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The Effects of Startle on Pilots During Critical Events: A Case Study Analysis

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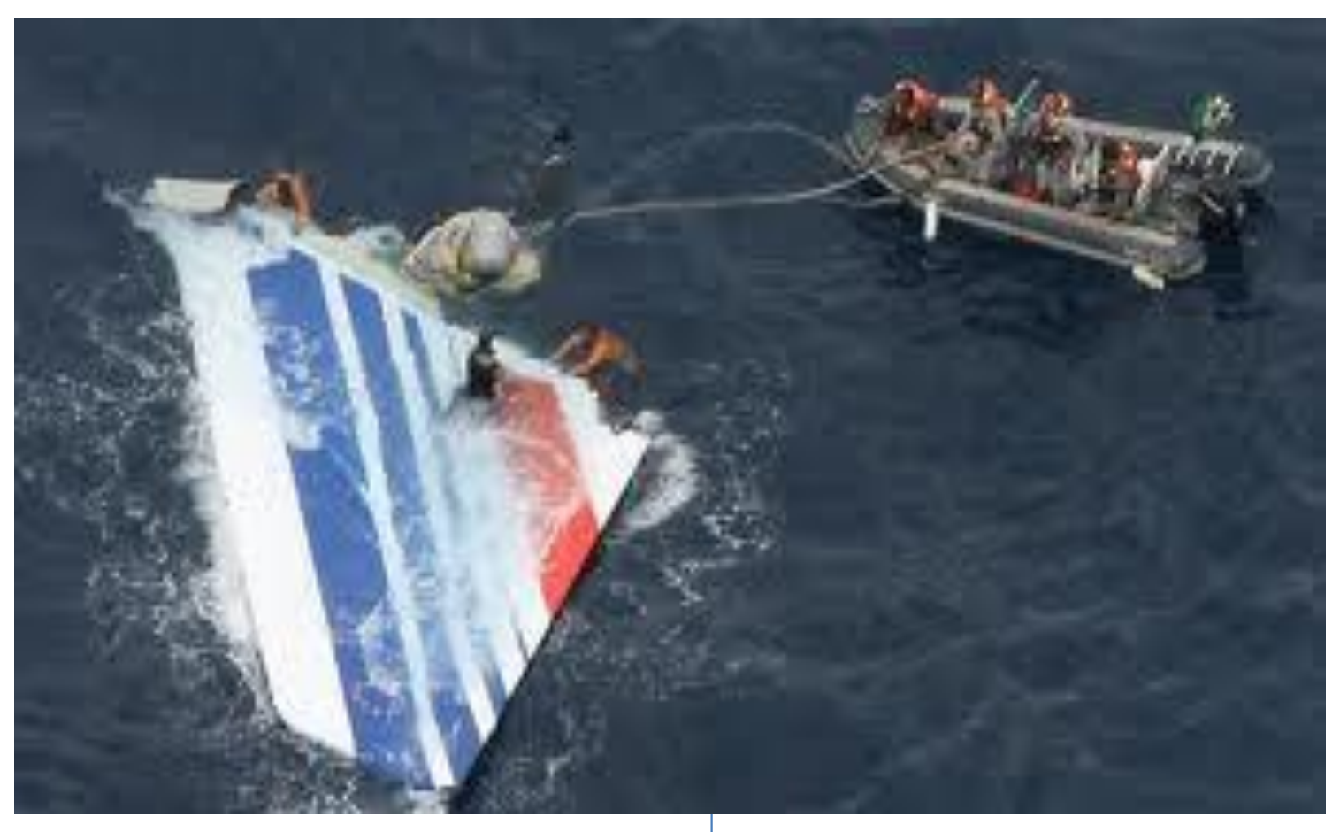
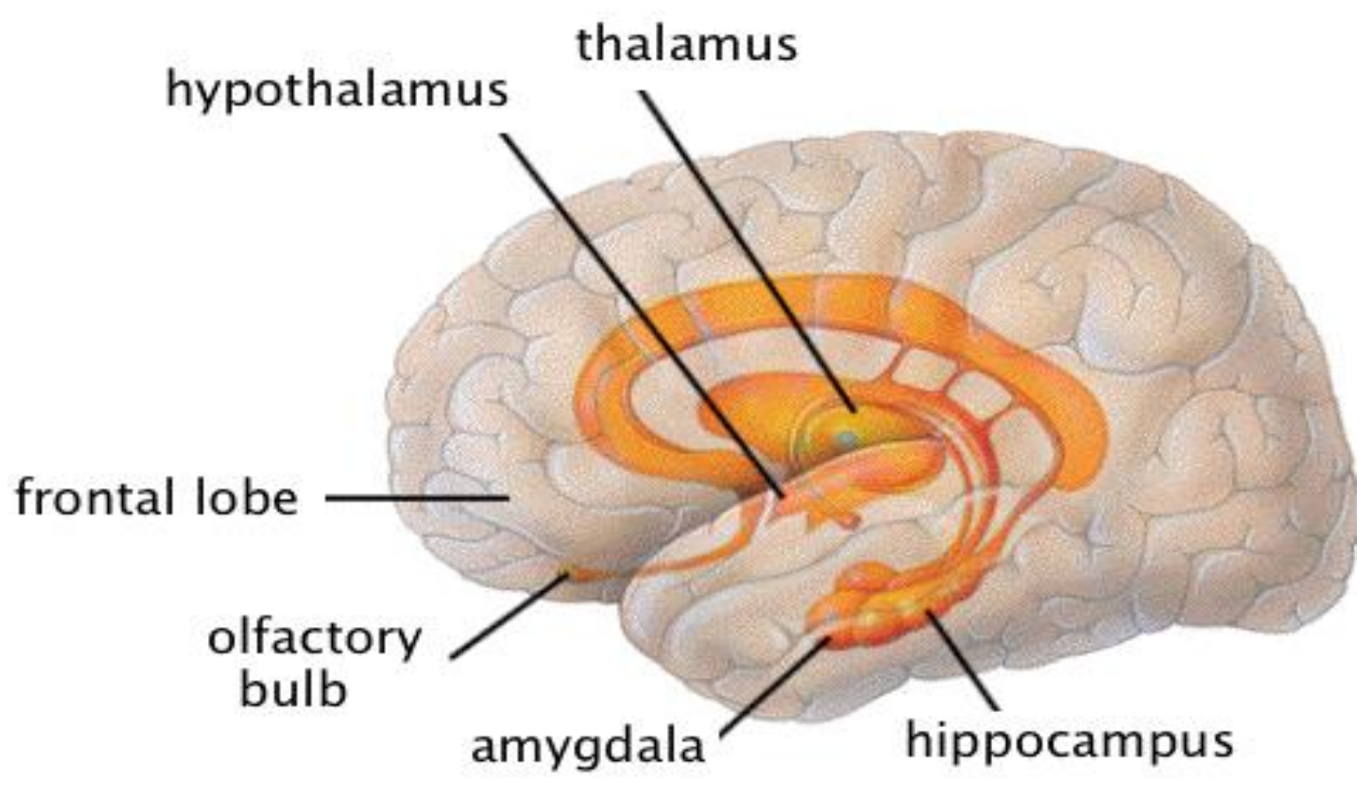
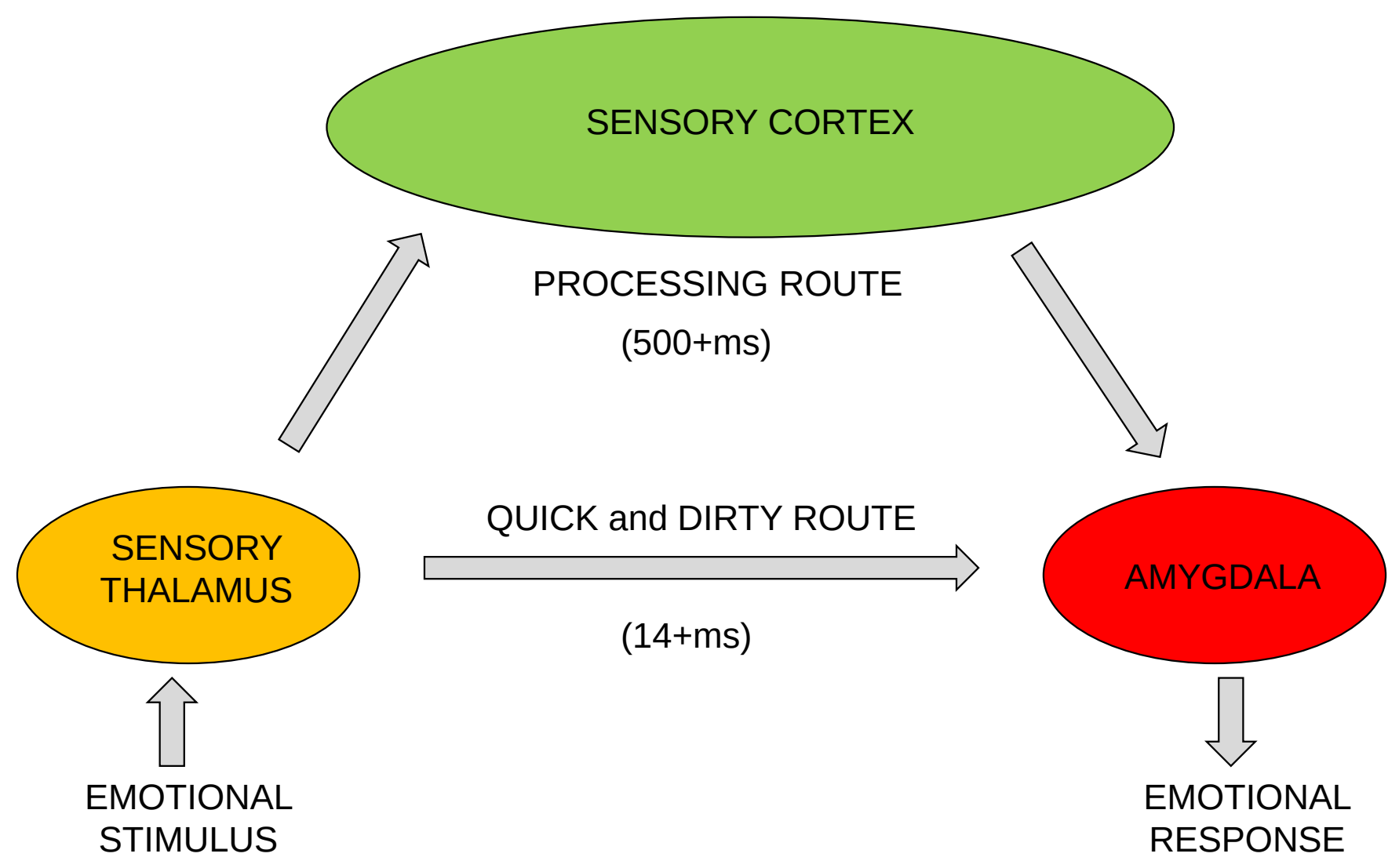


