Design Constraints and Their Influence upon Design Outcome

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Abstract

Background The Effect of two design constraints, ergonomic and aesthetic, on conceptual design ideation and development was investigated. The chosen constraints were selected as experimental conditions to understand the influence of design constraints more generally on concept design.

Methods Workshops were held with participant designers who provided the two constraints (ergonomics and aesthetics). Design outcomes were then assessed by both a sample of potential users and design experts.

Results The results indicated that ergonomic, rather than aesthetic, constraints resulted in radically new ideas. Aesthetic outcomes indicated a highly figurative process, resulting in appropriate, yet less novel solutions. Critical function failure was also identified in ergonomic derived outcomes.

Conclusions The provision of ergonomic design constraints provided a foundation for the emergence of more novel product design solutions. However, aesthetic derived concepts were assessed as more appropriate in terms of both form and function. The appropriation of ergonomic constraints may provide greater scope for novel design solutions but only if functional expectations are satisfied. Aesthetic design constraints stimulated analogous and metaphoric design approaches. Thus, the results indicate how the provision of differing constraints implicated design outcomes.

Keywords Design Constraints, Conceptual Design, Product Design, Design Process

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This work was supported by the 'Promotion of Graduate School of Creative Design Engineering' of the Korea Institute of Design Promotion with a grant from the Ministry of the Trade, Industry & Energy, Republic of Korea. (N0001436)

Citation: Kim, T., Self, J. A., & Hong, H. (2018). Design Constraints and Their Influence upon Design Outcome. *Archives of Design Research, 31*(4), 23-41.

http://dx.doi.org/10.15187/adr.2018.11.31.4.23

Received : May. 11. 2018 ; **Reviewed :** Aug. 24. 2018 ; **Accepted :** Aug. 24. 2018
pISSN 1226-8046 **eISSN** 2288-2987

1. Introduction

1. 1. Background

Typically, when developing a product in industry, companies create a document that contains information related to the target market, broad constraints, and project objectives. This document is often called the design brief (Ulrich, 2012; Sadowska and Laffy, 2017). Based on this document, product development teams establish a clear set of design specifications, which spell out in precise, measurable details information related to what the product should be and do in terms key features and expected deliverables. For instance, a design constraint might indicate quantifiable limits in the product size for a specific purpose (e.g., diameter, weight). However, design constraints could also be positioned in terms a qualitative aesthetic or sensory requirement that a future product is required to possess. However, little is yet known of how these different design constraints affect the outcomes of product design. In this study, we investigate how design outcomes are derived when two different sets of design constraints are provided to two groups of designers.

Research on the relationship between design process and constraint has been conducted in various fields. For example, Onarheim's (2012) work in the field of engineering design explored how design constraints affect creativity in the product development process. Likewise, the current study illustrates how designers may exhibit constraint-oriented tendencies to invent creative strategies to overcome initial constraints. In this context, the current paper empirically examines how the provision of specific constraints at the start of design ideation may implicate the design outcome. In doing we aim to understand how design constraints, provided at the beginning of a new product development process relate to and inform both outcomes and the means through which they are arrived. This knowledge has the potential to support the appropriate positioning of constraints through an understanding of how they may influence the direction of design development and the eventual outcome.

1. 2. Two Design Constraints: Ergonomic & Aesthetic

For the purposes of the current empirical study we focus upon two types of design constraint, *ergonomic* and *aesthetic*. Ergonomics refers to a discipline of study that explores user interact with the environment, adopting measurable and objective methods to understand humans/ product interactions (International Ergonomics Association., 2014). On the other hand, design aesthetics are associated with subjective feelings and emotional responses perceived through the senses and relate to more subjective sensory-emotional values (Zangwill, 2008).

These two design constraints have been chosen because, although both differ in theirprioritisation of design features (i.e. ergonomic function, aesthetic product attributes), both are often considered significantly important to product design. Previous studies have confirmed these two factors as important to commercial success (Nayak, 2015). In addition, it has been noted that ergonomics and aesthetics are important factors for innovation. For example, Rampino's (2011) theoretical model of product design innovation positions the three, related elements of innovation as: *Form*, *Mode-of-Use*, and *Technology* (Rampino, 2011). *The Mode-of-Use* construct has clear relation to ergonomic considerations in its focus upon innovation through different and improved use.

