Leveraging mental models to shape behavior in human-product interaction

With the aim of avoiding unintended actuation of important controls in electronics.

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ABSTRACT

The design of buttons and switches have the possibility to communicate function in ways that transcends information labels. Design for usability is generally focused around minimizing cognitive load to make an interaction easy and efficient to perform. However, sometimes critical interactions become too efficient, leading to increased risk of undesired actuation and confusion. Manipulating the physical properties of a control based on existing mental models has the potential to increase intuition and shape user behavior to avoid mistakes. Yet, little guidance and principles exist on the subject of behavior shaping to avoid unintended actuation. The use of constraints to shape behavior is neither commonly included in the concept phase of a user-centered design process, but often a result of iterations from extensive usability testing studies. Based on a literature review within the field of cognitive psychology and design principles for usability, two key principles for designing important controls were proposed: tooling and two-factoring. The application of these interaction principles can help designers explore innovative solutions when designing error proof controls for electronics.

KEYWORDS: mental models, behavior-shaping, human-product interaction, affordance, forcing functions, mistake proofing, Yerkes-Dodson Law

1. INTRODUCTION

The intersection between design and psychology is very profound and has been debated extensively. Many common design principles for usability are derived from studies conducted by psychologists. Some products with critical functions inherent these principles in a way that shape user behavior to reduce errors and avoid accidents. However, little guidance exists regarding the matter of shaping user behavior through the design of buttons and switches. The constraints that shape user behavior are not always based on thoughtful design decisions, but rather a result of an empirical understanding of user behavior, human errors, and failure analysis through observations and testing.

This paper aims to highlight different approaches for designers to consider in the concept phase of a design process when given a specific brief that includes interactions with critical outcomes.

Using mental models derived from past experience with other product proposes a potential to affect the users' behavior and reduce the risk of unwanted interactions. Therefore it can be beneficial to decompose already established mental models to understand how we can leverage already established conventions within a user target group.

2. METHOD AND STRUCTURE

This paper is based on a literature review in the field of human cognition and design principles for usability. The paper consists of 6 sections. The literature review was carried out to understand and map out how designers can shape user behavior and evoke deliberate interactions between human and product. Section 4 will present different real-life examples to map out possible approaches for evoking deliberate interaction, along with different design principles that could be used as components to affect the users' mental model through the design of buttons and switches of great importance. Although the use of visual cues in the form of warning graphics and labels is beneficial to communicate function, they will not be covered in detail, as labels should be complementary and not considered as the determining factor in behavior shaping.

The literature review has been conducted in association with the development of an IoT (Internet of Things) monitoring device for industrial gas cylinders that includes controls that should evoke deliberate interaction in use.

3. BACKGROUND

3.1 Importance of deliberate interaction

Modern technology products and services become ever more interconnected with each other. The modern generation of electronics are often products that function in a network of other products and services. Often combined with a business model referred to as a product-service-system, which is an integrated product and service offering that delivers value when in use (Baines et al., 2007). Electronics shift from just being gadgets used by a single user to complete a task, to a part of a complex network of products and services. Together, six components make out the product-service-interaction: the product or service, the user, the user's goal, other products, other users and the context of the interaction (Wever, van Kuijk & Boks, 2008). The interplay between the components introduces the possibility that interaction from one of the components could have a cumulative effect on other parts of the system (Reason, 1990). Therefore, if someone in the network interacts with the product in an unwanted or unfortunate way, it may induce problems for either the user itself, other users and ultimately compromise the purpose of the service. To avoid these mistakes, designers should prevent possible critical operations to be carried out if not genuinely desired by the end user. The next section will describe some design principles based on cognitive psychology that can be used as components to achieve this goal.

3.2 Human cognitive process

It is essential to understand the characteristics of the human cognitive process to understand how people interact with products. Research on cognitive psychology has stated that to achieve an ideal level of human performance the user should possess a moderate level of stress(referred to as arousal by psychologists) because it emphasizes awareness (Anderson, 1994; Yerkes & Dodson, 1908). This relationship between arousal and performance was postulated in 1908 and is called the Yerkes-Dodson Law (Figure 1). The study shows that a lower level of stress, e.g., being bored or inattentive would lead to lower performance. Thus a more significant risk of unintended behavior. On the other hand, when if the stress level becomes too high, the opposite will occur and the level of performance decreases drastically.