The Startle Reflex

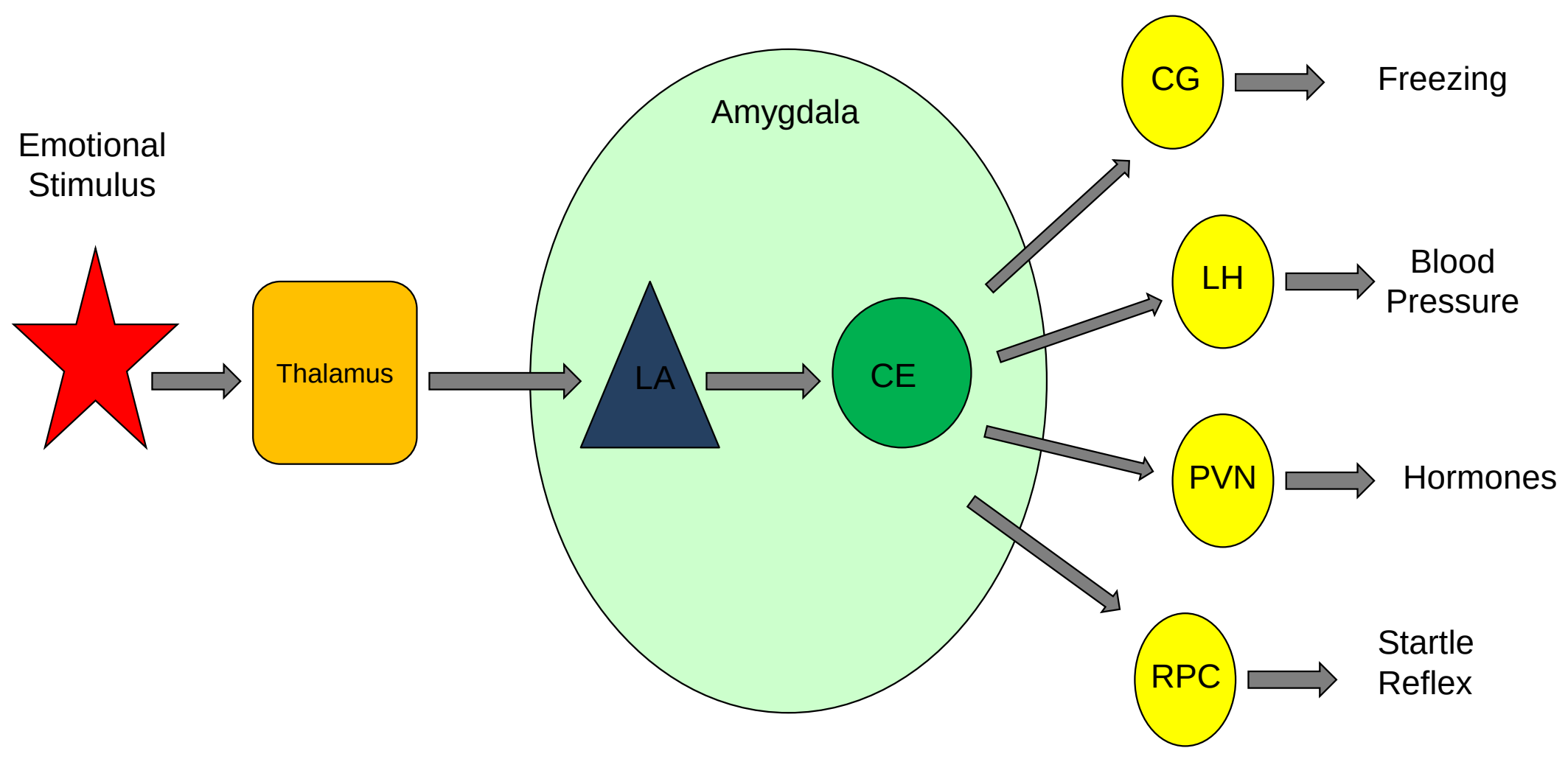
The amygdala in the limbic region of the brain appears to be central to the startle response, with sensory signals being projected through various regions of the amygdalin complex for rudimentary interpretation of emotional valence.



Signals with some significance may induce the startle reflex, while these same signals are also routed to the sensory cortex for cognitive processing. While processing in the pre-frontal cortex may take in excess of 500 milliseconds, the initial amygdalin analysis is very quick, resulting in an aversive startle reflex away from the stimulus, while at the same time orienting the attentional mechanism to the source of the stimulus.