However, this doesn't mean that two attributes; ergonomics and aesthetics may be considered to be in opposition and/or mutually exclusive. Both may, in fact factors complementary one another. The current study thus explores how the imposition of the constraints may implicate conceptual design outcomes as experimental conditions. These are thus used in our attempt to examine how design constraints may influence conceptual design outcome.
This pursuit of improved function often relates to and is informed by objective data on human beings' sensory and cognitive abilities (cognitive ergonomics), together with anthropometric measures (physical ergonomics). In contrast, *Form* is described as a more subjective lever related to human emotion. The Rampino (ibid) model of product innovation further describes these two levers as resulting in either *Aestheticor* of *Use* innovations. In this sense we position ergonomic design constraints as related to the objective, quantifiable requirements of design. In contrast our aesthetic dimension described the more subjective, qualitative and emotional needs of design.

1. 3. Research Aims

This paper reports a study aimed at examining the influence of design constraint, used during the design process, upon conceptual design outcomes. Towards this end we position Ergonomic and Aesthetic constraints as constructs to examine their influence. Towards these aims, we identified the following research question: How does the provision of *ergonomic* or *aesthetic* design constraints affect the quality and novelty of conceptual design outcomes?

Here we define *quality* as the extent to which outcomes have the potential to provide excellence in achieving functional requirements. For example, the concept's ability to support ease of scooping, comfort and convenience on storing, washing and practical application (scooping ice-cream). Quality also refers an ability to arouse positive emotion and stimulate improved user experience through the use of appropriate, aesthetically pleasing and/or emotionally stimulating forms, materials and composition of forms. Novelty is defined as the extent to which a concept design provides departures from a product archetype, on both functional and aestheticdimensions (i.e. how similar or different is the product's function and/or aesthetic when compared to a typical ice-cream scoop). In defining novelty as construct to measure dependent upon the independent variables ergonomic and aesthetic designconstraints, we realise a required subjectivity in assessment of novelty by the user. That is, degree of novelty is, to an extent, dependent upon one's own experience of ice-cream scoops and scooping ice-cream. However, we attempted to control for this subjectivity through our sampling approach to product evaluations at phase three of the empirical study.

2. Methods

To examine the research question above, a three-phase approach to the empirical study was designed. The approach included: 1) design workshop, 2) refinement process, 3) evaluation sessions (Figure 1).

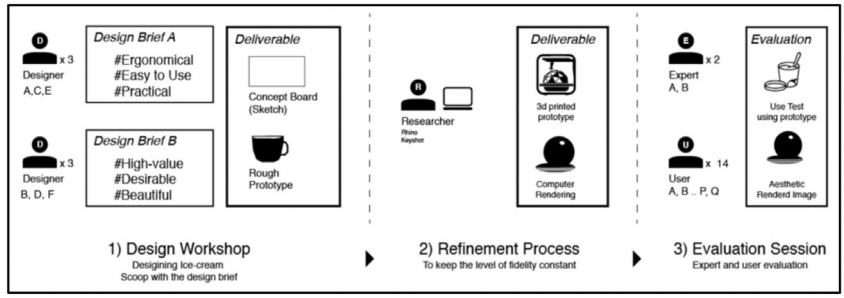

Figure 1 Three phase approach to empirical study

To understand how the two different types of design constraint affected design outcomes, we conducted three design workshop sessions consisting of two designer participants in each workshop. First, we divided the designers into two groups, with each group provided a different design brief and related design constraints (ergonomic design brief and aesthetic design brief). We then asked participants to submit one design concept per person based upon their provided design brief (1 Design Workshop, Figure 1). Following the workshop sessions, a researcher refined the submitted design deliverables from the two groups of designers by constructing 3D CAD (computer aided design) models, rendered images, and prototypes (2 refinement Process, Figure 1). This phase was important to achieve a comparatively consistent level of fidelity across the six conceptual design outcomes. Finally, we conducted evaluation sessions of the designs aimed at evaluating their quality and novelty. To achieve this, two groups of participants were recruited; expert evaluators and user evaluators (3 Evaluation Session, Figure 1).

