A REVIEW OF AFFORDANCES AND AFFORDANCE-BASED DESIGN TO ADDRESS USABILITY

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ABSTRACT

Maier and Fadel pioneered Affordance-Based Design (ABD) based on Gibson's revolutionary theory of affordances and Norman's deployment of the concept in his book, "The Design of Everyday Things". Gibson (1979) introduced the affordance concept into the discipline of Ecological Psychology to address the interactions between an object and an agent. The Ecological approach includes the direct perception of affordances for the user along with a consideration of the users' biomechanics. However, as the concept of affordance was imported and utilized in different disciplines, including engineering design, some important aspects of Ecological theory were omitted.

This paper is an attempt to review the definitions and different utilizations of the affordance concept focusing on the design of usable products to identify the different views and the missing elements. After addressing the divergent viewpoints of affordances, we provide recommendations to improve the usability aspects in ABD by considering direct perception and ergonomics. We claim that a design (based on affordances) that fails to address both criteria may result in a product that is less usable.

Keywords: User centred design, Human behaviour in design, Affordance based methods, Design cognition, Affordances

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Cite this article: Masoudi, N., Fadel, G.M., Pagano, C.C., Elena, M.V. (2019) 'A Review of Affordances and Affordance-Based Design to Address Usability', in *Proceedings of the 22nd International Conference on Engineering Design (ICED19),* Delft, The Netherlands, 5-8 August 2019. DOI:10.1017/dsi.2019.141

1 INTRODUCTION

Oftentimes designers attempt to come up with products that are easier to -learn and -use. However, it is possible that the outcome turns out to not be as usable as the designer intended. Therefore, it is paramount for designers to be familiar with usability principles and incorporate them while designing new products. The International Standardization Organization (ISO) has defined usability as “The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficacy, and satisfaction” (1998).

Researchers have studied the achievability of usability in design by providing definitions and guidelines to implement usability practices (for example see (Nielsen 1994; Mayhew & Mayhew 1999)). Gould and Lewis (1985) proposed the following key principles in system design to improve usability: early focus on users, empirical measurements of usage, and iterative design. Knowledge of the users can be achieved through studying users’ needs and their cognitive and anthropometric characteristics, as Gould and Lewis claim. Bennett (1984) also developed a method to study usability requirements. The three stages in Bennett’s method are (1) product definition, wherein user performance objectives are specified, (2) design and implementation, wherein human factors principles are applied, and (3) evaluation stage where the product is assessed for satisfying the users’ needs.

In interaction design, usability is defined as the study of centralizing and involving users in the design process (Norman & Draper 1986). According to Norman and Draper (1986), designers need to take into account the interactions between the user and the artifact when designing the latter. For a product to be usable, it needs to fit the human’s physical characteristics, and its uses (and dangers) must be perceptible with a minimal amount of cognitive deliberation. The scientific discipline studying human physical capabilities using anthropometric measurements is ergonomics or human factors. Ergonomists contribute to the design and evaluation of tasks, jobs, environments, and systems to make them compatible with human physical and cognitive abilities and limitations, avoid possible injuries and reduce possible discomfort and fatigue. As our study of the literature shows, design for usability is intertwined with ergonomics. For example, the second step in both Gould’s and Bennett’s methods alongside the Nielson’s and Mayhew’s guidelines deals with the ergonomics requirements in design to achieve usability.

Although ergonomic requirements are crucial in design for usability, it is not sufficient to rely only on the human’s physical capabilities to operate a product. As Norman (2013) claims, the designers should focus on the ability of the human to understand an artifact instead of designing the artifact first and then expecting the human to understand the machine’s logical behavior. Therefore, for users to be able to operate a product they must be able to perceive the possible actions.

Ecological Psychology provides a theory of how users perceive what actions are possible with a given object (i.e. the artifact’s *affordances*) and how this perception can be possible without elaborate cognitive activity, or even in the absence of any cognitive activity (i.e. direct perception (Fajen 2007; Warren 2005; 2006)). Thus, ergonomics and the direct perception of possible actions should be considered two essential elements of usable design.