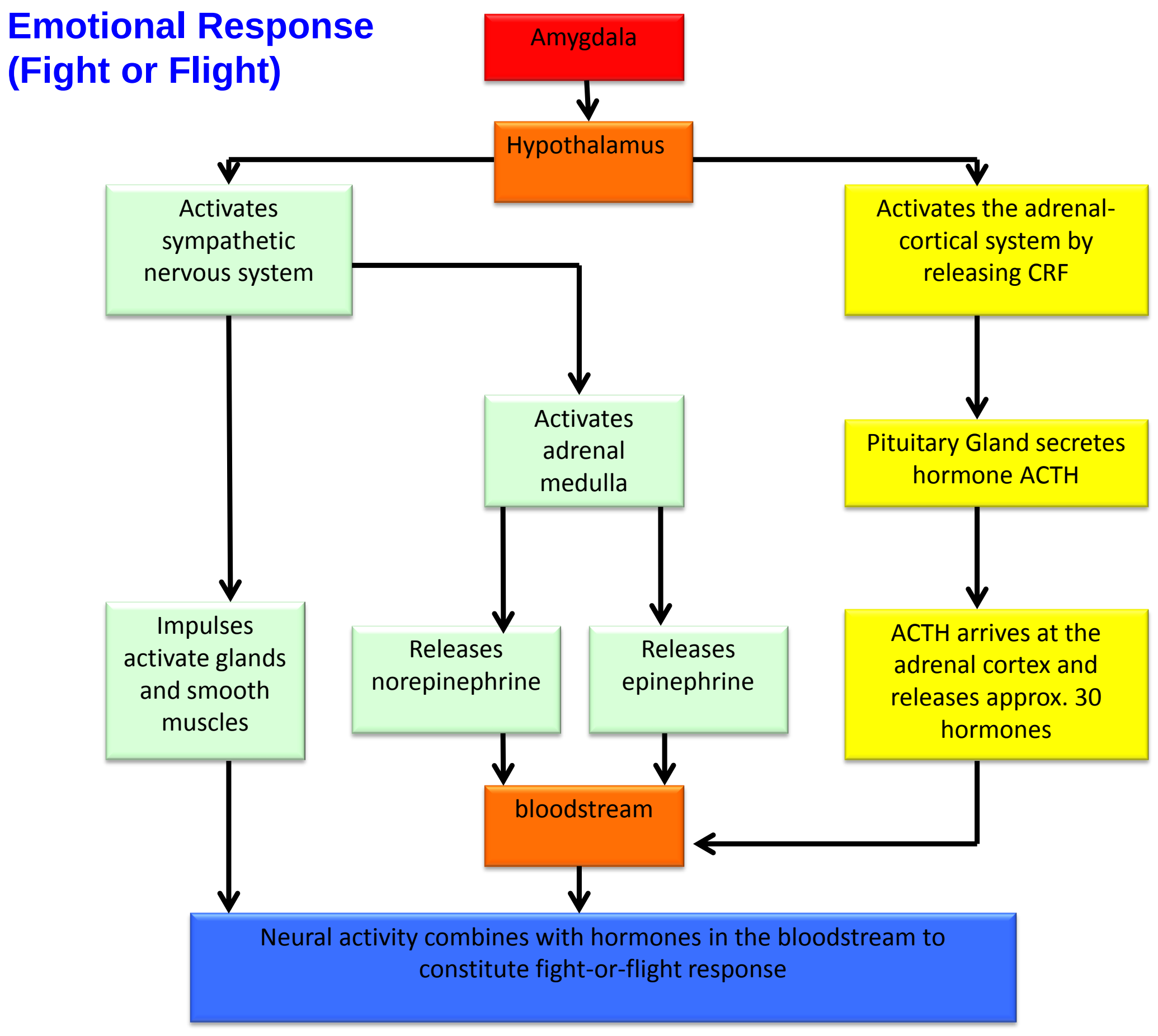


The Amygdala also projects to the sympathetic nervous system, activating endocrinal and cardiovascular arousal when a threat persists. This is where the startle reflex transitions to the startle or surprise reaction.



The startle or surprise reaction is commonly called the 'fight or flight' response and involves a number of bodily systems. The following diagram shows the principal systems and pathways initially activated in this process:

Emotional Response (Fight or Flight)


Amygdala
Hypothalamus
Activates sympathetic nervous system
Activates the adrenal-cortical system by releasing CRF
Activates adrenal medulla
Pituitary Gland secretes hormone ACTH
Impulses activate glands and smooth muscles
Releases norepinephrine
Releases epinephrine
ACTH arrives at the adrenal cortex and releases approx. 30 hormones
bloodstream
Neural activity combines with hormones in the bloodstream to constitute fight-or-flight response

Research shows that activation of this startle/surprise/fight or flight reaction may have deleterious effects on information processing for up to 30 seconds. This has major implications in the aviation paradigm for situational awareness, problem solving and decision making.

The following accidents are examples of situations where startle or surprise may have contributed to sub-standard performance following some unexpected critical event:

Turkish Airlines Flight 1951

- Schipol Airport, Amsterdam, 2009
- Fault with Captain's Radio Altimeter
- Thrust enters a 'retard flare' mode
- Speed decays until stick shaker warning
- F/O botches applies partial thrust
- Autothrottle reduces thrust to idle
- Captain takes over but leaves thrust at idle for 9 seconds
- Unable to recover from stall

Startle may have contributed to the inadequate response to the stall.

Air France Flight 447

- Atlantic Ocean off Brasil, 2010
- Pitot probes ice up giving false speeds
- Autopilot drops out and the aircraft reverts to alternate law mode
- Stick shaker stall warning commences
- F/O pulls up 2000 feet
- Aircraft enters a fully developed stall
- F/O applies full up control inputs
- Unable to recover from stall

Response consistent with either multiple startles or continued degraded information processing following startle.

Colgan Air Flight 3407

- Buffalo , New York, 2009
- Commencing approach from 2300 feet
- Flaps and Gear lowered, Condition Levers to maximum - all create drag
- Power left at idle, speed reduces
- Stall warning stick shaker activates
- Captain pulls up, aircraft stalls
- First Officer retracts Flaps
- Unable to recover from stall

Incorrect control responses by both Captain and First Officer were typical of startle induced confusion.

Pinnacle Airlines Flight 3701

- Jefferson City, Missouri, 2004
- 2 Pilots aboard only on Ferry Flight
- Decided to test maximum certified alt. (FL410)
- Autopilot tried to maintain altitude by increasing pitch attitude; speed reduces
- Stall warning stick shaker activates
- Nose raised and multiple stick pushes occur
- Aircraft enters aerodynamic stall (27° nose up)
- Both engines flame out
- Unable to recover from stall

The actions by the flying pilot were consistent with disrupted reasoning following startle.

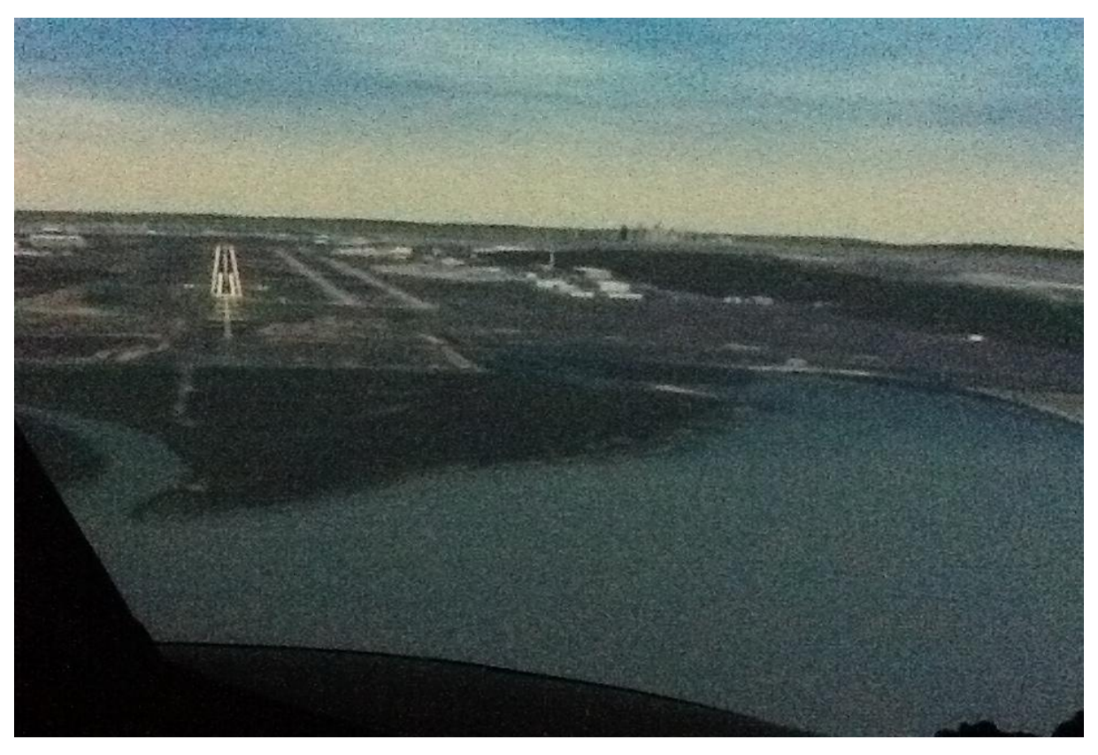
West Carribean Airlines Flight 708

- Venezuela, 2005
- Aircraft was climbed rapidly to 33,000ft
- Autothrottle reduced thrust
- Speed gradually decayed over 6 minutes
- Autopilot disengaged as aircraft was unable to maintain altitude
- Aircraft entered an aerodynamic stall
- Pilots never applied full thrust and held the control column fully back.
- Unable to recover from stall

The lack of situation recognition and inappropriate control inputs were typical of performances impaired by startle.

