Theoretical Issues in Ergonomics Science
Vol. 6, No. 2, March–April 2005, 193–211

Taylor & Francis
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On time distortion under stress

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Under conditions of extreme and life-threatening stress, people often report distortions of time. These distortional experiences are critical since, axiomatically, they occur in circumstances where small variations in behavior can mean the difference between survival and extinction. The present work examines the spectrum of evidence concerning such phenomena including observations from real-world events such as combat, ejection from high-performance aircraft, driving in dangerous environments and from less stressful, yet informative laboratory procedures. A contextual theory is promulgated which postulates that in addition to draining attentional resources, stress prevents the efficient production of such resources. The stress-depleted resources which remain are directed to task-relevant activities and consequently attention to time-based cues is minimized resulting in distortion effects for both time-in-passing and for time recollection in memory. A number of practical observations are advanced concerning the performance of professionals who are likely to meet such conditions in their occupations including those in aerospace, military, fire-fighting, law enforcement, and medical emergency service operations. In conclusion, we present a number of future research strategies that may be enacted in order to evaluate this ephemeral, real-world phenomenon.

Keywords: Stress; Time distortion; Operator performance; Emergency response

1. The nature of the problem

For well over a century, psychologists have sought to unlock the secrets of the mind by bringing individuals into sheltered, controlled environments so that the potential contamination of the external world is dampened down and the phenomenon of interest is isolated and emphasized. Much understanding and insight has been gained from the use of this experimental strategy. However, this very strength of laboratory testing is at once also its greatest weakness. We have come gradually to recognize that behavior is *situated*, so that, in order to fully understand and make valid and reliable generalizations about performance we have to evaluate individuals in *context* (see Flach *et al*. 1995, Hancock *et al*. 1995). In contemporary inquiry, many researchers are willing to trade some of the control of the experimental test chamber for the additional validity that real-world evaluation brings (Hutchins 1995). In actuality, it is often the case that experimental conditions are only faint reflections of actual experience. We suggest that there are some, if not many, high

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Theoretical Issues in Ergonomics Science
ISSN 1463–922X print/ISSN 1464–536X online
http://www.tandf.co.uk/journals
DOI 10.1080/14639220512331325747

impact and crucial life events that simply cannot be assessed within the confines of the traditional laboratory setting. One reason for this restriction is that such circumstances arise sporadically and cannot be easily re-created or even simulated effectively. Further, for moral and legal reasons, we are not permitted to deliberately expose normal experimental participants to conditions that pose a life-threatening degree of risk. From an experimentalist's perspective, this is frustrating, especially if the particular behavioral phenomenon of interest eludes *all* experimental control. Thus, our efforts to understand what may be crucial life experiences can be seriously restricted. This is especially true when we are concerned with the subjective experience of individuals as opposed to externally observable behavior.

Turning subjective experience into externally observable actions presents a significant challenge. One early strategy was to insist that all phenomenon of discourse had to be open to mutual inspection (Watson 1913). However, this fundamental behaviorist approach to human understanding eventually falls to the explicit recognition that we each possess a private, internal consciousness which is only partly amenable to such external inspection (cf. Rachlin 1980, Smith and Hancock 1995). Our present work on temporal distortion falls very much into this 'private' realm. However, since such distortions often occur under stressful conditions and since these latter conditions are often produced by a serious threat to existence, radical variation in perception at such junctures can prove vital to an individual's survival and of course, their performance capability. Hence, the search for understanding in this realm is at once both a highly theoretical but also a highly practical one.

We have all experienced the phenomenon of 'getting lost' in a good book or engrossed in a movie such that we become unaware of the passage of time (Csikszentmihalyi 1990). Early researchers into the psychological aspects of time clearly demonstrated that human temporal perception was not a simple chronometric record of events (Guyau 1890, Bergson 1910). Indeed, an early and continuing problem besetting research in this area is the vast differences between individuals in their estimation of common 'objective' durations (Doob 1971). Those factors which influence time perception have often been divided into those which come from the environment and those which emanate from the individual themselves. The environmental sources are the subject of traditional psychological research (see Roeckelein 2000), while the latter, endogenous factors are represented as direct influences on an 'internal clock' and feature mostly physiologically-based mediators (Francois 1927, Hoagland 1933, Bell 1966, Hancock 1984). Eventually, these two sources of influence have to be welded together into a single account and this is a challenge that continues to the present day (Treisman 1963, Hogan 1978, Treisman 1984, Block 1990, Hancock 1993). Such an account must also provide an explanatory, causal mechanism for the time distortions under stress as evaluated here.

Clock time does *not* represent 'real' time, but rather is an external referential rate of change of high relative accuracy. Perceived time in the present context is characterized as the percept measured by verbal estimation (see Bindra and Waksberg 1956, Cohen 1967). When verbal estimates indicate an underestimation of an interval this is directly correlated with an overestimation using the production method. This latter approach requires an individual to 'produce' a specified duration using button presses or the like to demarcate the requested interval. This method obviates the need to convert estimates into social time units such as minutes, seconds, etc. (see Hornstein and Rotter 1969). For example, an individual asked to experience 10 seconds and then provide a verbal estimation of that time passage, might respond

that 8 seconds has passed. Therefore, the individual has *perceived* each second as longer than the 'objective' reality. Thus, when this expanded sense of time is applied to an experimental situation requiring the production of 10 seconds, the individual produces a time period longer than the 10 seconds requested, i.e., an overestimation.

