Investigation of the Physical and Cognitive Factors Affecting Slip Error

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Abstract—**The proneness of human to errors is a proven fact. There have been numerous studies conducted in order to find out the cause of human slip errors so that by avoiding such errors humans could avoid catastrophes. The outcomes of these studies have been interesting as some researchers blame physical factors more than cognitive factors and vice versa. From the existing studies we can accomplish that there has not been much comparison done between physical and cognitive factors. This paper is aimed to study different experiments and papers in this area in order to see how physical and cognitive factors affect human slip error and whether or not one is more responsible than the other for human slip error. From the literature that has been studied, the paper concludes that it is the mix of physical and cognitive factors that are to be blamed for human slip errors to occur. Similarly it is suggested that a mix of physical and cognitive steps have to be taken for the human slip error rate to drop significantly or better eliminated completely.**

Human Error, Human Factors, Slip Error, Cognitive Factors, Procedural Error.

I. INTRODUCTION (HEADING 1)

There is a famous quote by Alexander Pope, "To err is human" [1]. A Human Error is an error made by a human. Why is it that one human makes more errors than the other, or the same human sometimes makes more errors than usual? "There is a belief among many engineers and managers that human error is both inevitable and unpredictable. However, human error is inevitable only if people are placed in situations that emphasize human weaknesses and that do not support human strengths" [1]. Research has shown that there are different factors which affect the rate of human error. Some believe cognitive factors are more to blame than physical while some disagree. There are also some who believe both play an equal part in tricking human into an error. Human Errors have been classified into different types in order to research in to the factors that affect Human Error; that will put concerned bodies in a better position to devise systems and strategies to reduce them. In Feb 1989 a compiled report was put forward in the Technical committee meeting organized by International Atomic Energy Agency (IAEA), which concentrated on the classification of human errors and how it can be reduced to ensure the safety in nuclear plants [3].

Steve Mason in his report "Improving Maintenance by Reducing Human Error" mentions three main types of human errors; mistakes, violations and slip errors/lapses [4]. A mistake is the kind of human error when a procedure has been forgotten or never been properly trained for. E.g. A driver driving in a new country, and parks his car in a prohibited area because he did not know about the rules. Violation as the name suggests is when a rule is deliberately ignored or is being violated. E.g. A driver deliberately parks his car in a prohibited area although he knew the rules. And Slip Error is the kind of human error where a person has to carry out a list of tasks in a specific order but he misses out on a step, does the wrong thing at the time or performs the tasks in a wrong order. This can also be called a slip or lapse. Procedural Error is another term normally used for Slip Error. An example from a day to day life would be a person forgetting to turn off the headlights before switching off the engine or a person clicking play button on a DVD player having forgotten to click the power on button first.

The purpose of this paper is to look in to the research that has been done so far on different physical factors affecting Human Slip Errors.

II. MOTIVATION

Slip Errors would not be so critical if they were only limited to normal day to day tasks like forgetting to power on the DVD player before hitting the play button, or forgetting to attach the file before sending an email. The consequences of a slip error can be fatal and disastrous. ABC News reported in August 2008 that human error was to blame for one of Philippines worst disaster when a ferry sunk leaving nearly 800 people dead or missing [5]. BBC News suspected the nuclear accident at the Tokaimura processing plant in Japan in 1999 was a classic case of Human Error when the workers made a simple but terrible mistake and the radiations were leaked to the wider environment [6]. Similarly human error is believed to be the reason behind 70-80% of aviation accidents [7].

There are hundreds of cases reported where a normal human slip error resulted in situations where the safety and security of human beings is put in jeopardy. Since the consequences of a human slip error can be fatal, this has become a very critical area of research so that the different factors can be researched into to find out the causes of human slip errors and how they can be reduced. The motivation to write this paper comes from the fact that slip errors must be reduced to the minimum level, if not eliminated, to save lives and environment. The objective of this paper is to research different studies carried out to determine how physical factors affect human slip errors and what conclusions have been drawn from those studies.