Startle Research in an Airline Flight Simulator

In June 2012, simulator research was conducted in a modern flight simulator using 18 type rated pilots. Each pilot flew an identical exercise involving two instrument approaches with the cloud base requiring a missed approach . On the first approach a startling stimulus was introduced at 40 feet above the decision altitude. No stimulus was introduced on the second approach.



Approximately one third (n=5) participants performed nominally; one third exhibited a slightly delayed reaction (n = 6) and approximately one third (n=7) displayed behaviours which were either significantly delayed or dangerously unstable. In the latter group three pilots continued descent so far that they became visual, with two receiving EGPWS warnings "Pull Up, Pull Up". Two continued with their unstable approaches and landed, while one went around from a very low altitude.

Comparitive data between the first approach (with stimulus) and second approach (without stimulus) was analysed. The following are the results obtained:

	Approach 1	Approach 2
Stimulus Altitude (AGL)	Minimum Alt on Go Around	Minimum Alt on Go Around
	With Stimulus	Without Stimulus
240 ft	170	170
240 ft	170	140
240 ft	170	190
240 ft	160	110*
240 ft	160	170
240 ft	150	180
240 ft	150	160
240 ft	150	170
240 ft	150	170
240 ft	140	170
240 ft	140	160
240 ft	200	170
240 ft	220	160
240 ft	86	140
240 ft	66	150
240 ft	56	180
240 ft	0 (Landed)	150
240 ft	0 (Landed)	190

A one sample t test was applied to the minimum altitudes achieved in approach 1 (with stimulus) and approach 2 (without stimulus). The averaged altitude in the second approach was used as a baseline comparison (excluding the 110ft outlier result).

Average delay in reaction on the first approach was 36.1 feet; SD = 62.64, t = -2.246, 17 df, p<0.005.

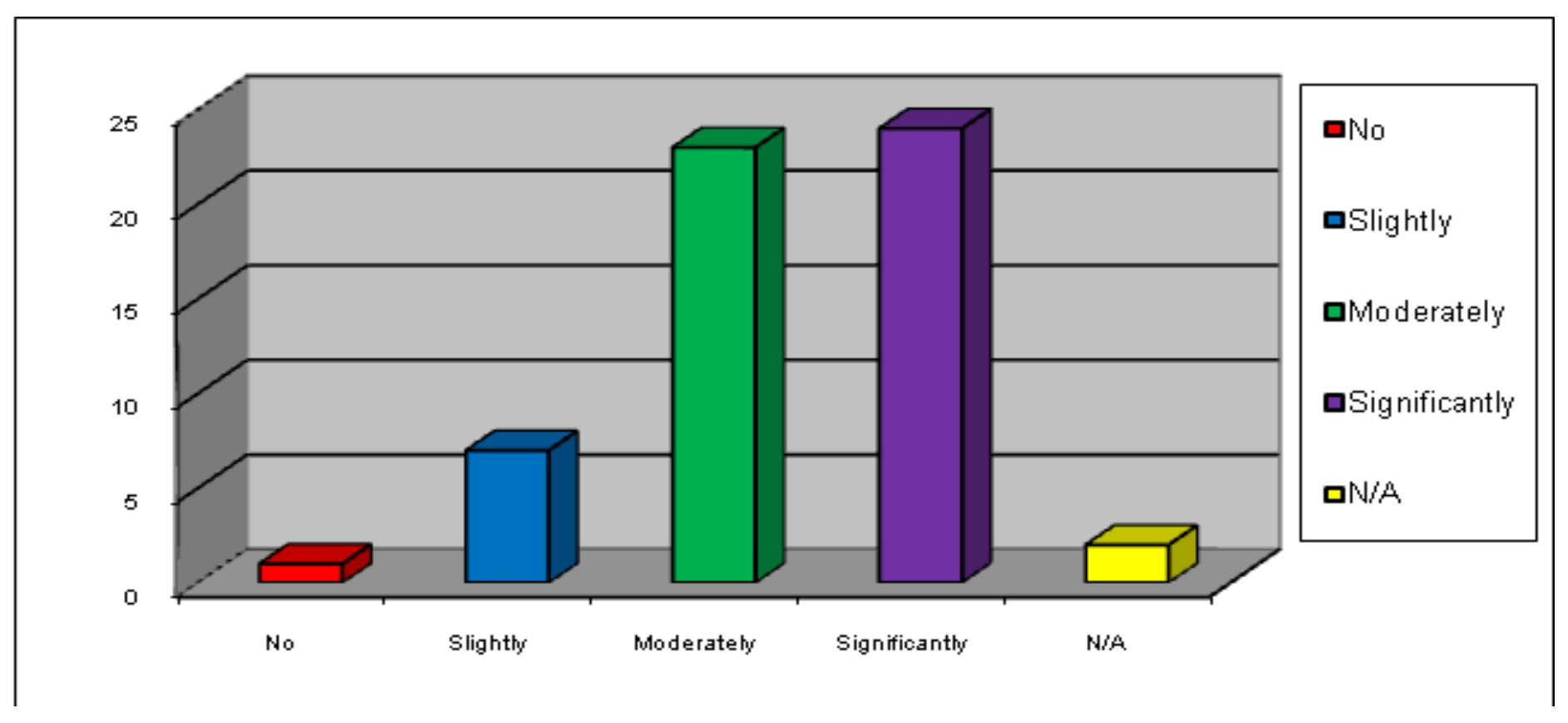
Of the 18 participants most (n=14) reported noticing some physiological reaction to the startling stimulus (generally increased heart rate and adrenaline).