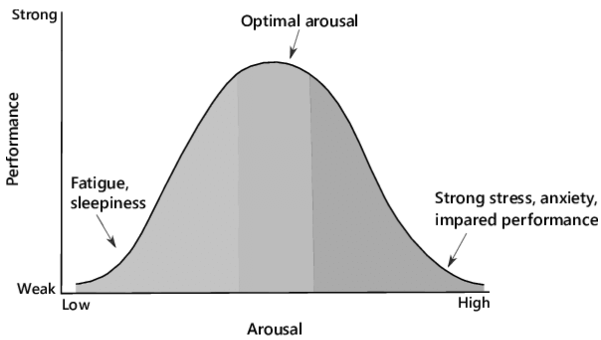

Figure 1: Yerkes-Dodson law.

3.3 Mental and conceptual models

Cognitive scientists have been studying mental models to understand how people make decisions and construct behavior in different environments (Davidson, Dove & Weltz, 1999). Carey (1986) defines the term mental models in her journal article "Cognitive Science and Science Education" like this:

> A mental model represents a person's thought process for how something works (i.e., a person's understanding of the surrounding world). Mental models are based on incomplete facts, past experiences, and even intuitive perceptions. They help shape actions and behavior, influence what people pay attention to in complicated situations, and define how people approach and solve problems (Carey, 1986).

A mental model is a perception or representation that a person constructs in their mind derived from past experience. These assumptions and beliefs that the users form are used to help them understand how the object they interact with will work. On the other hand, we have conceptual models. "A conceptual model is the actual model that is given to the person through the design and interface of the actual product" (Weinschenk, 2011). The mental model may not always match the conceptual model which may cause confusion and result in poor user experience. Weinschenk (2011) states that if there is a mismatch between the conceptual model and the mental model, designers should provide training to alter peoples mental model so they will be able to use the product with ease.

3.4 Perceived affordance

As early as in 1935, gestalt psychologists argued that the meaning or the value of a thing seems to be perceived just as immediately as its color (Koffka, 1935). In other words, he claimed that humans are typically able to recognize the functional abilities of natural objects. This theory was developed further by Gibson (1979) in his final book *The Ecological Approach to Visual Perception* as something he called affordances. Affordances are relations between perception and action that tells the observer how to use an object. He argued that the early gestalt psychologists failed to mention that an affordance also could lie and concluded that "the basic affordances of the environment are perceivable and are usually perceivable directly, without an excessive amount of learning" (Gibson, 1979).

The concept of affordances was not considered a universal principle in the field of design until Norman (2013) revived the term in his book *The Design of Everyday Things*. Every object and environment has an affordance and tells us how something can be used. A chair could afford sitting, and a button could afford pushing. He argued that affordances are instead a relationship between the object and the agent, and not a property in itself. "The presence of an affordance is jointly determined by the qualities of the object and the abilities of the agent that is interacting" (Norman, 2013). A heavy object could afford lifting for some people, but not for everyone.

3.5 Gestalt psychology

One of the earliest attempts to understand how humans perceive patterns was conceived in 1912 by psychologists Wertheimer, Koffka, and Kohler. They developed what is today known as the *Gestalt Laws*, which describe how we can use simple principles to construct perceivable patterns. Helping us understand why we see things as a whole, rather than the individual parts. The law of gestalt theory can be broken down into principles including proximity, similarity, continuity, closure, connectedness, symmetry, closure, relative size, and common fate (Koffka, 1935; Palmer & Rock, 1994; Wagemans, Elder, Kubovy, Palmer, Peterson, Singh & von der Heydt, 2012; Ware, 2004). The principles of gestalt psychology are still relevant today as they effectively describe different perceptual phenomena which can be utilized by designers.

3.5.1 Similarity

The principle of similarity is the notion that we place objects with similar characteristics in a group. These characteristics include color, size, texture, form.

3.5.2 Proximity

Spacial proximity says that objects that are close to each other are perceptually grouped together.

3.6 Meaning conveyed by color

People connect different meaning and associations with different colors. In the western world, people often associate buttons with the color red as something that means danger or stop. (ISO, 2016; Weinschenk, 2011). Moreover, green could mean on or go. Designers have the possibility to leverage these already established associations in their designs to convey the correct meaning. However, it is also important to notice that colors may have different meaning across different cultures or subgroups.

3.7 Behavior-shaping constraints

Every user interacts with a product in different ways, and mistakes will happen regardless of how well the product is designed. Some people tend to make decisions intuitively, and others tend to make them in a deliberate way (Weinschenk, 2011). Nevertheless, some precautions can be made to limit the risk of mistakes. A technique which has its foundations in cognitive systems engineering is called behavior-shaping constraints (Rasmussen, Pejtersen & Goodstein, 1994). Its purpose is to prevent an error from happening rather than trying to recover after the error has occurred. Guiding the user to act in the desired way is better than offering assistance afterward to correct the error. The technique of error proofing has also been referred to as the term *forcing functions* and *poka-yoke* (Norman, 2013; Shingo, 1986). By Norman's (2013) definition, forcing functions are the extreme case of strong constraints that can prevent inappropriate behavior. Forcing functions can be used as a tool to force attention and evoke deliberation before performing a specific task. Thus, it is a way to influence user behavior at the expense of either effectiveness or limitation of an interaction to achieve a particular goal.