The Ecological Psychologist, James Gibson (1979), introduced the term *affordance* to describe the aforementioned interactions between the animal and object as action possibilities with respect to the animal. Ever since Gibson’s seminal work, a plethora of studies have been carried out to define, clarify, and apply affordances in different disciplines that deal with interactions between humans and objects in the environment. A decade after Gibson’s introduction of the theory of affordance, Donald Norman, initially a cognitive psychologist, introduced the concept of affordance to the interface design community in his book, *The Psychology of Everyday Things* (Norman 1988). In this book, he describes how his interest in affordances was spurred by his struggles with operating everyday artifacts such as water taps and sliding doors while visiting a foreign country. However, Norman’s use of affordance was fundamentally different from its original use in Ecological Psychology. When Gibson defined affordances as action possibilities, he referred to “direct perception”, i.e. an animal directly perceives an affordance without a further cognitive process (Fajen 2007; Warren 2005; 2006). Norman, on the other hand, believes in the necessity of an internal mental process for affordances to be perceived. However, according to Gibson and the discipline of Ecological Psychology that developed after him, the goal of design should be to design for direct perception by providing sufficient information to the senses, hence, minimizing the mental burden for the user to perceive the affordances.

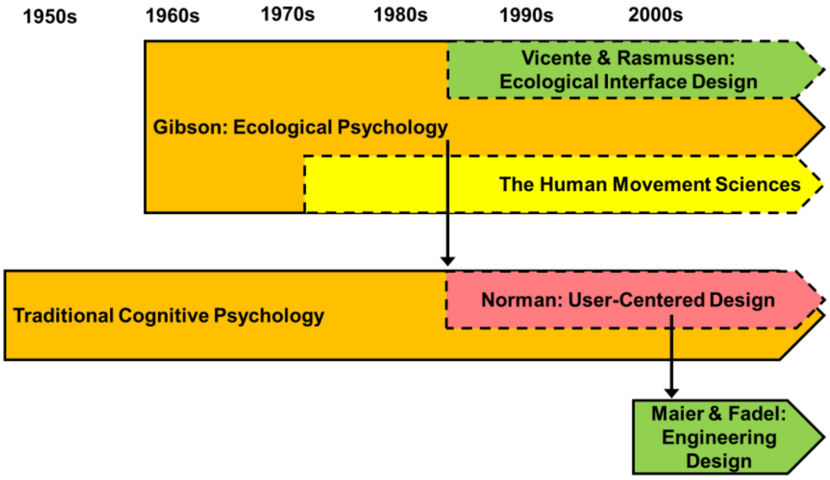

Figure 1. Evolution of the concept of affordance

Thus, the study of previous work shows that while Norman imported affordances in design, he eliminated direct perception and Ecological Psychology's view of biomechanics as action possibilities with respect to the human. Furthermore, Norman stopped short of incorporating the concept of affordance to the design of any artifacts in general. Maier and Fadel in their series of papers (2001; 2003; 2006; 2009a; 2009b), developed a systematic design method, Affordance-Based Design (ABD), the pillar of which was the affordance concept. As Maier and Fadel claim, ABD is a more effective method than previous function based methods in addressing the user needs and capabilities. The work of Maier and Fadel brought back the ergonomic aspects of usability in design, which was overlooked in Norman's interpretation. Direct perception, however, was still left behind from the original definition in Ecological Psychology. Figure 1 illustrates the evolution of affordance from Ecological Psychology to ABD in Engineering Design. Despite previous work to study and utilize affordances in design to improve usability, there still exists a gap in addressing this aspect. In this paper, we show that the gap stems from missing elements in the definition of affordance after the concept was imported from Ecological Psychology. This effort is a comparative study of the affordance concept presented in chronological order. Our objective is to revisit the definitions of affordance and address the divergence of views between psychologists and design engineers when designing usable products, and satisfying perception and ergonomic requirements.

2 AFFORDANCES: DEFINITIONS AND USABILITY CRITERIA

In this section, we provide an overview of the concept of affordances from Ecological Psychology to Engineering Design to address usability from the aspects of perception and ergonomics. While there are many studies that address the concept of affordance and its usage in different disciplines, we focus on the major contributions in defining the term and its usage in design disciplines. Table 1 summarizes each definition of the concept of affordance in its corresponding discipline. Each definition is explained in further details in the following subsections.