2. 1. Design Workshop: Participants

Six designer participants were recruited for the design workshop studies and divided into two groups: *Ergonomic Group* and *Aesthetic Group*. We then ran three design workshop sessions with two participants each. Each session took 2.5~3 hours to complete. Participants all possessed a bachelor's degree in industrial design and had experience working on Industry related design projects of one year or more. As part of their education, all had taken product design studio courses which cover creating design concepts, visualizing, and design skills. Four females and two males participated (Avg. age: 24.8, SD=1.36), with all participants enrolled onto a graduate industrial design programme at the authors' home institution.

2. 2. Design Workshop: Product

Because the two design constraints used within the current study are derived from ergonomic and aesthetic considerations, it was important to identify a product where both ergonomics and aesthetics are of particular importance. Following the online learning course undertaken by Karl (2017), ice-cream scoop was selected as product for the Design Workshops at phase one of the empirical study. In terms both aesthetic and ergonomic design considerations, contemporary products often consider both practical and emotional factors in design towards ice-cream, its branding and sale. For example, the ice-cream producers, Haagen-Dazs, employ a brand image implying luxury and high-quality (Newlands, 2016). In such contexts, their products need to exemplify their brand image through careful consideration of product personality derived from form, colors, material and finishes.

Figure 2 Haagen–Dazss premium Ice–cream Boutique (Haagen–Dazs, 2018)

From a more functional perspective, scooping ice-cream can often cause stress fracture of the hand. Previous studies reveal that strain injuries represent a significant portion of worker's compensation claims in retail ice-cream outlets (Dempsey, 2000). Thus, design towards improved ice-cream scoops provided both opportunities for aesthetic and ergonomic considerations in pursuit of improved quality.

2. 3. Design Workshop: Design Brief

Three key terms were provided to the Ergonomic Group: *ergonomic*, *practical*, and e*ase-of-use*. At the start of the workshop guidelines were provided for designing an ice-cream scoop through the application of ergonomic knowledge and design principles (Figure 3). The appropriate handle diameter, angle available, and grip-types were provided for this purpose.

We also introduced how the goals of ergonomic design may be met, including relevant example cases of best practice in ergonomic design; i.e. OxO Good Grips by OxO/Smart Design (Smart Design, 2017). The OxO Good Grips/Smart Design reference was provided as a classic example of a focus upon functional improvement in pursuit of universal design.

In contrast, the provided keywords within the aesthetics workshop were: *high-value*, *desirability* and *beauty*. Again, example cases were provided to participants; the Alessi *Familiy Follows Fiction* kitchen range (Alessi, 2017). The Alessi kitchenware range is often cited in the literature as example of meaning change in design (Verganti, 2009). That is, the Alessi range aimed to elicit motional response from users, where before kitchen products had been sold on utilitarian reasons of usefulness to the task at hand. In this sense the Alessi examples were provided as indicative of emotional design, drawing upon product aesthetic to elicite motive response (Norman, 2004).

In both cases, possible contexts for product use were also provided as examples (Figure 3).