Where verbal estimates are greater than clock time—the time distortion ratio is greater than unity—then the individual has speeded up with respect to external reference and the opposite is the case where the time distortion ratio is less than one. However, these observations are inverted for the production method. This observation is important since differences in the method of assessment are a source of great confusion in this arena.

2. The phenomenon itself

As yet, we do not understand enough about the phenomenon of time distortion to make it appear on demand. However, a sufficient number of individuals have reported time distortion under conditions of stress to render the claim beyond the level of the obviously extraordinary (see Hume 1739).[†] In point of fact, we do know empirically that the content of an interval affects the perception of the length of that interval (cf. Ornstein 1969, Block 1990). Indeed, if the dominating social and environmental cues are minimized under conditions of sensory or perceptual deprivation, we can systematically influence the perception of duration (e.g. Banks and Cappon 1962, Hancock *et al.*1994). In this work we are concerned with extreme changes in duration perception sufficient to earn the label 'time distortion'. With respect to these distortions, we have several levels of evidence ranging from the personal accounts of 'private' experiences during emergency conditions to empirical evidence from early explorations of the influence of danger on time perception when it was possible for researchers to expose subjects to more radically disturbing conditions.

3. Anecdotal evidence

The weakest, but often the most colorful and emotionally compelling form of evidence, comes from anecdotal accounts of individuals in extreme circumstances. Such stories emanate from a variety of sources. Consider the following:

> '*I was aware of a flash, and tremendous heat, and the crackling of the radar set in front of my face as it began to disintegrate. There was smoke everywhere, complete devastation. It seems like an age but your brain does funny things with time and you just concentrate on getting out. I could feel nothing. No pain, nothing*.' David Hart-Dyke, Captain of HMS Coventry, sunk during the Falklands War [emphasis added].

While combat is a relatively rare circumstance, temporal distortions occur regularly in stressful aviation episodes (Carson 1983). Consider this account of a mishap taken from Carson (1982):

[†] Hume's proposition was that extraordinary claims required extraordinary proof. The present claim is at the edge of experience but not so extraordinary as to require an existence proof of a level beyond that of general psychological/behavioral evaluation.

> '*(The) emergency was (the) left wing folding on takeoff. As soon as we were airborne, the aircraft started to roll to the left. I delayed ejection until I felt the aircraft would hit a clear area. Time was expanded greatly, so it felt like several minutes before it was time to get out. Still no feelings of excitement. Waiting to eject felt no different than waiting to change the INS to the next turn point. I assumed ejection posture and pulled the lower handle. Again there was time expansion. The canopy leaving, the seat going up the rail, and the aircraft disappearing below me seemed to take several minutes. Because of the altitude, I had elected not to perform the four-line jettison, but it seemed to be taking forever to come down. Since I was coming down on the parking ramp, I wanted to see where I was going to hit and what I was going to hit. Only a few seconds later, my feet hit the ground and I felt a pain in my left ankle... I managed to release my harness and came to an immediate stop. Just as immediate, I was surrounded by people asking how I was, and the one and a half minute ordeal that took ten minutes was over*.' (p.26) [parentheses added].

Clearly, the extreme levels of time distortion reported here are not confined to combat or aviation alone but rather occur when individuals are placed *in extremis*. Our contention is that such phenomena become most evident in these exceptionally attention demanding conditions. This is not to say that temporal distortion does not occur in everyday activities. Indeed, we believe that to some extent perceived variation in temporal flow is involved in all attention-demanding task situations. However, the most memorable distortion events are recorded as occurring under these highly stressful, and for the individuals so exposed, even unique circumstances. The following two examples come from law enforcement.

> '*Kim remembers that steamy September night in 1979 as if it were yesterday. She had a split second to react before the gunman blasted her from an open window over her head. 'When you think you're going to die', she says 'your brain works so fast that everything else seems to be in slow motion*.' (Wozencraft 1990)

and

> '*. . .my mind slipped into. . .the time deception phenomena, where, during extreme stress things appear to happen in slow motion. They don't, of course, but because the mind can digest so much more information than the body can react to in the same time frame, it seems like the body is acting in slow motion*.' (Klein 2000) [emphasis added].

One method of addressing time distortion experiences is to collect the responses of individuals who have each been through a common, high-threat experience and this aggregation of responses allows us to begin examining the generality and the nature of the factors associated with temporal variation. One such survey was conducted by Fair (1984) who interviewed pilots who had ejected from jet aircrafts. The ejection decision is a critical one, since the decision to eject from, or stay with, a damaged or crippled aircraft is most difficult and in such circumstances, fractions of a second mean the difference between life and death (Carson 1982, 1983). Fair (1984) surveyed twenty-eight pilots who answered questions about their ejection experience. In respect to the temporal aspect of the event, the pilots were asked five questions: (1) Was there a change in the apparent passage of time? (2) If a distortion was experienced, what was the apparent effect? (3) Have you ever experienced an apparent distortion of time on a previous occasion? (4) If you experienced such effects previously, what was the apparent effect? and (5) How well do you remember the events of the mishap sequence? Of the twenty-eight pilots, 75% had experienced a temporal distortion, 7% indicated they were uncertain and 18% reported no change in temporal experience. Of the pilots who responded either yes or uncertain

to the first question, 64% reported that time appeared to slow down while 18% indicated that time speeded up. In respect to prior experiences, 36% reported that they had previously gone through temporal distortion, while 46% had not. Eighteen percent either did not respond or were unsure. Of those with such experience, 90% reported a previous phenomenological slowing of time. In recalling the specific mishap, 61% remembered the events with vivid clarity, 36% remember the overall sequence of events as hazy, while one individual reported that they had virtually no memory of the ejection event. The totality of these findings was that the majority of the pilots did experience some alteration in their temporal flow, and for a majority of these time appeared to slow down. However, it is important to note the existence of individual differences even in this homogenous group. Such anecdotal accounts serve to illustrate the utility and appropriateness of subjective assessment methods to study this form of experience and further points to the primacy of such reports and descriptions in initiating more empirically-based evaluations of unusual perceptual phenomena.