III. TYPES OF HUMAN ERROR

It is easy to talk about human error as one broad category which is not very wrong to think, but as Trevor Kletz in his book "An Engineer's view of Human Error" mentions that it would be analogous to a "book on transport talking about the Jet Travel and seaside donkey rides discussed under same headings" [8]. Researchers have been classifying human errors in to sub categories, and then the sub categories further in to sub categories in order to find the root causes of the factors from which the errors originate and what measures could be taken to minimize human errors and if possible eliminate them. NATO held a conference on human error and subsequently published a paper in a conference on human error in which they defined human error differentiating it from other terms like accident, fault, mistake etc. [9]. Based on the research so far, human error is normally considered to have three main types which are the following.

A. Mistake

A mistake is defined to be the kind of human error when a procedure has been forgotten or never been properly trained for. E.g. A driver driving in a new country, and parks his car in a prohibited area because he did not know about the rules.

B. Violation

Violation as the name suggests is when a rule is deliberately ignored or is being violated. E.g. A driver deliberately parks his car in a prohibited area although he knew the rules.

C. Slip Error

Slip error or procedural error is the kind of human error where a person has to carry out a list of tasks in a specific order but he misses out on a step, does the wrong thing at the time or performs the tasks in a wrong order. This can also be called a slip or lapse. Norman defines that slip is an error which has the correct intention and it's not the lack of knowledge that causes the error to happen [10]. A classic example from day to day life would be forgetting the original documents in the photocopier after the photocopies are done. Another example would be one forgetting to attach the file to an email before sending. For clarity lets add another example from day to day life and that would be if a person forgets to switch off the headlights before switching the engine off. There can be several reasons for the human slip errors to occur like work memory load, cognitive factors such as lack of motivation or tense environments. Also, it can occur at different positions such as at the start which is called initialization error or at the end called post completion error. This paper will concentrate on the research carried out on the physical factors affecting slip error.

IV. WHAT IS A PHYSICAL FACTOR?

Physical factor is defined as non-living factor that affect organisms and their survival in some way. Another definition of physical factor is, "a factor in the abiotic environment that influences the growth and development of organisms or biological communities [11]."

V. WHAT IS A COGNITIVE FACTOR?

Cognitive factor is defined as something immaterial like an influence or circumstances that affect the outcome.

Following is the non-exhaustive list of physical and cognitive factors that researchers believe to affect human error in one way or the other.

VI. PHYSICAL AND COGNITIVE FACTORS AFFECTING HUMAN ERROR

Reason found that human behaviour is frail and there are many factors which can affect human error like lack of motivation, ergonomic factors and various cognitive/psychological and physical factors [12].

Following are the physical and cognitive factors discussed in this paper.

A. Poor System Design

This is one of the big factors that researchers have believed to affect human error rate. Byrne and Davis suggested a simple design change can reduce post completion error with no time trade off [13].

A system can be designed in a way which does not let a user does a wrong thing. When ATM machines were developed one of the errors humans would make was; after withdrawing money the user would walk away forgetting to pick his card up from the machine. That is because the money came out first and the card would follow. They slightly changed the system design by changing the procedure in which steps were carried out which means the card comes out first and money follows. This means the money does not come out until you have picked up your card.

Many have believed lack of proper cue is one of the major reasons for the slip errors to happen. Different types of cues like "Just in Time" cues, asynchronous cues etc have been used to try and reduce human errors. Adding visual cue has been one of the favourite ways to reduce error. Chung and Byrne elaborated the importance of the timing of the cue, their movement and characteristics especially in dynamic tasks with external loads. In their study Chung and Byrne compared the different timings and places of the cue, studying the effect of enhanced visual cue and mode cue on the rate of post

completion errors. Their findings suggested that visual cue was much more effective than the normal controlled state where there was no cue, and the error rate was even lower than the mode cue [14].

Similarly, Li et al. tested participants with a simple static visual cue to observe the effect it has on error rate. Their results suggested that the addition of a cue can reduce errors [15]. But there have been suggestions that cues can perform well in reducing the error if they are prominent. Back et al. suggest the procedural (internal to the cognitive system) and sensory (external to the system) cues should be salient and strong enough to interrupt individual's attention away from the normal actions and make them attend to the cue (which will suggest avoiding the error). The study proved that adding a visible and salient cue can significantly reduce post completion error (which is a kind of slip error when the main task is completed and there is a known (but not vital) final step which has to be done, but it's either forgotten or not performed, example from daily life would be forgetting the original documents in the photocopier after copying is done) [16].

