to tame the tigers.

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