4. Experimental evidence

As might be anticipated, there are relatively few examples of experimental procedures that evaluate systematically the distortion of time under stress. Typically, the degree of stress that has to be placed upon an individual to induce such an experience would not presently be allowed by human subjects committees concerned with the health and safety of their experimental participants and the legal vulnerability of their respective institutions. Therefore, most of the experimental evidence that does show variation in time perception comes from older studies which have evaluated factors such as motivating conditions (Filer and Meals 1949), need tension (Rosenzweig and Koht 1933, Meade 1960), perceived failure (Greenberg and Kurz 1968) and anxiety (Prabhu *et al.* 1969). In general, these manipulations were produced through minimal forms of laboratory-induced change (Falk and Bindra 1954) that do not represent particularly adverse or life-threatening conditions.

One interesting study using a personal phobia as a source of stress was reported by Watts and Sharrock (1984) who tested the proposition that fear shortens estimated time intervals. They recruited 35 spider-phobic individuals and compared their estimates with those of 18 fearless controls. All participants sat adjacent to a table upon which was a 3 centimeter spider in a glass container. After 45 seconds of viewing, individuals were asked for a verbal estimate of the interval and, after a brief break, a second trial was conducted. The results, analyzed separately for each trial, showed a significantly higher mean estimate by the phobics on the second trial compared with controls (i.e., 60.14 vs. 41.11s) and significantly higher variability (i.e., 37.31 vs. 18.25s and 36.83 vs 20.83s) on both trials. As there were no baseline estimates to provide control comparisons, the stress/fear effect can only be interpreted as across group effects. Even with such a restriction, the findings are consistent with the notion that stress distorts time, and further, when the method of estimation is taken into account, the mean results are consistent with other reported findings on this effect.

Of all the existing laboratory studies, perhaps the most interesting is the set of experiments conducted by Langer *et al.* (1961) (see also Werner and Wapner 1955, Langer *et al.* 1965). In an ingenious manipulation, they had participants either walk

toward or carried by a small, motorized trolley toward the edge of a stairwell. In the control condition, participants covered the same distances but traveled away from the stairwell. The change of direction obviated the 'threat' of falling down the stairwell, which was the stress-inducing factor. A variety of dependent variables were employed, including the perception of space, locomotion velocity, and most importantly for the present purposes, the perception of time. Since the collective results of their sequence of studies are mutually supportive, the data for time perception is both representative and illustrative. Blindfolded in all conditions, the participant stood on the platform that proceeded at a velocity of 2 mph. The safe condition had the participant start at the stairwell and proceed away from it. The lesser of the two dangerous conditions had the platform start at 20 ft while the more dangerous one had the platform start at 15 ft from and proceed toward the stairwell. The task of the participant was to judge when 5 seconds had elapsed. They did this by pressing a button, which started the platform moving forward, and then releasing the button, which stopped the platform, when they perceived that the 5 seconds had passed. Langer *et al.* (1961) found that in the safe conditions, proceeding away from the stairwell, the average prediction was 4.11 seconds which was significantly greater than the 3.52 seconds in the danger conditions. There was also an interaction between the degree of danger, as represented by the distance to be traveled and the direction of travel, either toward or away from the stairwell. These results show that the degree of distortion varies according to the level of perceived danger. The closer proximity of the start to the stairwell induced a decrease in the estimated interval in the danger condition but had the reverse effect in the safe condition. The authors concluded that "in general [this result] means that as danger increases, space and time stretch, or perception of a given physical distance or interval of time shrinks". Phenomenologically, time slowed down in the stressful condition. Given the nature of the task and the lack of visual feedback, this represents an adaptive and appropriate response. This form of underestimation is also seen in time-to-contact studies in which individuals are asked to estimate when an approaching vehicle will reach and intersect their own position, another potentially dangerous circumstance (see Caird and Hancock 1994, Hancock and Manser 1997).

In terms of testing in controlled experimental conditions that manipulated a significant source of real-world stress, the work of Frankenhaeuser (1960) stands out (and see Frankenhaeuser 1959). She exposed seven subjects to a stress of three times the force of gravity (3g) in a centrifuge facility. The time estimation method was the reproduction of auditory intervals ranging from one to twenty seconds. Frankenhaeuser also used an interesting bisection method by asking participants to also reproduce half the requested interval. However, since results were equivalent in all essentials, only the full reproductions are considered here. In these conditions, participants consistently estimated the interval as shorter under the gravitational stress as compared to the normal conditions. Since the difference grows proportionately with the length of the estimate, it appears to be consistent with an interpretation of a clocking mechanism that is speeded by the elevated stress level in a manner directly analogous to elevated body temperature (Hancock 1993). Frankenhaeuser (1960) interpreted her results in terms of a memory influence in which gravitational stress acted to reduce the memory of the previously presented standard interval. However, it is also possible to conclude that the standard was memorized correctly

but time 'in passing' itself was speeded and thus an effect was observed on immediate perception as opposed to memory.