Table 1. Comparison of views of affordances in three disciplines

Reference	Definition of affordance			Background	Usability Criteria	
	Action possibilities	**Actual/ perceived**	**Independent of human needs/perception**		**Ergonomics**	**perception**
Gibson Turvey	✓	×	✓	Ecological Psychology	Intrinsic units	Direct
Norman Hartson	×	✓	×	Interface Design	Traditional guidelines	Indirect
Maier and Fadel	✓	✓	-	Engineering Design	Traditional guidelines	Indirect

https://doi.org/10.1017/dsi.2019.141 Published online by Cambridge University Press

2.1 Affordances in ecological psychology

As part of his work in launching the discipline of Ecological Psychology, Gibson (1979) coined the term *affordance* and defined it as what the objects of the environment provide or offer the animal for good or ill. By the term affordance, Gibson formalizes the complementarity of the environment and the animal. In the Ecological view, affordances exist in interactions between animals (including people), objects, and the environment. Thus, an important element in affordance is the animal-environment as an interacting system.

Ecological Psychology claims that affordances are real and independent of the human's needs. Furthermore, affordances exist even if they are not utilized and whether or not they are perceived, such as when one trips over an unseen object. Affordances bear multiplicity, i.e. an object can provide more than one distinct affordance without inconsistency, such as a stool that affords lifting, carrying, stepping upon, but also tripping over. Therefore, in the Ecological approach, affordances can be both positive (beneficial affordances, e.g. nutrition) and negative (injurious affordances, e.g. poison).

Additionally, affordances are dispositional properties of the environment, meaning that they emerge only under certain circumstances (Turvey 1992). For example, being edible as the property is true for certain objects in the environment (such as nontoxic) concerning certain animals (e.g. grass may not be as edible for humans as it is for farm animals).

2.1.1 View of ergonomics and direct perception

The Ecological approach requires that the artifact has certain physical properties for it to provide affordances (e.g., knee-high above the ground for a surface makes it *sit-on-able*). Moreover, affordances are relative to the size of the individual. For example, knee-high is different for people of different heights. Hence, the artifact's size must be comparable to that of the human to provide certain affordances. Considering the human size and physical measurements, biomechanics is integral to the theory of affordances. For instance, *grasp-ability* is an affordance of objects with opposite surfaces placed at a distance less than the human's hand span, therefore, considering human body size.

According to the Ecological approach, affordances have both critical points and optimal points (Warren 1984; 1995). A critical point is where an affordance changes or ceases to exist. For example, in Warren's famous stair climbing study (1984, 1995), biomechanical analyses revealed that a stair is no longer climbable when it is taller than 88% of a person's leg length (measured from ground to the hip). Additionally, the most efficient stairway in terms of oxygen consumption is one that has stairs that are about 25% of a person's leg length. These are the critical and optimal points, respectively, and they are intimately tied to the person's motor control system. Stairs less than 25% of one's leg length, and those larger than 25% but smaller than 88%, still afford climbing, but not in the optimal manner (i.e., not in the most efficient or comfortable manner). These proportions remained invariant over different sized people, thus the proper way to measure affordances is not in extrinsic units, such as centimeters, but in units intrinsic to the body, such as leg-lengths. Warren specified unitless π numbers as ratios between stair height (the stairway) and leg length (the climber). It is noteworthy that he treated the animal property, or A, as the standard for measuring the environment property, or E, to create the E/A ratio. Thus, Warren determined metrics to measure the affordance – the fit between the user and environment – that was objective despite the fact that the affordance may be different for different people. Importantly, Warren also found that people's perceptions of climbable stairs and stairs that are most comfortable to climb followed the same optimal and critical points that were revealed by the biomechanical analyses. Both tall and short subjects judged the same optimal and critical points specified by the π numbers. Following up on Warren's work, Cesari (2005) showed that older people perceive stairs differently than young people, but an invariant relation based on biomechanics (e.g., flexibility) is still possible.

Our review of the Ecological theory shows that it indeed accounts for human fit and ergonomics when affordances are defined as action possibilities measured with respect to the animal and the complementarity of the animal and the environment. Affordances may be independent of an animal's needs and perceptions but are dependent upon the animal's body morphology and action capabilities (Gibson, 1979; Turvey 1992).