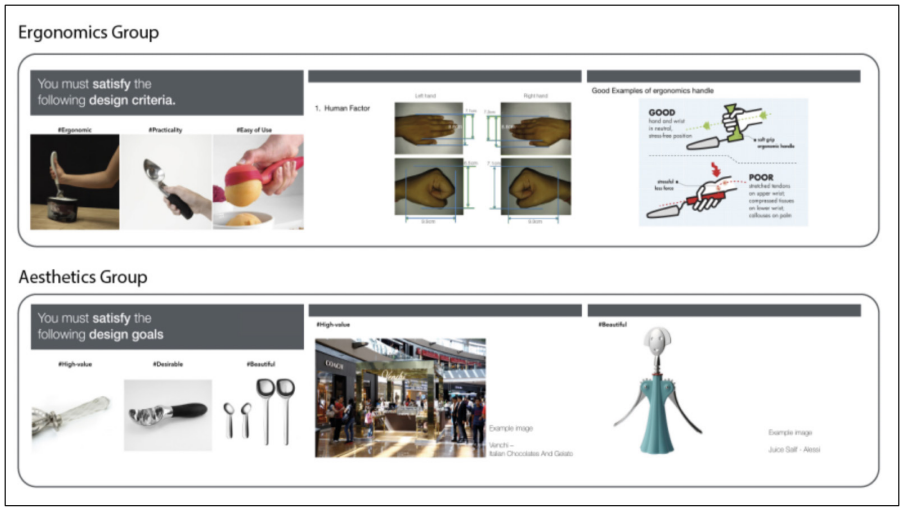

Figure 3 Workshop materials provided to participants: Ergonomic design group (above), aesthetic design group (below).

2. 4. Design Refinement Process

Due to time constraints, designers participating in the workshops were required to communicate their ideas through one concept board and a low-fidelity prototype. However, the completeness and detail of these submissions differed dependent upon the groups. Therefore, it was necessary to standardise the quality of design outcomes derived from each of the workshop sessions. To do this, the researchers produced 3D models, rendered 3D images, and prototypes based upon design outputs. The aim was to express the characteristics of the concepts designed by the participants. In an attempt to ensure the designers' intent was maintained as far as possible during the process of refinement, the refined designs were subjected to a validation session with the original designers. The extent to which the designs reflected original intent was discussed and revisions made as appropriate. Figure 4 provides an illustrative example of a design refinement expressed through a 3D CAD (Computer Aided Design) model and prototype.

To further help illustrate the designs, we made introduction videos to help evaluators understand how to hold and use the scoops. The concept sketches originally submitted by the designers contained a rough overview of how to hold and use each scoop design (Figure 4). However, the fidelity was not constant, with some sketches difficult to understand. Therefore, we needed to make the fidelity of communication constant in terms how the scoops were designed to be used. Therefore, we recorded short (typically 10-15 seconds each) videos showing how to grip and use the scoop. Our researchers recorded each video using 3D printed prototypes. Each video recording provided a close-up of how to hold the scoop, including grip-type and scooping action. No actual ice-cream was scooped during the video recordings.

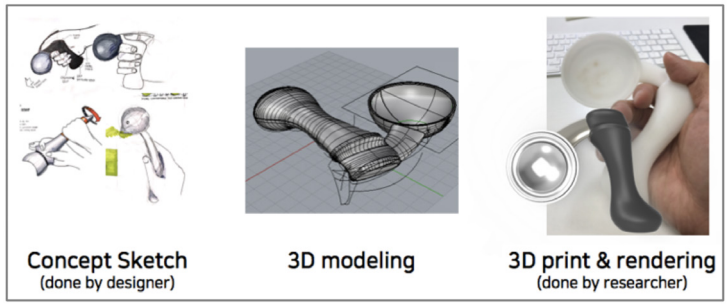

Figure 4 Example design refinements

2. 5. Expert Evaluation

The six concepts, derived through the design refinement process, underwent professional evaluation by two design experts. The two experts had eight and five year's industry experience respectively. Both held under and postgraduate degrees in the field of industrial design. During the evaluation session, experts evaluated each design concept through consideration of a design concept board, product introduction video and prototype.

In order to further assess the usability of the designed products, tubs of frozen ice-cream were provided during evaluation sessions. The expert participants were asked to evaluate the refined design outcomes through an open-ended evaluation approach, with conversation and discussion recorded for subsequent qualitative analysis. An evaluation sheet was also provided to assist in the assessment of the refined design outcomes based upon the review criteria of the *Reddot* design awards competition, with particular focus upon ergonomic and aesthetic evaluation (Reddot, 2017).This criteria includes 1) Degree of Innovation, 2) Aesthetic quality, 3) Functionality, 4) Emotional content, and 5) Impact. We included evaluation sheet in the appendix section [C5].

A further final question was added to specifically evaluate degree of innovativeness. The expert evaluation session lasted 75 minutes in total.