Most (n=11) reported a period of confusion or indecision of varying duration, following the startle.

The ubiquitous reliability of modern aircraft has created an unconscious expectation of normalcy amongst Pilots. This lack of expectation for things going wrong can have negative effects on acute stress levels and startle reactions.

A 2010 study identified scenario discussions as a means for raising expectations and overall sense of efficacy for handling critical and novel events.

"As a result of these discussions do you think that you would be better prepared to handle one of these novel or emergency events if it happened unexpectedly?"



Further research is warranted.

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Abstract

The ubiquitous reliability of the modern airliner continues to make aviation a very safe mode of transport. This reliability does not however extend to pilots it would seem, with major lapses in performance during critical events a common theme in major incidents and accidents. The conditioned expectation of normalcy amongst pilots may contribute to underperformance during surprise critical events, resulting in poor handling of complex situations. The effects of startle, an autonomic reaction with deleterious effects on information processing, may be a strong contributor to poor pilot performance during critical events. These effects may seriously impair situational awareness, decision making and problem solving, all critical skills in the handling of a complex emergency. The startle reaction is examined from a cognitive perspective, followed by an analysis of several recent aircraft accidents where startle effects may have been strong contributory factors. The link between startle and pilot expectation for such events is discussed with implications for further research and interventions.

Introduction

Aviation is considered a high risk industry, not because of the likelihood of accidents, but rather because of the consequences of such accidents. However, despite graphic news footage of aircraft accidents across the media suggesting otherwise, these catastrophic events are becoming rarer, with annual fatality rates in the mere hundreds across the globe. Indeed, the fatal accident rate per flight hour in 2011 was just 1.4×10^{-6} (ICAO, 2012). Contrast this with vehicle accident rates or deaths through medical misadventure and the scarcity of aircraft accidents shows an industry which has ultra-high reliability and robust resilience to systemic and individual failures.

This universal reliability is the result of numerous initiatives, all operating in concert to provide multi-layered defenses in the battle for aviation safety. Aircraft engine and system reliability is one area where huge technological advances have been made over the last fifty years. The modern turbofan or turboprop engine are so inherently reliable that twin engine aircraft are now routinely operated up to four hours from a suitable airport, safe in the knowledge that the chances of a double engine failure or major and multiple system malfunction are so statistically unlikely as to make such operations feasible with incredibly high assurance of safety.

The introduction and widespread normalization of safety enhancing devices such as Enhanced Ground Proximity Warning Systems (EGPWS), Airborne Collision Avoidance Systems (ACAS), Vertical Situation Displays (VSD), Head Up Displays (HUD), Electronic Flight Bags (EFB) and the Global Positioning System (GPS) for instance, coupled with technological and systemic improvements in Air Traffic Control (ATC) and Airline Safety Management Systems (SMS), have also created an environment where human failings are consistently minimized, caught, corrected and obviated. Coupled with much work on the human element over the last thirty years, through initiatives such as Crew Resource Management (CRM) and Non-technical Skills (NTS) training, Threat and Error Management (TEM) strategies, Fatigue Risk Management Systems (FRMS) and Flight Data Monitoring (FDM) systems, the whole aviation system has become very safe.

The question remains then, in such a reliable system, why aircraft accidents still occur. Data obtained over the last few decades has consistently shown that humans are the principal problem, contributing to around 70-80% of all aircraft accident causes (Wiegman & Schapelle, 2003). Indeed, some recent high profile accidents have shown the pilots to have been far from optimal in their handling of unexpected events and rather than utilizing their skills, training and knowledge, have underperformed at exactly the time when these skills were most needed.

One of the common themes which has emerged as aircraft have become ever more reliable, is that pilots have been surprised or startled by some event, and have as a result either taken no action, or alternatively have taken the wrong action, which has created an undesired aircraft state, or in some cases, an accident. This surprise or startle is largely due to the enduring reliability of the aircraft and the aviation system, which has unwittingly created a conditioned expectation of normalcy amongst today's pilots. If aircraft perform nominally day after day, year after year, and pilots are rarely exposed to actual malfunctions, then it is not hard to see how this conditioned expectation of boring sameness and normality can develop. The problem then is that the level of expectation for novel or critical events is so low that the level of surprise or startle which pilots encounter during such events, is higher than they would perhaps have had some decades ago, when things routinely went wrong.

Startle research has been conducted in laboratories for some decades, with participants largely subjected to starter pistols, buzzers or shocking pictures as startling stimuli. The results of these experiments have shown considerable effects on information processing following the startle, with research by Vlasek (1969), Woodhead (1959, 1969) and Thackray & Touchstone (1970) showing that cognitive and dexterous impairment could last for up to 30 seconds following a strong startle. Reductions in information processing capability has significant implications for things like decision making, problem solving and situational awareness in the aviation paradigm and recent research by the author showed significant reductions in performance following startle in flight simulator experiments in approximately one third of participants.

An analysis of the human startle reaction will be further discussed. Data from startle experiments will also be introduced and analysis of possible startle reactions from several aircraft accidents will be conducted. Implications for the industry and further research are discussed.

Discussion

The inherent reliability in modern airline aircraft has engendered an unwanted and undesirable conditioning of pilots to expect that things will not go wrong. This complacent attitude is simply a function of ubiquitous reliability and may be considered statistically warranted by some. The problem arises however when things do go wrong. If pilots are not expecting things to go wrong, because they never do, then the level of surprise or startle which they experience when they do go wrong, can be significant and underperformance, due to the effects of this startle on the body's systems, can be detrimental to their handling of such events. Simons (1996) suggests that when people are subjected to some sort of startling stimulus where a real threat exists, then the intensity of that startle is enhanced. This fear potentiated startle is a distinct possibility where pilots are suddenly confronted with a potentially life threatening situation, which may engender a distinct mortality salience within certain individuals.