Byrne observed the three key properties of a cue (salience, specificity and just in time nature). His findings showed that just in time property of the cue is the most vital while the salience surprisingly was the least critical [17].

Similarly Akram et al. further suggested that adding a post completion warning message is better than adding a static cue to the system to reduce post completion errors [18].

This all points in one direction that the studies conducted using ways like adding cues or altering procedures to monitor their effects on human error have focused on system design, and they all are coherent in concluding that system design can be altered to reduce human errors.

Based on the findings of many studies discussed we can safely say that humans are more prone to error if they are using a poor system design which lack proper cues or procedures that help humans avoid errors.

B. Fatigue

Fatigue is believed to be another reason which makes a human prone to errors. According to Finkelman work induced fatigue can occur by processing too much or too little information [19], and fatigue according to Summala and Mikkola increases the risk of accidents which means the driver is more prone to error if fatigued [20].

Dionisio suggests that fatigue, sleepiness and stress all add greatly to the amount and severity of human errors in the aviation system [21].

There have been a lot of studies connecting fatigue to human errors, accidents, injuries due to accidents etc. Bourgeois-Bougrine et al. conducted a study and found a direct link between workload compounded by stress, and fatigue [22]. Furthermore Kirwan et al. suggested that high workload can cause fatigue and that is associated with safety concerns [23].

Similarly Hah and Willems used the relation of stress and fatigue with human error and accidents to conclude that air traffic controllers must not be presented with more traffic than they can handle [24]. Macpherson and Tvaryanas also supported the argument that fatigue and stress can affect the health and safety of those involved [25].

There is a need to take fatigue seriously as fatigue can cause human errors and they can have disastrous consequences. The Aerospace Medical Association Fatigue Countermeasures Subcommittee (AMAFCS) has stated that "…fatigue represents a significant risk in aviation when left unaddressed, there are currently numerous countermeasures and strategies that can be employed to increase safety" [26].

This is where cues (strong system design) can play their part as Back et al. suggest the procedural and sensory cues should be salient and strong enough to interrupt individual's attention away from the normal actions and make them attend to the cue (which will suggest avoiding the error) [16]. This is supported by Akram et al. suggesting adding a warning message can take the user's attention away and make him/her attend to the step that needs to be done [18]. Another suggestion is better management of the shift work and work load.

C. Interruptions and Distractions

Like poor system design and fatigue, distractions and interruptions can also cause human errors even if system design is strong and fatigue is not an issue. Akram et al. in their experiments used participants to compare the effects static cue and post completion warning message has on human post completion error. They used participants who were not fatigued, and the prototype having a post completion warning message was concluded to be a very strong design as it significantly reduced the post completion errors in comparison to the prototype which had a static cue and the one which did not have any cue at all. It is important to note that the well trained participants were continuously interrupted and distracted through questions at different stages while performing the experiments. The stronger system design (containing the post completion warning message) reduced the errors significantly though not eliminate it as shown in the Fig. 1 [18]. This shows that although the design was strong, participants were well trained and fatigue was not there but still their experiments contained a few post completion errors.

This can be concluded that the interruptions and distractions were to blame for those few errors.

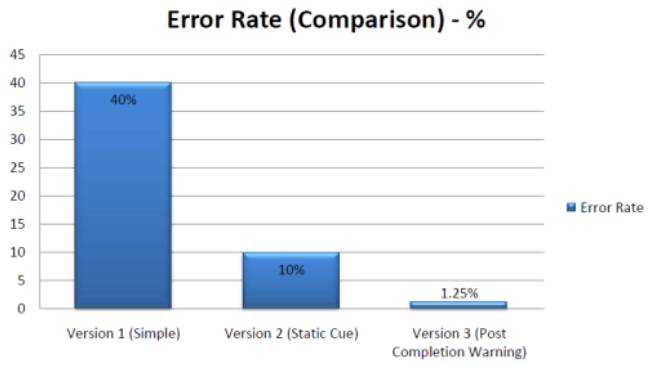

Fig. 1: PCE Comparison of a simple Prototype with Prototypes with a Cue and Post Completion Warning Message (Adopted from Akram et al. [18)]

Similarly Li et al. suggests introducing interruptions just before the post completion step can have an effect on the rate of post completion errors and force participants into post completion errors [27]. Latino also discusses in his detailed article about the effects of distractions on human performance that there are a lot of distractions in the environment which affects our performance as humans and subsequently forces us in to errors e.g. constant interruptions by co-workers or high noise levels in the working environment etc [28].