The presence of danger appears to alter sensory search behavior. In their work on driving, Chapman and Underwood (1998) found that when a threat was present, the length of the fixation time increased while the length of a saccade decreased. This suggests individuals were sampling more intensely from a smaller area and so stress focused attention in space and time. These findings are informative and intuitively reasonable. Having recognized the presence of a source of threat, less effort is directed to search for additional threats and more is devoted to evaluating the threat that has been recognized. Like other laboratory investigations of 'danger' these authors were forced to use videotape presentations of threats and thus the consequences of threat are not as evident to the driver as they would be on the actual roadway, although this expectation of course requires further experimental confirmation. Methods to elicit such evidence are only now in the process of development. Chapman and Underwood (1998) relate these results directly to the notion of cue salience and cue utilization under stress (see Easterbrook 1959, Dirkin and Hancock 1984). As is discussed below, these findings provide support for our present theory on stress and temporal distortion.

Since laboratory studies are significantly constrained, it can be very useful to look at field evaluations. One of the most informative was conducted by Jurkovich *et al.* (1987) who examined the perception of paramedics in their response to varying calls. Their work was fundamentally concerned with two questions. First, how long do paramedics take to perform specific duties and second, how long do the paramedics perceive that these tasks take? Since these questions were largely pragmatic, the desired measures were expressed in terms of percentage errors and were further divided into windows of accuracy ranging from exact precision to within five minutes above or below the actual time. Since these expressions are deviations, it is difficult to recover the exact estimates, especially since occasionally over- and under-estimations were combined. However, it is possible to examine the response for on-scene time in two conditions. The first condition required advanced life support skills (ALS), which were often used in cases of trauma. It is assumed that these conditions were highly stressful in comparison to the non-ALS condition in which no life-threatening emergency was present. Paramedics spent longer actual scene times during ALS events (15.3 minutes) then during non-ALS events (9.0 minutes). However, the combined results indicated that underestimation was consistently larger in the ALS conditions compared with the non-ALS conditions. These finding suggest that time perception in the field is consistently influenced by the presence of stress and that the degree of that influence is directly related to the level of stress. This is a brief synopsis of existing empirical evidence and it is clear that more studies are required to quantify this effect and that innovative methods are required to evaluate the real-world conditions where the effect is liable to be most dramatic.

5. Assessment of temporal distortion

Assessing temporal distortions is a difficult enterprise. Perhaps the most appropriate strategy is to link the definition of time distortion to existing measures of time perception variation. One such measure is the duration judgment ratio (DJR) (see Block *et al.* 1998, 1999, 2000). The DJR is calculated as the individually perceived

interval divided by the reference interval as measured in clock time units. Episodes of time distortion are then represented as extreme values on the DJR continuum.

As we have seen, such time distortion episodes typically occur under conditions of extreme stress and it has not escaped attention that if this relation is robust, time perception itself may be used as an index of stress as it has been for cognitive workload. However, it may well also be that comparable time distortion events occur not as the result of a singular acute incident but such distortion may also result from more chronic long-term influences such as illness and disease (see Cohen 1967, Hancock 1993). Thus, while the present work focuses on a rather specific circumstance, the time duration ratio measure may well be helpful in a number of different situations in which temporal mal-adaptation can occur.

It is also important to point out that the ratio between perceived time and clock time has been used in many applications beyond the present context. Indeed, this relation between perceived and physical magnitudes is the very foundation of psychophysics. In the temporal realm, Block *et al*. (1998) have reported on the differences in duration judgment ratio between younger and older adults. The same measure has been used to distinguish between the responses of adults and children (Block *et al*. 1999) and most recently between males and females (Block *et al*., 2000). Temporal psychophysical indices have also been used in a much more contentious and theoretical manner by Bentov (1977) and Newman (1982) who claim that this measure can be used as an 'index of consciousness', although unfortunately such speculations have not yet been tied directly to empirical measures or allied theories of performance variability.

6. Theoretical account of time distortion

Phenomenologically, individuals who experience 'time distortion' under stress typically report one of two forms of experience. In the first type of experience, everything appears hazy or as a 'blur' as though events were stacked together almost into one temporal 'moment' (Fair 1984). A second pattern of perception has the individual reporting many different events with startling clarity as time appears to 'slow down'. Both of these patterns represent effects of 'time-in-memory'. That is, in these retrospective accounts, individuals are recalling events rather than referring to their immediate experience. In contrast, immediate experience is referred to 'time-in-passing' (Roeckelein 2000). The first step toward an understanding of this phenomenon is the linkage between time-in-memory and time-in-passing. A simple approach to understanding this linkage uses the concept of attention and accumulation models of time perception. Accumulation models suggest that the individual 'creates' their own time perception by filling 'moments' with a sequence of experiences. A version of the accumulation concept is given in figure 1. Suppose it takes ten 'events' to create a moment and that those 'events' were fixations of attention to external stimuli. In a normal situation, ten 'events' are recorded and compared to a time base that we each learn as we assimilate the social meaning of time. Given that time perception is primarily a learned capacity, when conditions are 'normal' our sense of time thus accords with the social referent, or 'clock' time and we perceive a regular, uninterrupted and 'accurate' sense of duration. Now, suppose there is a sudden emergency condition in which the attention of the individual is drawn by the novelty, the intensity, and the complexity of the situation to fixate on stimuli at a rate