Gibson's significant contribution to the theory of affordances, besides the term affordance itself, was the idea of direct perception. With direct perception, affordances are perceived by the animal without cognitive mediation or internal representation (Fajen 2007; Warren 1995; 2005; 2006). Direct perception occurs through information contained in ambient energy arrays such as the complex pattern of wavelength and lightness distributions in the light comprising the ambient optic array (Gibson 1966; 1979). Importantly,

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this information is often contained within the optic flow, which is the transformations of the optic array that occurs when the animal is in motion relative to the surfaces of the environment (Gibson 1966, 1979; Fajen 2007; Warren 2006). In many cases, this information is only contained in optic (or other) flow generated by self-produced motions of the actor, such as a metric for visual depth perception that is both intrinsic and absolute (Bingham & Pagano 1998; Mantel *et al.*, 2015) or haptic weight perception via hefting (Turvey, 1996). Thus, perception is intimately tied to motor control and affordances are independent of the animal's culture and experience. Therefore, for direct perception to occur there needs to be information for the animal to pick up. In short, Ecological psychology advocates designing to support the direct perception and motor control, when it comes to affordances, but designers have by and large not been exposed to these aspects of affordance theory.

Designers and design engineers have also started to utilize the concept of affordance in designing usable products and interfaces due to its strength in considering the user-artifact interactions. The following two sections review the affordance deployment in designing artifacts initiated by Norman's studies.

2.2 Affordances in interface design

Influenced by Gibson's original theory of affordance, Norman (1988; 2013) introduced affordance to the Human-Computer Interaction (HCI) community. The intention was to use the concept in the design of everyday products to achieve and improve usability through more effective human-machine interfaces. Norman defines affordance as the relationship between an agent and a physical object. Properties of the object and capabilities of the agent determine if the object provides certain affordances, which was indeed discussed in Ecological theory. In other words, affordances are *actual* as well as *perceived* properties of objects that the animal can use. Perceived affordances need not correspond to actual affordances. Thus, he differentiates between real and perceived affordances, which he sees as central to the determination of usability (Norman 2013), and both are seen equally important in design. Norman states that designers are concerned with the real affordances and their objective should be to determine whether the artifact affords the desired affordances, whether it affords undesired affordances, or if its multiple affordances are perceivable. If affordance is not perceivable, then Norman suggests using other means to point to that affordance, what he calls a *signifier*. Signifiers are elements such as signs that rely on the mental interpretation of the user to communicate what actions are possible and where. They can be used deliberately in design to indicate to the users that a particular affordance is present, such as the PUSH/PULL sign on some doors or by accident, e.g. when one follows a trail on snow left by a previous person. In Norman's perspective, signifiers are critical since they provide information to indicate the presence of affordances; thus, they serve to improve usability. Nevertheless, they rely on prior knowledge and cognitive deliberations by the user and are thus open to misinterpretation (Hansen 1995). Additionally, they unitize cognitive resources that may be better utilized for other aspects of a task (Vicente & Rasmussen 1990). For this reason, it may be best to design affordances in such a way that they are perceptible without signifiers.

Norman (1999) argued over the misuse or overuse of the term affordance and the importance of a distinction between affordances and conventions in design. He emphasized that perceived affordances are the actions that users *perceive* to be possible, whether or not they are actually possible. He believed that what Gibson defined as affordances could be categorized as real physical affordances. Further, conventions or cultural constraints are conventional interpretations shared by a cultural group. They restrict the possibility of perceived actions by the user. Constraints and conventions are helpful tools to assist users in understanding how to operate a product, i.e. to signify the affordances. Although Norman's defined conventions may seem to be a solution to resolve the perceptibility of a product, they may not be transferable to other generations or cultural groups. Thus, for people unfamiliar with the conventions of a given society, the product may seem less usable (Hansen 1995).

Following Norman's argument that the broadness of Gibson's definition made it difficult for the design community to apply affordances (Burlamaqui & Dong 2015), multiple researchers have provided more specific definitions and clarifications of the affordance concept. For a comprehensive review of these definitions readers are referred to (Burlamaqui & Dong 2015). Hartson's effort to clarify affordances resulted in classifying them into four types: physical, cognitive, sensory, and functional (Hartson 2003). In his definition, a cognitive affordance enables understanding (i.e. the information used to either perceive or cognitively deduce the presence of an affordance) whereas the Ecological theory attributes this to the information available to perceive affordances; thus, they Hartson's cognitive affordances are not really a separate affordance category. Hartson's Physical affordance, on the other hand, is a feature

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that enables physical actions. This definition is attributed to Norman's real affordances and Gibson's original definition of affordance. He further defines functional and sensory affordances as design enablers of *purposeful* actions and features that help user sense something, respectively.