The Startle/Surprise Reaction

The startle reflex is common to all mammals, birds, reptiles and amphibians (Simons, 1996). It is an innate and involuntary reaction to some startling stimulus which can be perceived in any sensory modality. Early research into startle commonly used starter pistols, loud bells, buzzers, and shocking pictures as stimuli, although more practical research using car air bag deployment or car bonnet fly-ups, attempted to make the experiments more realistically focussed (Thackray, 1988).

The startle reflex happens very quickly following a startling stimulus, with the first signs occurring in humans in as little as 14 milliseconds (Simons, 1996; Yeomans & Frankland,1996). This suggests a very rudimentary link between the senses and the various muscles involved in the reflex actions, and extensive work by a number of researchers (eg. Davis,1986; Eaton, 1984; Landis & Hunt, 1939; Lang, Bradley & Cuthbert, 1990; Le Doux 1996, 2000; Phelps & Le Doux, 2005; Whalen & Phelps, 2009) has determined both the common patterns of startle and the neural pathways involved.

The amygdala in the limbic region of the brain appears to be central to the startle response (Davis, 1992; Le Doux, 2000), with sensory signals being projected through various regions of the amygdalan complex for rudimentary interpretation of emotional valence. Signals with some significance may induce the startle reflex, while these same signals are also routed to the sensory cortex for cognitive processing. While processing in the pre-frontal cortex may take in excess of 500 milliseconds (Asli & Flaten, 2012), the initial amygdalan analysis is very quick, resulting in an aversive startle reflex away from the stimulus, while at the same time orienting the attentional mechanism to the source of the stimulus. This provides us with a means of reacting very quickly to threatening stimuli, but also creates a large number of false alarms. The whole startle may last between 0.3 and 1.5 seconds, depending on the severity of it, the propensity of the individual to startle, emotional state and a number of other contributing issues. Figure 1.

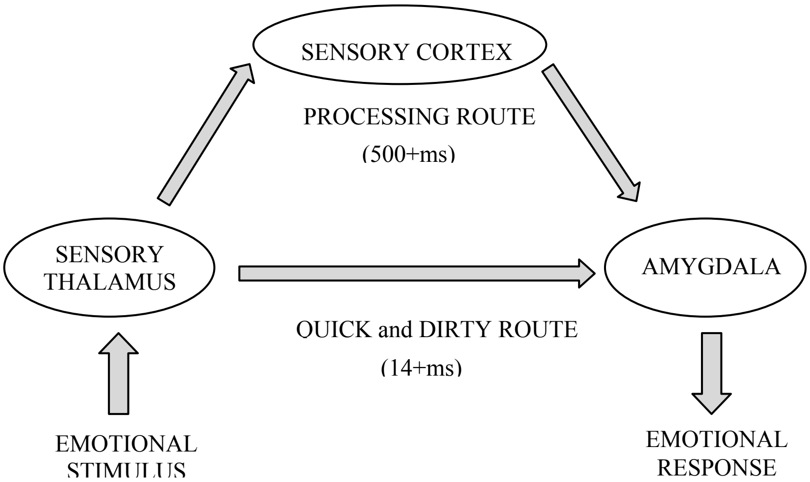

Figure 1. Le Doux (1996)

The problem remains an issue when the threat persists and the startle transitions from a simple aversive reflex movement to a full-blown startle or surprise reaction. This involves the activation of the sympathetic nervous system and the endocrinal system in a reaction commonly known as the ‘fight or flight’ reaction. This reaction affects heart rate, blood pressure and respiratory rate and directs blood away from the extremities to the major muscle groups. This process contributes to the ‘confusion’ or delays in processing, commonly experienced following a strong startle.

There is also a large variation in the intensity of the startle/surprise reaction amongst different people, and even within the same person in different circumstances. Some people are naturally ‘low reactors’ (Thackray, 1988), while others may fall into a category known as ‘hyperstartlers’ (Simons, 1996). These hyperstartlers are very prone to adverse reactions and may perform poorly in cognitive tasks following startle. Pilots would ideally be low reactors, but this isn’t always the case with a recent flight simulator experiment showing a significant variation in response to a moderate startle.

The experiment involved 18 type rated pilots who flew two Instrument Landing System (ILS) approaches in a modern airline jet simulator, without the use of an autopilot. The cloud base was set 100 feet below the minima (Decision Altitude) requiring a missed approach to be executed at the minima (200ft AGL) for both approaches. During the first approach a startling stimulus (Cargo Fire Warning Bell and simultaneous loud bang) was introduced 40 feet above the decision altitude. No stimulus was introduced on the second approach.

The results showed that approximately one third (n=5) performed optimally, one third (n=6) showed a slight reactionary delay, and one third (n=7) performed significantly worse than optimal. The results were intended to show reactionary delay by measuring the minimum altitude achieved during the first go-around (with stimulus) compared to the baseline minimum altitude on the second go-around. The following table shows the minimum altitudes achieved in order of reactionary delay. Note: two of the pilots in the third group reacted impulsively and commenced the missed approach prior to the decision altitude – a pathological response.

Stimulus Alt (ft AGL)	App 1 Min Alt (Stimulus)	App 2 Min Alt (No Stimulus)
240	170	170
240	170	140
240	170	190
240	160	110*
240	160	170
240	150	180
240	150	160
240	150	170
240	150	170
240	140	170
240	140	160
240	200	170
240	220	160
240	86	140
240	66	150
240	56	180
240	0 (Landed)	150
240	0 (Landed)	190

In the third group, three pilots continued descent so far that they actually became visual (<100ft AGL), with two of these receiving EGPWS warnings “Pull Up, Pull Up”. Of these, two continued with their unstable approaches and landed, while one finally went around from below 100 feet AGL.

*The 110ft achieved on the second missed approach by one pilot was sub-standard and a self-acknowledged ‘lazy’ go around which would have resulted in a fail if performed during a standards check. This outlier result was removed from averages during statistical analysis, giving an averaged minimum altitude of 166 feet from the second baseline approach.

A one sample t test was applied to the minimum altitudes achieved in approach 1 (with stimulus) and approach 2 (without stimulus). Average delay in reaction on the first approach was 36.1 feet; SD = 62.64, t = -2.246, 17 df, p<0.005.