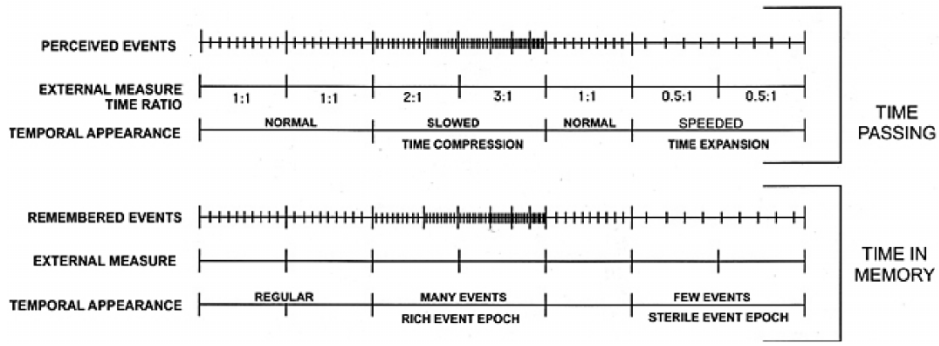

Figure 1. Time distortion in passing and in memory.

significantly different from that normally generated. In figure 1, we can see the ratio between the perceived and actual time climb from 1:1 to 2:1 to 3:1 and even beyond. This adaptive response may well be useful in searching for critical stimuli that might indicate strategies for successful resolution of the threatening condition. In passing, time for this individual has been 'compressed' such that event registration overwhelms the learned translation between event frequency and clock time. Phenomenologically, time slows in proportion to the increase in event registration.

In stress conditions sufficient to induce such time distortion, the increase in event registration must be substantial but to a level yet to be determined by empirical investigation. For such an individual recalling the incident in memory is thus characterized by a recognition of the time distortion itself and a clarity of recall of many events which, since they cannot be reconciled with the learned time translation, are reported as being outside the normal run of behavior, e.g., 'time seemed to slow down'.

Now let us consider the contrasting case, which is also shown diagrammatically in figure 1. Here, if attention is not directed toward environmental events but instead is re-directed toward 'internal' events, then this 'flight' from the incident would mean that few if any events are now registered. Without sufficient events to fill epochs, time seems suddenly 'speeded'. Again, in a highly consistent manner, the phenomenological appearance of time co-varies with the rate of event registration, in this case a sudden decrease of the accumulation. To the individual recalling such an incident, time would appear to have sped up and everything would have gone past 'in a blur'. These two patterns of behavior, both for time-in-passing and time-in-memory, seem to accord well with each of the accounts reported (e.g. Fair 1984). The next step is to understand how stress produces these reactions and for this we have to link stress reaction to attentional strategy. There is already a first link in the chain when we associate the direction of attention to external events as a form of 'fight' reaction, while withdrawal from external events may be considered a 'flight' reaction.

To understand this form of behavior, we can turn to the illustration given in figure 2. This shows population frequency versus the focus of attention in low and high stress conditions. Let us first consider the low stress situation. Here we can see a 'normal' or Gaussian distribution in which few individuals show extremes of attentional focus to either internal (body) or external (environmental) sources of stimulation. The degree to which an individual exhibits such tendencies may

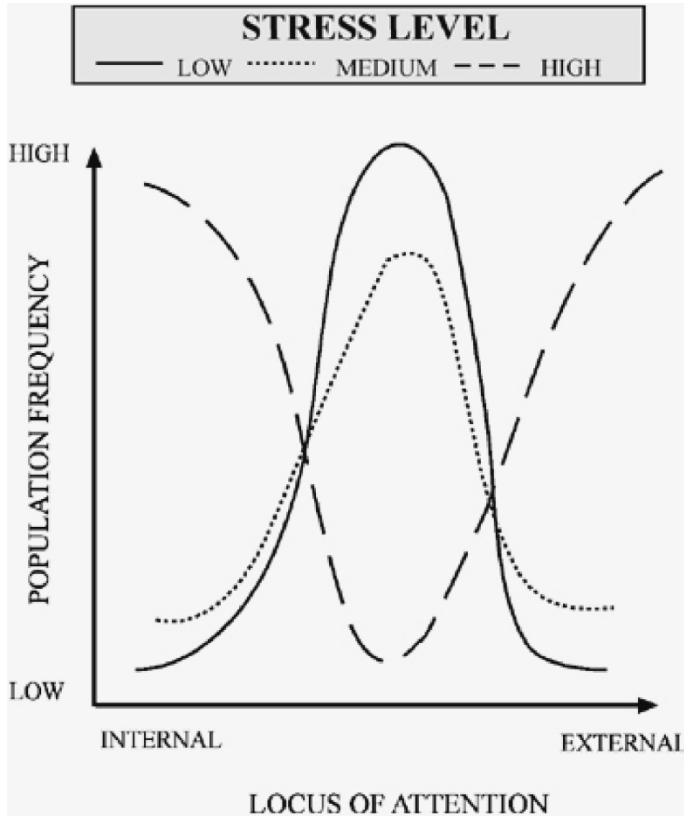

Figure 2. The population frequency of locus of attention as a function of the stress level experienced. Note that the transformation from a unimodal to a bimodal distribution is not a simple linear one. Indeed, the diagram indicates that the inversion to bi-modality happens very rapidly and only at extremely high stress levels.

well be related to introversion-extroversion dichotomies (Eysenck 1959, Gray *et al.* 1975). However, as is evident, the majority of individuals balance the source of stimulation between internal and external sources. The situation under high levels of stress is in direct contrast. Increasing stress acts to depress the center of the distribution and has the effect of polarizing the distribution. In effect stress magnifies response stereotypy such that those who focus on internal sources of stimulation generally increase in this tendency and the same effect is evident in those for whom the environment provides the predominant source of information. That introverts would thus favor 'flight' forms of response and extroverts adhere more to 'fight' responses is a direct prediction of this framework.