3.7.1 Lockouts and lock-ins

Within the domain of forcing functions there exist methods called lockouts and lock-ins (Norman, 2013). The lockout method is implemented for safety reasons and prevention of accidental misuse. Lockouts can be generalized to something that obstructs an interaction to provide safety, like a switch cover that has to be lifted or a safety firing pin on a firearm. Whereas lockouts prevent an action from occurring, a lock-in serves the opposite purpose, ie. to keep an action for being terminated.

Before considering to implement this powerful technique, it is crucial to understand the context of use, the user flow, and possible misuse. If the lockout function imposes negative emotions by the user, it is likely that they will remove the safety mechanism and thereby compromising the behavior-shaping function. "The clever designer has to minimize the nuisance value while retaining the safety feature of the forcing function that guards against the occasional tragedy." (Norman, 2013). Therefore it is fundamental that any deviation from a conventional interaction technique is as self-explanatory and intuitive as possible.

4. DESIGNING CRITICAL CONTROLS

4.1 Leveraging existing mental models

When designing a new conceptual model, designers have the opportunity to design this model based on existing mental models to shape user behavior. In its purest form, a target group could, for instance, have a strong mental model connected to the concept of a big red button. Based on past experience, their mental model subconsciously tells the user that it is most likely related to an action of high importance, e.g., an emergency, a signal or something that will trigger something of great magnitude. Designers can leverage this acknowledgment and combine different components of mental models to induce the desired mental model. The mental model will tell the user what to expect based on past experience as they will transfer their expectations for the outcome of a controller if it has similarities to something familiar.

The effect of established mental models is even more obvious when misapplied, causing undesired confusion. Older transit buses used to have a pull cord for the passengers to inform the driver to stop at the next station. When people learn the function of this type of interaction for the first time — their mental model is formed. Older trains used to have a similar type of pull cord, though these were meant for the emergency brakes. Because the mental model connected to the interaction of the pull cord was constructed as an interaction to make a signal, the emergency brakes were inevitably mistaken as a stop signal. If the order in which mental model related to a pull cord was reversed, the opposite would presumably happen. Resulting in that no one would intuitively pull the cord to get off the bus unless an emergency occurred. Thus, the concept of building upon already constructed mental models can be used as a tool for behavior-shaping, likewise, as it can confuse if misapplied.

4.2 Reducing task efficiency
Usually, one of the main goals of usability is to reduce the interaction cost to a bare minimum. Therefore designers often strive to increase efficiency to make products easier to use. However, increasing efficiency related to an important interaction can cause undesired behavior if a critical interaction too efficient. In this case, a way to minimize risk would be to reduce the task efficiency related to critical controls. It is important to distinguish between interactions that require rapid triggering if, e.g., an emergency occurs as opposed to an interaction that is not time sensitive. If interaction time is not of the essence, the reduction of task efficiency could be beneficial in shaping behavior.

Within the field of interaction design, it has been argued that designers should not prioritize efficiency over expectations (Harley, 2015). If a user is able to close an application on a computer without being prompted with a confirmation step that communicates that changes will be lost or a critical task will terminate, it usually causes negative outcomes and emotions. The same strategy could be transferred to human-machine interaction on a product design level with a *two-factor* interaction as either a lockout or lock-in forcing function. Meaning adding an additional step before actuation. Introducing a *two-factor* interaction for a button or a switch can reduce the number of errors conducted by the user because it reduces the task efficiency, therefore minimizing the risk of unconscious interaction. Most fire extinguishers make use of two-factoring as a safety feature as they require the user to retract a safety pin before squeezing the lever. The same technique can be found in manual call points for some legacy fire alarms, where the user have to push in, then pull down (Figure 4).

Figure 4: Manual call point for fire alarm system (Schumin, 2002).

4.3 Increasing task difficulty
As mentioned in section 3, the Yerkes-Dodson Law tells us that increased difficulty will lead to increased levels of arousal that will increase performance. Therefore designers can use this knowledge to make interactions that stimulate problem-solving to activate more cognitive thinking when performing a task. In other terms, A critical function should prevent the user from acting on impulse and inject thinking before performing the task. An increase in difficulty will give the user a chance to stop and think before completing the task. A way of increasing task difficulty for a button or a switch could be to introduce *tooling* as a lockout forcing function. The term tooling is referred to as the use of a separate object needed to perform the interaction. The tool required to actuate should, however, be commonly accessible to ensure usability and to minimize hostility, e.g., a screwdriver or coin to turn a switch.