We have enough evidence to say that distractions and interruptions alone play their part in forcing humans in to slip errors.

D. Motivation Levels

Researchers have also believed over time that motivation to perform a task can also have effects on the rate of slip error. Meister writes that inadequate training and poor motivation entices human error [29]. Similarly Dhillon believes that carelessness, low motivation and bad attitude towards work can also contribute to human error [30]. Reason supported the argument with the findings that human behaviour is frail and there are many factors which can affect human error like lack of motivation, ergonomic factors and various cognitive/psychological and physical factors [12].

Anita in her report Human Error and Marine Safety declares that human performance, among other factors, is influenced by motivation and alertness [31]. But even though there is a lot of evidence to say motivation does have effects on human performance and errors but there is some evidence which says that motivation alone is not enough for a human to completely avoid error. Back et al. studied this aspect of the potential of PCE happening. They conducted experiments by making games and the result of the participant were reset to zero whenever they made a post completion error, this built their motivation to avoid PCE, however, their results concluded that an individual is prone to post completion error even if he/she is motivated to avoid them; they also concluded that the vulnerability to this type of error will be more in demanding situations [32].

It can be concluded that lack of motivation is factor that entices human slip error but being motivated is not enough to avoid human errors.

E. Lack of Training

Lack of training is another factor widely believed to have effects on the rate of human slip error. Researchers have believed that lack of training is one of the biggest factors in causing human slip errors. However, it is important to mention that recent studies have used well trained participants for experiments and that may have improved the rate of human slip errors though not eliminate them.

As mentioned above Meister writes that inadequate training and poor motivation entices human error [29]. Anita believes that crew size and training decisions affect workload which in turn affects their capabilities to perform safely and effectively [31].

However many experiments such as Akram et al. used well-trained participants for the experiments and they still could not eliminate human slip error [18]. Based on which we can say lack of training affects human slip errors but that alone cannot be blamed for slip errors. Other factors have to be improved if we are to dramatically reduce, if not eliminate, human slip errors.

F. Working Memory Load

If a human's memory is filled up or in other words if there is high working memory load then he/she is more prone to slip errors.

Byrne and Bovair investigated further through experiments claiming that human errors may occur more if working memory load is high [33]. Just and Carpenter predicted the association of high working memory load with post completion errors [34].

Adding to the Fothergill and Neal [35], Byrne and Bovair used Just and Carpenter's Collaborative Activation-based Production System (CAPS) [34] to prove that post completion errors can occur in the laboratory setting too by filling up participant's memory [33].

Li et al. made use of working memory load to ensure participants make post completion error and test them with cue to observe the effect of cues on the error rate. They used an example of non-real life scenario in which the participants had to solve problems in the head to ensure memory demands and load, and they were tested with the prototypes made to move the items across the river. There was evidence that working memory load can be used in laboratory setting to cause slip errors. The results suggested that adding a cue can reduce those slip errors [15].

We can say that in situations where there is high working memory demand can force humans into slip errors.

G. Environment

Other real life factors could be the environment or work place, weather for the people who work outside as in the scenario adopted in the study conducted by Akram et al. where they discussed door to door sales scenario [18]. Environmental effects can be in many shapes or forms e.g. background noise, interrupting colleagues (as discussed in Interruptions and Distractions section that interruptions and interruptions position can have notable effects on the rate human slip errors), bad light, bad weather for people working outdoor such as door to door salesmen (filling out forms while raining pouring down, or working in extreme hot and humid conditions which causes fatigue and as discussed in the fatigue section fatigue leads to human slip errors), or flying in adverse weather as that significantly reduces visual cues which in turn can cause human errors (as we discussed in the Poor System Design section and many other places in this paper that visual cues can reduce human errors.) Many flights and trains are either delayed or terminated because of bad weather. It is because humans are more prone to error if weather is bad, as discussed above that bad weather can reduce visibility resulting in reduced visual cues and more proneness to error. Fig. 2 gives the delays in the National Airspace System. It clearly shows that out of all the delays experienced, majority of the times it is because of bad weather.