Albeit Hartson attempted to mediate the ambiguities in the usage of affordances in design, we believe his classification instead adds to the confusion. This is because physical, functional, and sensory affordances are all included in Gibson's original view of the affordance concept as action possibilities, hence, the additional classification does not introduce new definitions for affordance and nor does it resolve the misuse of the term. Cognitive affordance, on the other hand, is an imprecise perception of an affordance rather than actually affording something for the user.

2.2.1 View of ergonomics and direct perception

Although Norman considers human capabilities in affordances, other researchers in interface design barely discuss and apply ergonomics in their studies. It can be concluded that the primary focus of interface design has been on cognition such as decreasing the mental burden required to form an internal mental representation of the artifact and its operation rather than the human's physical fit.

Contrary to Ecological Psychology, and following traditional cognitive psychology, Norman (2013) believes in interpretation and that the brain needs to process everything before being able to perceive it; hence, rejecting the notion of direct perception. According to McGrenere and Ho (2000), one of the important debates between Ecological and Norman's approaches to affordance lies in their view of perception. In the Ecological approach, affordances are independent of the animal's perception while in Norman's view perception can play a role in the presence of an affordance. Thus, Norman substantially deviated from the Ecological view of direct perception. This deviation from direct perception led Norman to the introduction of signifiers and conventions. Hartson's (2003) classification of affordances further deviated from Ecological Psychology's direct perception by introducing multiple mechanisms by which affordances could be perceived indirectly.

2.3 Affordance-based design (ABD): An engineering design methodology

Although Norman introduced Gibson's affordance to the design community and used the term to help in the design of everyday products, he stopped short of incorporating the concept of *affordance* as fundamental to the design of artifacts in general (Norman 2013). Maier and Fadel (2001) were the first to use affordance as a fundamental concept to engineering design which they deem more effective than previous functional approaches (e.g. see Pahl & Beitz 2013) since it focuses on the user-product interactions and user satisfaction rather than the artifact's mere functions (Maier & Fadel 2003; 2006). They defined affordance as a relationship between two subsystems in which potential behaviors can occur that would not be possible with either subsystem in isolation (Maier & Fadel 2009a).

Maier and Fadel (2003) pointed to the importance of perception in affordances but also stressed that the user needs to augment raw sensory information through a mental process of cognition in order to perceive affordances, thus aligning themselves theoretically with traditional cognitive psychology. Consistent with Ecological psychology, however, they referred to sensation in general to include all senses that will aid perception, such as a visually impaired user relying more on an audition to perceive the same affordances (Rosenblum 2011). In addition, with the example of a robot and a visually impaired person both being able to walk on the ground, Maier and Fadel further stressed that affordances do exist independent of animals' (or robots') perception. A robot's perception of affordances was seen by them as using internal cognitive (i.e., computational) processes, albeit with computer algorithms rather than biological structures. Thus, they created a new class of affordances referred to as artifact-artifact affordances (AAA) which, like much of robotic engineering, is modeled after the cognitivist tradition. They, therefore, expanded the interactions beyond the classical animal-artifact noted by Gibson. AAAs are interactions between artifacts that are possible due to the specific properties of each artifact. An example of an AAA could be the power transmit-ability between two gears or stack-ability of chairs for shipping purposes which is only possible for more than one chair (Maier & Fadel 2009b).

Maier and Fadel explained methods for design based on affordances which had not been addressed before (Maier & Fadel 2003). From their perspective, such methods should include the following steps: defining the desired affordances, understanding those affordances, identifying the relevant characteristics of the artifact, identifying and quantifying the upper/lower bounds for each characteristic, iterating to determine all characteristics of the artifact, organizing the artifact characteristics and bounds as well as user characteristics, and reconciling the conflicting characteristics.