What can account for these striking and frequent observations of time distortion when under extreme stress or danger? We suggest that a causal account can be constructed through reference to our current understanding of how stress interacts with attention. The model proposed by Hancock and Warm (1989) provides this linkage by indicating how stress acts to reduce attentional capabilities which works in a similar manner to the way that sources of environmental disturbance tax physiological response capacity. What was not explored by Hancock and Warm (1989) to any

great degree was the process of failure as attentional capability waned and it is this aspect of performance that is examined here.

It is the process of failure that is crucial to an understanding of temporal distortion and we have illustrated this in figure 3. The first stage of failure is no failure at all, but rather a more economic and efficient use of remaining attentional resources. In the spatial allocation of attention, this narrowing effect was first experimentally observed by Bursill (1958). However, it was Easterbrook (1959) who gave the phenomenon a degree of formalization and a theoretical foundation. He proposed that the range of 'cue utilization' was restricted, essentially as stress increased. This theme was most fully explored by Hockey (1970a, b) who established experimental control using noise as the source of disturbance. One particular aspect of Hockey's work attracted the attention of Dirkin and Hancock (1984) (see also Hancock and Dirkin 1983). This was the observation that change in cue frequency could move attention to different parts of the visual field. Formerly, it was difficult to disambiguate whether the 'narrowing' phenomenon was a facet of the visual system itself or more of an attentional strategy. The experiments reported by Dirkin and Hancock (1984) confirmed that 'narrowing' could occur to any portion of the visual field and hence was an attentional rather than a purely sensory construct. This is an important difference to establish since the phenomenon of 'tunnel vision' frequently encountered in high-G environments (such as occur in single-seat, high-performance, fighter aircraft) is a physiological outcome of circulation deprivation to the eye, a fundamentally different process. Although since high-G loading is itself a stress, this does not eliminate more central effects such as observed by Frankenhaeuser (1960). Collectively, these findings suggest that stress distorts both perceptual space and time in a fairly systematic manner.

Attentional 'narrowing,' (or 'cognitive tunneling' as it has sometimes been called) to salient visuo-spatial cues is not a new observation. However, the notion that there is a comparable 'narrowing' to temporal cues is. In reality, there is good reason to believe they are actually facets of the same phenomenon representing a global space-time distortion (see Langer *et al*. 1961, Hancock 1997). In the early stages of incipient failure, upon initial encounter with stress, the narrowing strategy is most helpful in making best use of remaining attentional resources. Further, previous experience with the stress and/or specific task performance skill provides initial defense again stress-induced deterioration (Hancock 1986). However, as stress drains attention even further, the processing of both spatial and temporal cues begin to fail. In accord with Block (1979, 1990, 1994, 1996), it can be observed that the perceived passage of time is contingent upon the attention directed to it. Consequently, as attention is either directed away from the passage of time (as for example in reading a highly involving book, or putting money in hypnotic Las Vegas slots), or reduced by the presence of stress, time in passing, and time in recall are both distorted (Curton and Lordhal 1974). In highly dangerous situations this represents a sudden onset, acute form of disturbance and hence its vivid phenomenological impact.

This progressive inhibition of sampling helps explain another feature of distortion. That is, when participants experience a slowing effect, the question remains whether the individual feels themselves slowing down or the environment speeding up? This is an inside-out versus outside-in problem. Pilots in the survey of Fair (1984) noted that for them time appeared consistent with their normal experience, it was the rate of flow of the external environment which appeared to dramatically change.