Latino also discusses in his detailed article about the effects of distractions on human performance that there are a lot of distractions in the environment which affects our performance as humans and subsequently forces us in to errors e.g. constant interruptions by co-workers or high noise levels in the working environment etc. [28].

But the problem Researchers face is that it is very hard to create the actual real life setting in the laboratory to perform an experiment as Sellen and Norman suggests, "The laboratory environment is possibly the least likely place where we are likely to see truly spontaneous, absentminded errors [36]." So, human factors' researchers have made use of other factors/influences to emulate the real life scenarios.

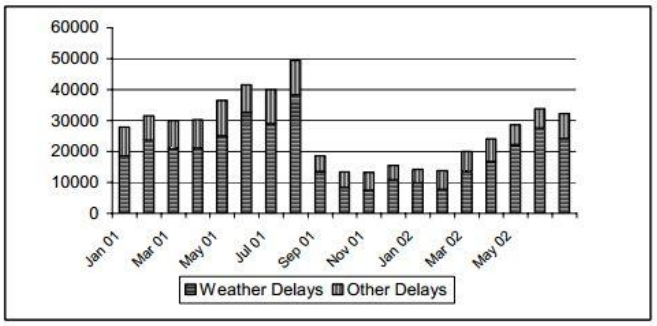

Fig. 2 Delay hours in the National Airspace System for January 2001 to July 2002 (Adopted from Kulesa, year unknown [37])

Researchers have made use of different types of interruptions and physical and cognitive loads to force humans into error in the laboratory setup. For example loads like intrinsic load and extraneous load are being used to expose the error proneness of human beings in laboratory conditions. Intrinsic load refers to the complexity and difficulty of the task while extraneous load refers to the quantity of (irrelevant) information given to a person to perform a task.

It can be said that environment affects us as humans in different forms. For some it can be a mood swing due to gloomy winter weather, for pilots it could be lack of cues due to adverse weather conditions, for others it could be working alongside colleagues who constantly interrupts and for some it may be lack of proper light to perform a certain task etc. All of these, as discussed in different sections, somehow cause or promote the occurrence of human slip errors.

VII. DISCUSSION

There are numerous ways to achieve the minimization of human slip errors, if not elimination. The research done so far should be used to create a mix and match to create error-free work environment that works best for a particular organization. It is also suggested from many experiments that a combination of factors can escalate rate of human slip error. For example if a person X is poorly trained for a certain task, he is made to work on a poorly designed system, in an environment where he is constantly interrupted by the colleagues and he is fatigued as well, it is very likely that the error rate would escalate as these factors individually are proven in different studies to be the causes of human slip errors so combination of these factors are likely to worsen the rate human slip errors. The point is addressing only one aspect will not reduce the error-rate dramatically. This is where right combination of steps should be taken for human X to avoid slip error. In the example of human X he should be well-trained for the task, should be provided with a strong system design and disciplined environment where he is not interrupted without need and he should have had enough rest to be fresh (and not fatigued).

VIII. CONCLUSION

An error is always caused by different factors, whether it's lack of motivation, lack of training, fatigue, environment; we can, however, minimize the errors by taking a combination of necessary physical and cognitive steps to minimize the effects caused by physical and cognitive factors affecting human slip errors. For example we can always aim to build a strong design that may be achieved by adding a post completion warning message, or salient cues etc. We can, where possible, provide a work environment that is suitable for the task. Humans on their part can take proper rest to be prepared to deal with long days. They can keep themselves hydrated by keeping a water bottle with them to slow down drainage of energy due to hot and humid weather. There is a lot of room for further research as there could be many factors that needs

to be discovered in order to minimize human slip errors as we all agree that human errors can lead to disastrous situations which could be avoided.

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