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In another work from Maier and Fadel (2006), Affordance-Based Design as a systematic method is studied and compared to the functional approaches. The theory of affordance itself is developed and addressed in (Maier & Fadel 2009a), wherein its applications and limitations as it relates to the design and reverse engineering are explained. The effort was made as a response to Simon's argument regarding the lack of a theoretical foundation for engineering design methods (Simon 1996). In addition, they described a high-level method for ABD, which elucidates design phases from inception to the finished product. They propose different tasks for designers at each phase and suggest tools and methods (such as affordance structures matrix, ideation methods, etc.) to accomplish those tasks.
Building upon Norman's usage of affordances, Maier and Fadel (2009a) described the key properties of affordances as the following:

- **Complementarity.** An affordance describes the interaction between two subsystems and cannot exist with either of them in isolation.
- **Polarity.** The positive and negative affordances of an artifact. While positive affordances are favored in designing for the end-user, there may simultaneously exist undesirables. For example, the cutting-ability of a knife, while being a positive affordance when used in cutting a piece of cake, could bear a negative affordance when the knife cuts the user instead.
- **Multiplicity.** An artifact could have multiple affordances.
- **Quality.** A measure of how well an affordance is achieved. For example, a chair and a briefcase both have the affordance of sitting-ability, but a chair has a higher sitting-ability quality than that of the briefcase.
- **Form-dependence.** Unlike functional approaches, affordances are form dependent. The structure of an artifact (i.e. its geometry) determines what it affords to a user. For example, the affordance of grasp-ability is pertinent to a water bottle but not a wall.

In their relational model of design, Maier and Fadel (2009b) specified the basic entities associated with describing affordances: the designer of the artifact, the artifact being designed, and the user of the artifact. Figure 2. shows the designer-artifact-user (DAU) relational model developed by Maier and Fadel (2006) that describes the complementarity of affordances (Maier & Fadel 2009b). For example, the interactions between the designer and user help to determine the positive affordances to be included and the negative ones to be eliminated.

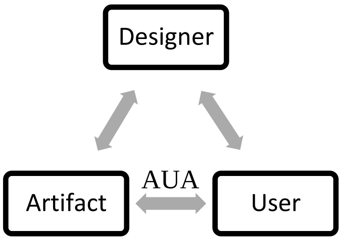

Figure 2. Design-Artifact-User system

The definition of an affordance-based paradigm provided in (Maier & Fadel 2009b) specifies the goal of ABD for the designer to be improving the design by adding or improving the quality of existing positive affordances and reducing the effect of negative ones (Maier & Fadel 2009a). To further ABD, Srivastava, and Shu (2012), proposed a technique called affordance listing to expedite discovering the main affordances associated with a product or artifact. Following this approach, designers can improve positive or diminish negative affordances to fulfill users' needs.

2.3.1 View of ergonomics and direct perception

From the design methodology perspective, it does not seem reasonable to consider ergonomics as an individual method of design, since it does not conform to the requirements for a design methodology like the one introduced by Pahl and Beitz (2013). However, an approach like ABD provides a systematic way to encompass ergonomics or biomechanics in design to identify the extent of human-environment fit in design based on affordance.
Therefore, Maier and Fadel acknowledged ergonomics in their developed ABD method and brought back the perspective of human-environment fit by specifying the upper/lower bounds of the interactions between the human and the artifact. However, it seems that in ABD the ergonomic considerations rely on the traditional guidelines to design which are not always helpful in designing physically usable products

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(Warren 1995; Dainoff & Mark 2001). Intrinsic units relating the artifact's characteristics to the human body's action capabilities are more reliable. They make the affordances objective and define the invariant critical and optimal points of the product for users with different body scales and different capabilities, thus enhancing the adjustability of the product to better fit human characteristics. Hence, designers can benefit from understanding the intrinsic metrics introduced in Ecological Psychology when evaluating the ergonomic aspects of a design.

Further, in Maier and Fadel's series of work, the perception of affordances is discussed as an indirect way of interpreting information, which requires a mental process; therefore, they did not conform to Ecological Psychology's direct perception view. In fact, one of the objectives of designers should be to design to make the affordances perceptible as directly as possible, hence removing the need for adding signifiers and other information to direct the users to the affordances. Thus, while we do not entirely refute internal information processing to perceive affordances, we believe that a design objective of direct perception can result in products that are more usable since the users can perceive the possible actions with minimal cognitive processing.

3 DISCUSSION

Ecological psychology includes both the direct perception of affordance and ergonomic aspects. Designing to ensure direct perception can help reduce the mental burden for users and the consideration of ergonomic aspects through intrinsic units determines the human-environment fit with optimal and critical points. These aspects of affordances, however, were abandoned when Norman used the term in interface design.