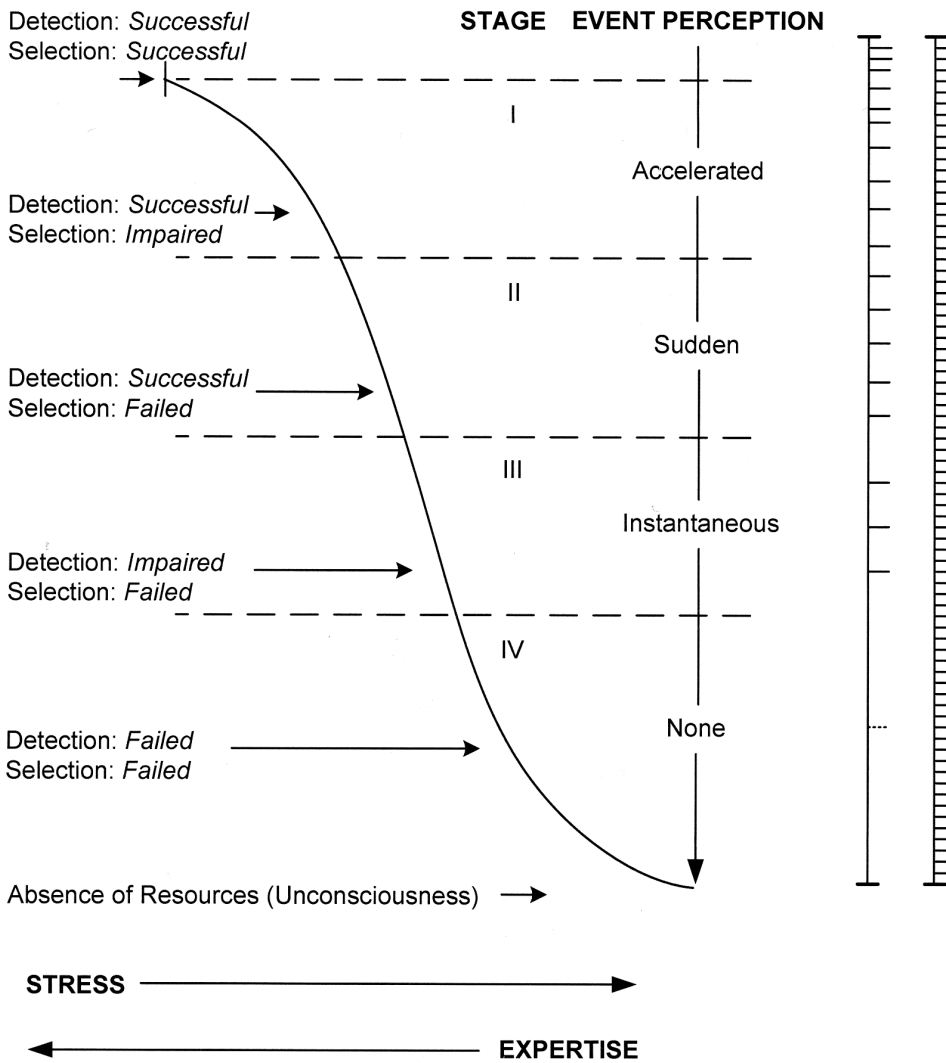

Figure 3. A model of failure under extremes of stress. As the level of stress increases to the right, the attention available to directed to cue detection, cue selection and temporal appreciation is progressively decreased. While expertise in the situation at hand can mitigate these effects, eventually attention is decreased to a level where no temporal information or cues are processed. This is a convenient definition of unconsciousness (although note that we are aware upon regaining consciousness that some time has elapsed). The comparable condition in the failure of physiological functioning is death. We rarely recover from this latter state.

This is why the methodology used in assessment is so important in this realm. Further, this is the reason that time distortions need to be considered as mismatches rather than simply being classed as temporal 'errors'. The latter implies a problem to be solved. However, the mismatch might on occasions be a useful aspect of perform-

ance ability by providing a greater phenomenological 'duration' for response. Of course, it is critical to remember the large differences between individuals in their reactions to stressful conditions and that not all persons will experience temporal distortion, and even for those who do, the time distortion need not always represent the same experiential reality. Clearly, there is still much to understand about this phenomenon, especially about the neuro-physiological patterns of activation involved (Binkofski and Block 1996, Rao *et al*. 2001).

7. Practical observations

Temporal distortions may occur anywhere that insufficient attention is directed to temporal cues. For example, after walking out of a particularly engaging or particularly boring film, one can be quite surprised at the respective length of time that has passed, sometimes pleasantly, sometimes not so pleasantly. In many everyday occupations, such variations are interesting but rarely do they achieve the level of impact they attain in highly stressful circumstances. For example, in flight during an uncontrolled spin the pilot may well be focusing on a slowing of spin rate as precursor to aircraft recovery. Temporal distortion under these circumstances is particularly pernicious in that it encourages the pilot to remain with a vehicle which cannot be recovered. In such circumstances, temporal distortion represents a life-threatening issue. Thus, loss of temporal awareness can be as important as loss of spatial awareness in some circumstances. Indeed, temporal acuity must be critical to efficient situational awareness (Beringer and Hancock 1989, Endsley 1995, Smith and Hancock 1995).

Understanding temporal distortions is important in all emergency, adrenaline-replete situations such as those involved in paramedic response, law-enforcement, military activities, and of course flight. While such considerations are liable to be prominent in high-performance and test aircraft, they also impact commercial aviation when emergencies arise. Since temporal distortion is not limited to emergency situations but can occur under extreme levels of task demands, there is reason to suggest that this can be quite a widespread phenomenon. What is needed at present is much more formal and comprehensive information on the occurrence of time distortions. Indeed, one purpose of the present work is to encourage a more formal experimental program. Consequently, the section that follows will offer suggestions for the advancement of research and knowledge in this area by recommending directions for such a program. Specifically, we will indicate some of the factors that deserve further study and methods that might prove effective for expanding our understanding within this domain.

8. Directions for future research

As a function of the characteristic of the phenomenon itself, knowledge accumulated thus far regarding time distortion under stress has been largely anecdotal in nature. Therefore, a first step in increasing our understanding of this phenomenon is to conduct further empirical survey evaluations in order to better capture the epidemiology of these events. Such a program would be most effective by combining field studies with basic research. Although the primary questions of interest are

those related to time distortion under extraordinary real-world circumstances, it is nevertheless true that laboratory evaluation could be conducted to facilitate our basic understanding.