Of the 18 participants most (n=14) reported noticing some physiological reaction to the startling stimulus (generally increased heart rate and adrenaline).

Of the 18 participants most (n=11) reported a period of confusion or indecision of varying durations, following the startle.

Accident Analysis

A number of accidents have occurred in recent years where adverse pilot performance following startle may have contributed or been directly causal. The following are some examples where startle may have been contributory:

Turkish Airlines Flight 1951 – This Boeing 737-800 suffered a fault with the Captain’s Radio Altimeter during an approach to Schipol Airport at Amsterdam. The Captain’s radio altitude started erroneously reading -8 feet, causing the autothrottle to transition to a ‘retard flare’ thrust mode. This caused the speed to decay to the point where the aircraft eventually received a stall warning stick shaker, then stalled, at about 460 feet above the ground. A normal stall recovery would generally be achieved with 0-200 feet height loss, however the mishandling by the flying pilot was typical of somebody surprised by an unexpected event. The Captain attempted to take over and recover the aircraft, however the autothrottles had retarded the thrust after the First Officer’s initial push forward and the Captain did not take any action to reset full thrust for some nine seconds after this. The Captain was unable to achieve a satisfactory recovery before the aircraft hit the ground (The Dutch Safety Board, 2010)

The mishandling and lack of action to apply full thrust were typical of performances impaired by adverse effects on information processing caused through startle. An appraisal of continued threat and mortality salience would have likely escalated physiological reactions into a full arousal of the sympathetic nervous system, with accompanying effects on processing.

Air France Flight 447 – This Airbus A330 was in the cruise over the Atlantic at an altitude of Flight Level 350 (35,000ft) in an area of thunderstorm activity. Following the obstruction of the pitot tubes due to ice crystal ingestion, the autopilot disengaged and the aircraft control systems entered a degraded mode (alternate law). Despite auditory, visual and tactile indications of a stall situation, the First Officer pulled up and continued to apply full back pressure on the control stick for the remainder of the flight. The aircraft descended rapidly, being held in the fully stalled condition by the First Officer, eventually crashing into the Atlantic Ocean some 3-4 minutes after the initial signs of aerodynamic stall. The correct response to any stall should have been to apply maximum thrust and either nose down or wings level control inputs (BEA, 2012).

The initial response of the First Officer to pull up hard on the control stick was consistent with impaired information processing, decision making and problem solving, typical of a startle reaction. His persistence in maintaining full backward pressure on the stick all the way down was also consistent with either multiple startles or continued degraded information processing following startle.

Colgan Air Flight 3407 – This Bombardier Dash 8-Q400 was on approach to Buffalo Airport, New York when the Captain levelled the aircraft at 2300 feet prior to commencing the ILS approach. Before the aircraft captured the Glideslope and commenced descent the Captain lowered the landing gear, lowered some flap and took the Condition Levers to maximum, all the while leaving power close to flight idle. This additional drag rapidly caused the speed to decrease to the point where the aircraft stall warning stick shaker activated. The Captain's response should have been to apply maximum power and to lower the nose to increase speed. The actual reaction from the Captain was the opposite: He pulled back on the controls while only applying around 75% of available power. When the stick pusher then attempted to push the nose forward in response to the aerodynamic stall, the Captain overrode this and continued pulling back. The First Officer also appeared to have raised the flaps to zero during this time, which had the effect of exacerbating the stall. The aircraft descended in a fully stalled condition, pitching and rolling uncontrollably until impacting a house on the ground (NTSB, 2010).

It is likely that the Captain was initially very startled by the stick shaker and accompanied disengaging of the autopilot. His action to pull back and then continue pulling back against the pressure of the stick pusher were consistent with a severe information processing breakdown. His reactions were contrary to all previous stall training and could well have been induced by physiological effects from the startle reaction. The First Officer also exhibited confusing actions in raising the flaps, which may have been due to startle induced impairment.

Conclusion

The effects of startle are common to all humans, although the propensity for severe startle is greater in some people and is dependent on other variables such as emotional state, ongoing stress levels and attentional processes at the time. Where people are startled and the threat persists, such as in a life threatening aircraft emergency, then the startle reflex is likely to transition into a full surprise or startle reaction, with its ensuing activation of the sympathetic nervous system.

Research has shown adverse effects in a proportion of volunteers during startle experiments. Tests by Vlasek (1969), Woodhead (1959, 1969) and others have shown cognitive impairment for up to 30 seconds following startle and this has been shown in some accidents to be a period where underperformance has been critical to recovery. While it is difficult to prove startle as a cause in historical accidents, interviews with startled pilots and qualitative data in flight simulator experiments suggest that the negative effects of surprise/startle are real and significant in some people. Quantitative data obtained from flight simulator experiments showed varying degrees of affectedness following startle, with some people not affected and others so badly affected that flight safety was compromised.

A review of various accidents, such as Turkish Airlines Flight 1951, Air France Flight 447 and Colgan Air Flight 3407 suggest that Pilot performance was impaired following the onset of an unexpected critical event. Had the Pilots of these aircraft been working with impaired faculties induced by startle, then that would perhaps account for their mishandling of the emergencies encountered.

The inherent reliability of the modern aircraft has had a significantly positive impact on aviation safety. Automation, engine technology and system reliability has become so robust that critical events are somewhat of a rarity. Events such as the catastrophic engine failure aboard Qantas Flight 32, or the dual engine failure aboard US Airways flight 1549 are examples where pilots performed well, both as individuals and as teams, and these positive outcomes are clearly the aims of expensive airline training programs. Such engine failures are remarkably uncommon however, and while pilots continue to train for such events, regulators, airlines and other bodies around the world are starting to trial evidence based training programs (EBT) which provide more emphasis on managing the most common and unusual events. Training in managing these unusual but critical events allows pilots to develop cognitive strategies for dealing with such 'black swan' occurrences (Taleb, 2007).

While startled pilots may have been responsible for sub-optimal performance in the past, providing training for pilots in handling unexpected critical events will likely have two benefits: It will raise expectations for such events and provide pilots with both generic and specific skill-sets for handling them. Further development of the EBT and ITQI initiatives will widen the acceptance of the current problem and improve pilot performance when critical events occur.

Further research is warranted.

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