Figure 5 Expert evaluation session

2. 6. User Evaluation

While professional evaluation measured design quality, user evaluation was conducted to evaluate design outcomes from the potential user group. Fourteen potential users (6 female, 8 male, $n=14$, average age 24, $SD=4.5$) were recruited for a user-evaluation study. Design

evaluation was conducted using concept boards, prototypes and video materials. Taken from the validated set of bipolar semantic differential scales (SDs) identified by Khalaj and Pedgley (2014), users were asked to assess design quality in terms form and usability. Table 1 illustrates the SD scales provided during the user evaluation.

Table 1 Bipolar adjective pairs, user evaluations [C7]

Evaluation criteria	Left Bipolar	Right Bipolar
Usability	Clear	Confusing
	Easy to use	Difficult to use
	Comfortable	Uncomfortable
	Practical	Impractical
	Safe	Dangerous
	Reliable	Unreliable
Aesthetics	Elegant	Inelegant
	Organic	Geometric
	Ornate	Plain
	Symmetrical	Asymmetrical
	High-Class	Low-Class
	Expensive	Cheap

3. Results

3. 1. Comparing Ergonomic & Aesthetic Design Outcomes

Table 2 Compares design outcomes produced by the ergonomics group.

Table 2 Three ergonomic design outcomes

Group	Code	Design Features
Ergonomics Group	 Ergo Scoop A	Design to reduce arm fatigue through two-handed use alternately. Inspired from climbing stick (Hiking pole).
	 Ergo Scoop C	Rotating-blade concept to more easily scoop hard-frozen ice-cream.
	 Ergo Scoop E	Scoop to minimise wrist-stress by reducing rotating action of users' wrist.

In terms the ergonomic design group, as expected, participants focused on the usability of their ice-cream scoop designs. For example, the handle grip of *Ergo Scoop* A is designed to be used with both hands freely. The designer mentioned the application of insights from mountain climbing sticks. Further, the form of the pointed scoop end was designed to scoop

frozen ice-cream easily. In terms *Ergo Scoop C*, the concept was designed to allow users to rotate the handle, which in turn rotated the scoop's blade. The designer described this function as helping users scoop frozen ice-cream more effectively. As with *Ergo Scoop A*, *Ergo Scoop C* was designed to be operated through two-handed use for increased efficiency in power transmit. *Ergo Scoop E*, in contract, aimed to minimisewrist rotation during scooping.

Unsurprisingly, design outcomes derived from the *Ergonomic Group* showed various attempts to improve product use-function (grabbing and holding, grip-types, scooping method etc.). Conversely, *Aesthetic Group* design outcomes (Table 3) showed evidence to indicatesimilar usage characteristics (i.e. the standard scooping use-action) across the three concept designs submitted, with differentiation between concept derived from form, colour and materials.

Table 3 Three aesthetic design outcomes

Group	Code	Design Features
Aesthetics Group	 *Aes Scoop B*	Streamlined ice cream scoop design.
	 *Aes Scoop D*	Designed with a motif/metaphor of the form of a bird's beak Sharp, bird–like scoop–spoon.
	 *Aes Scoop F*	Motif in material and form of Korean *embroidery* Meaning blessing and good luck.

As expected, the aesthetics group identified ideas towards the form and personality characteristics of their design concepts. For example, *Aes Scoop B* applied the theme of natural-curve, designed to combine two different materials with consideration of form composition. *Aes Scoop D* expressed a bird's beak motif with its use function of scooping hard ice cream. Likewise, *Aes Scoop F* was inspired by the traditional Korean craft product *Amboori*. Holistically, if the *Ergonomics Group* focused upon use-function aspects of their design concepts, the Aesthetic Group showed various attempts to explore forms and materials to derive novel product personality as driver for differentiation from an archetypal scoop design. Relatedly, a notable feature of *Aesthetic Group* design outcomes was the use of analogy/metaphor as inspiration for design. The final six refined design outcomes are illustrated in Figure 6.

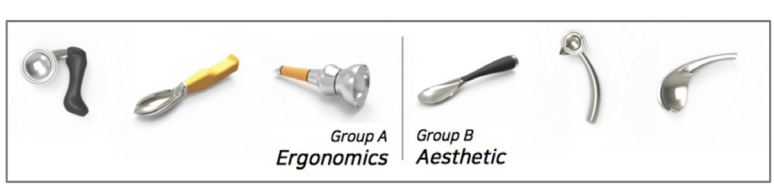

Figure 6 Designed outcomes.