Maier and Fadel, on the other hand, developed ABD to broaden Norman's implementation and introduce a formal systematic method to design based on affordances. The work of Maier and Fadel reconsidered the ergonomic constraints though without determining intrinsic units to measure the quality of affordances. Nevertheless, their method did not formally consider criteria to design for easier (or direct) perception. While ABD is a powerful approach that systematically outlines different stages of design, it can further improve usability by considering the direct perception an objective in the early design stages. In addition, using the intrinsic units the designer could further analyze the critical and optimal points of the design for the most efficient operation of the product.

The analysis of these methods and theories shows that the original work on affordances in Ecological Psychology does indeed provide recommendations to improve usability in design based on affordances. These recommendations include designing for direct perception and defining intrinsic units to relate user characteristics and artifact's properties. In the next section, we show examples of designs that support the strength of these recommendations in Ecological Psychology. Therefore, a design that solely relies on ergonomic guidelines or follows ABD without accounting for direct perception may overlook some usability aspects. On the other hand, as Ecological Psychology does not provide a systematic approach to design, we claim that for a successful design, the designers should apply the aforementioned recommendations in the context of a systematic design approach such as ABD.

3.1 Direct perception in design based on affordance

A successful application of direct perception principles can be found in the work of Vicente and Rasmussen (1990) on mediating direct perception in complex work-domains. The idea of smart instruments discussed in their paper is a concept from the Ecological approach to direct perception, which allows complex relations to be perceived without first separately perceiving constituent parts and then mentally integrating them. These instruments eliminate the painstaking task of inference and problem solving for operators by facilitating direct perception, which is of high importance in interface design. They, therefore, assert that the goal in interface design should be to allow direct perception for operators, and they referred to this strategy as Ecological Interface Design (EID). Significantly, they showed how direct perception is possible even when the user's contact with the domain system is mediated by physical tools or artificial computer displays and controls (Pagano & Day in press). Importantly, the tool or the display is not a signifier indicating the presence of an affordance; it conveys information related to the affordance itself. Whereas a signifier is like a sign saying "Watch your step," EID is more like a cane used to probe the hazard. Vicente and Rasmussen's framework for display design is a framework for improving the controls used by operators, and the mutual consideration of perception and motor control is a key element to optimizing both.

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3.2 Ergonomic design to improve usability

The previous examples show how the recommendations of direct perception and ergonomics in Ecological Psychology that also follow a systematic approach can result in usable products. In this section, we investigate a design that merely relies on ergonomic guidelines and evaluate its outcome. Galen *et al.* (2007) redesigned the conventional keyboard (flat and horizontal design) to minimize forearm pronation; the rotation of the hand and forearm so that the palm of the hand faces downwards. The solution created is a vertical keyboard (Figure 3) which eliminates user forearm pronation.

Figure 3. Flat vs. vertical keyboards

They found through experiments that users deem the vertical keyboard more comfortable than a conventional keyboard. Muscular activation data confirmed that the vertical keyboard is less burdening for certain muscle groups of the arm when compared to muscle activation using a conventional keyboard. The authors, however, did not account for the user perception in the new design. To clarify, the users know the placement of each key on the conventional keyboard through conventions and experience; however, when transitioning to this new keyboard they may struggle to perceive the same (or additional) affordances. In addition, in these ergonomic designs, users need to adjust the system for an optimal operation to increase its effectivity and user comfort, which may not be straightforward due to the additional degrees of freedom discussed in Dainoff's example. To achieve these goals, we suggest that one follows ABD as a systematic design approach augmented by the recommendations for direct perception and intrinsic units in ergonomic.

4 CONCLUSIONS

In this paper, we reviewed the work done to define and apply the theory of affordance in designing more usable products. As identified, the two essential elements of a usable product are the ergonomic design identified by intrinsic units to specify optimal and critical points of design as well as the user's ability to perceive affordances directly. We claim that designers need to consider the recommendations provided by Ecological psychologists and augment ABD to design more usable products.
In the future, experimental analyses could be performed to support and quantify the perception and ergonomic aspects in ABD, and extrapolate the conclusions quantitatively. For example, one of the research questions we intend to explore is whether or not it is possible to experimentally find intrinsic metrics to quantify perception similar to the intrinsic units for ergonomics and as a result study the possibility of enabling direct perception.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the efforts of Dr. Ivan Mata and Dr. Sara Riggs in providing helpful feedback on the early revisions of the paper.

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