Tutoring, training and informative labeling may be necessary when a product introduces an entirely new way of interaction, such as the first touch-based smartphones did. However, this approach should not be the relying factor unless a misconception is inevitable. If the user does not understand how to complete the task due to an unconventional approach, the forcing function should be redesigned rather than providing guidance labels.

4.4 Communicating frequency of use and level of importance

Adjacent or in combination with the implementation of motoric properties related to a controller, the design can include visual properties to influence behavior by communicating the frequency of use associated with the interaction. A button that is relatively small, different, isolated or less accessible, could help the user form the correct mental model by making use of the gestalt principles of relative size, similarity, and proximity. A small button isolated from normal sized buttons will communicate its relative frequency of operation as it appears less accessible and independent. Reset buttons on calculators and computers are examples where the application of these principles can be recognized.

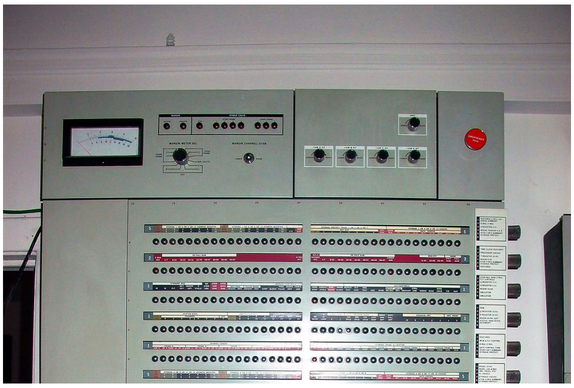

Figure 3: IBM System 360 Model 65 operator's console (Ross, 2013).

Emergency alarms and kill switches usually use color and relative size to attract attention and communicate importance. In 1965, IBM launched IBM System 360 which had an emergency pull switch to terminate the power on all units connected to the product (IBM Corporation, 1968). As seen in Figure 3, the separate placement, relative size, and color communicate its level of importance and frequency of use by utilizing gestalt principles. The emergency button in Figure 4, however, presents a usability paradox. On the one hand, the button should attract attention, afford pushing and easy of use to avoid any delay if an emergency arises. On the other hand, the interaction should only be carried out during emergencies and should not be triggered accidentally. Therefore a safeguard has been retrofitted on top of the button itself, inhibiting the efficiency intent.

Figure 4: A retrofitted safeguard for an emergency stop button (Wahl, 2013).

5. DESIGNING A POWER SWITCH FOR AN IOT DEVICE

The product designed in conjunction with this article makes use of *tooling* as a mean to evoke deliberate interaction by increasing task difficulty (Figure 5). The actuator itself is a rotary switch used to control the power supply for the product and is located on a surface facing the ground. The product is an essential part of a bigger network of services and products and should therefore not be powered off if not actually desired. The affordance of the coin-slotted indent indicates that a coin or a flathead screwdriver is needed in order to operate the switch. Thereby forcing the user into acting deliberately by the introduction of a separate tool (tooling). Additionally, the rotary switch itself functions as a safety feature as it will not accidentally be triggered unless the user actually interacts with it intentionally, compared to a push-button that could be actuated by e.g. gravel.

6. CONCLUSION

The aim of this paper was to highlight how designers can shape user behavior when designing buttons and switches for important controls. By understanding the mental models connected to similar controls in existing products, designers can design controls that convey meaning in ways that make information labels and warnings redundant. In this paper, four key ideas were presented as ways designers can shape behavior by leveraging existing mental models derived from similar interactions with critical outcomes: reducing task efficiency, increasing task difficulty, communicating the frequency of use and communicating the level of importance. Alongside with shedding light at the importance of visual properties designed into controls by utilizing gestalt psychology, two motoric approaches for shaping behavior were proposed as solutions: *tooling* and *two-factoring*. A power switch for an IoT device using the approach of tooling was presented to illustrate a possible application. Furthermore, the value of these approaches has not been empirically established and may cause confusion in some cases. The principles of the tooling and two-factoring should be considered as tools to explore innovative solutions that could affect user behavior and reduce the risk of errors and confusion related to critical controls if applied correctly.

Figure 5: Coin slotted rotary switch that increases task difficulty by utilizing the concept of tooling to evoke deliberation before interacting.

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