For example, one initial finding is that the experience of individuals differs radically with regard to the distortion experience. Specifically, it differs with regard to the perception of the event's *duration* and thus *clarity of event recall*. Some people tend to perceive that time has slowed, or methodologically, that their time estimates are greater than that which has actually passed. However, perceived time distortions also occur in the opposing direction such that other individuals report the phenomenological experience that time has 'sped up'. We have shown those bifurcated responses graphically in figure 2. Under normal and even medium levels of stress there is a unitary distribution for locus of attention. However, under extremes of stress, this distribution is bimodal. Investigations may attempt to discern the extent that individual difference variables (e.g. introversion/extroversion, self-control, boredom proneness) interact with the type of task being performed and the nature of the ambient source of stressor. The identification of individual difference variables related to these experiences will have implications not only for clarifying research that has been conducted previously, but also serve to provide guidance regarding selection of personnel in occupations where time distortions are likely to be most prevalent. However, before such procedures could be put into place, it would of course be necessary to obtain compelling data that such methods would be warranted. By furthering the identification and investigation of individual difference variables that influence the degree and type of time distortion, we might be able to better predict the occurrence of the phenomena and use or inhibit it to our advantage.

An additional research question to be addressed relates to the identification of circumstances under which one's perception of time as slowing down might actually prove to have beneficial vs. deleterious effects (e.g., changes with regard to task). As previously noted, under some circumstances persons literally perceive that they have additional time to complete the task at hand. This would appear to have greater benefit in task performance situations where attentional narrowing is less likely to have deleterious effects (e.g., tasks with fewer cues that must be attended to). However, at this point, this is an empirical question that might be amenable to controlled testing.

A further suggestion relates to the proposition that attentional demands are related to distortions in time perception. Specifically, what might be tested is whether the requirement for increased attentional resources increases the degree of temporal distortion. Such an evaluation could be readily accomplished by varying tasks with different attentional demands and measuring subjective time passage. Such studies could be conducted in the controlled laboratory setting. This would reveal the functional relationship between demands for attention and time estimation/distortion (see Block 1990). Finally, one additional question that might be addressed is whether tasks requiring different types of encoding (i.e., visual vs. auditory) influence the type and/or extent of time distortion. A logical extrapolation from this question related to the previous question is whether tasks heavily loaded in *multiple* modalities would be even more likely to be associated with distortions in time. If attention overload is truly a predominant mechanism influencing time estimation, it would be predicted that an individual overwhelmed in multiple modalities would be more likely to report larger time distortions via the most overloaded sensory channel.

As we noted earlier, temporal distortion occurs under stress and can therefore be difficult to study in a laboratory setting primarily due to ethical considerations. However, given that our primary interest lies in understanding time distortion as it occurs under extraordinary circumstances, in all likelihood, some of the most useful research would necessarily be conducted in this field. This approach would not only provide superior ecological validity but would also avoid many of the practical problems associated with stress and laboratory investigations. As one example, emergency service operation promises to provide a most fertile ground for observational studies directed toward a fuller understanding of time distortion under stress. Consequently, it is critical that methodologies be developed and adapted to evaluate field experience. Furthermore, this area of research might explore the use of technical aids to mark time passage in order to evaluate whether technology may minimize time distortion by increasing the salience of time cues.

Given that increase in our understanding of this phenomena emerges, it may well be that temporal as well as spatial scanning is a capability that will be fostered in training programs since practice with a task provides protection against the failure of that task under stress (Hancock 1986). That is, through the use of such training techniques as Stress Exposure Training (Johnston and Cannon-Bowers 1996), it might be possible to incorporate into such interventions the acquisition of the ability to more accurately estimate time passage. However, there is one further step to be taken. Slowing the temporal flow under stress may well be an adaptive mechanism that promotes survival in such circumstances. It might be possible in the future to envisage controlling such a phenomenon, thereby providing a significant performance enhancement and operational advantage over those unable to exercise such an ability.

9. Conclusions

We have a strong social imperative to consider time as a linear, homogeneous medium within which events occur. Such a conception underlies many information-processing models of human capability that each rely on the assumption of the equivalence of one time unit with the next that follows it (i.e., every second is fundamentally the same). Yet for those who experience the phenomenon of time distortion, the fallacy of such a notion with respect to behavioral capability is clearly exposed. Typically, the most vivid experiences of temporal distortion occur under the stress of life-threatening conditions. These cannot be easily replicated in controlled laboratory facilities, even if permission to do so were forthcoming. Nevertheless, such a phenomenon can have a strong influence on performance in a number of the time-restricted performance realms. Until we have models of human performance that deal with such conditions, our ability to predict an operator's efficiency at the most crucial moments of intervention will remain poor to nonexistent. The present linkage between stress, attention, and temporal perception (Hancock and Warm 1989, Stokes and Kite 1994) is an attempt to provide one step toward such an understanding. However, full elucidation of this critical area of research may require a radically different approach than our traditional hypothetic deductive methodology. In particular, a fuller understanding of the context of performance, the characteristics which govern the reactions of different individuals in various

contexts, and the consequences of performance deterioration (Hancock 1989) are crucial areas for immediate exploration.

Acknowledgements

We are grateful to all the individuals who have contributed to the present conceptions, especially to the late Rolf Braune who provided most useful suggestions on an earlier version of this work. His recent demise is a loss to our community and he will be missed. The research reported here was supported by a grant from the Army Research Organization (Grant# DAAD19-01-1-0621). The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Army, Department of Defense, or the US Government. The authors wish to thank Dr Sherry Tove, Dr Mike Drillings and Dr Paul Gade for providing administrative and technical direction for the Grant.

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