3. 2. User Evaluations

Users evaluated the appropriateness of the six outcomes through two sets of SD scales (Khalaj and Pedgley, 2014) targeting both ergonomic (*Usability SDs*) and aesthetic (*Form SDs*) considerations (Table 4). The advantage of using the prescribed bipolar pairs was that they provided a common reference to ease comparison between designs. A two-tail *t*-test was run to examine if there were any significant differences in user responses between design concepts derived from the two groups (i.e. Ergonomic design concepts and Aesthetic design concepts). 14 participants evaluated the 6 ice-cream scoop designs in a repeated measures experiment using 12 SDs (Table 4).A mean score (*x*) for each of the 12 SD-scale response items was then derived through the sum of user responses to the three ergonomic designs across the 12 scales. This process was repeated for aesthetic designs. A *t-test* was then conducted to statistically compare the 12 mean scores for each of the two groups across the 12 SD-scale response items. Table 4 provides results including statistically significant difference ($p < .05$) in response towards the two groups of design outcomes across the 12 SD-scale response items.

Table 4 Analysis result of SD responses using (*t–test, two–tailed*)

Label	Code	Left Bipolar	Right Bipolar	Ergo. Scoop		Aes. Scoop		*t*–test *(t–crit = 1.98 df = 82)*
		1 ---------- 5		M	SD	M	SD	
Usability Ergonomics	U1	Clear	Confusing	3.02	1.58	1.97	0.90	*.000
	U2	Easy to use	Difficult to use	3.07	1.38	2.5	1.47	*.031
	U3	Comfortable	Uncomfortable	3.40	1.17	2.64	1.35	*.002
	U4	Practical	Impractical	2.90	1.16	2.57	1.22	.165
	U5	Safe	Dangerous	2.52	1.27	2.45	1.13	.766
	U6	Reliable	Unreliable	2.97	1.04	2.30	0.60	*.001
Quality of Form Aesthetic	F1	Elegant	Inelegant	3.30	1.09	2.11	0.93	*.000
	F2	Organic	Geometric	2.57	1.47	1.76	0.47	*.000
	F3	Ornate	Plain	2.73	1.27	3.02	1.97	.307
	F4	Symmetrical	Asymmetrical	2.85	2.75	3.66	2.22	*.021
	F5	High–Class	Low–Class	3.19	1.18	2.30	0.90	*.000
	F6	Expensive	Cheap	2.88	1.57	2.45	1.32	.106

* significant difference p 〈 .05

3. 2. 1. Usability

Significant differences between *Usability (ergonomic)* response items U1, U2, U3 and U6 (Table 4) are further illustrated in Figure 7.

Analyzed as a group, the three aesthetic design outcomes were evaluated significantly more positively compared to the ergonomic group in terms four response items related to product usability (Khalaj and Pedgley).Specifically, user participant responses indicated design concepts from the aesthetics group were assessed to be significantly more *Clear(M=1.97, SD=0.9), Easy to use (M=2.5, SD=1.4), Comfortable (M=2.6, SD=1.3),* and *Reliable (M=2.3, SD=0.6)*. This was an unexpected result in that we assumed designs derived from the Ergonomic design sessions would attract more positive user response in termsusability aspects compared to the aesthetic derived designs. It may have been that, in their exploration and proposition of concepts that significantly departed from archetypal use-functions (i.e.

two-handed use, twist and cut design, *Ergo Scoop C*) participants felt unsure of their ability to achieve their practical function. That is, in their pursuit of innovative use interventions, the ergonomic derived designs were seen as potentially less functional in their ability to achieve the goal of their intended use (i.e. scooping frozen ice-cream). This result was supported by findings from the expert session. If this was the case, it appeared the ergonomic design constraints, while stimulating pursuit of difference in use-function, the same difference may have stimulated feelings of uncertainty towards the radically different concepts' ability to perform the intended task (ice-cream scooping).

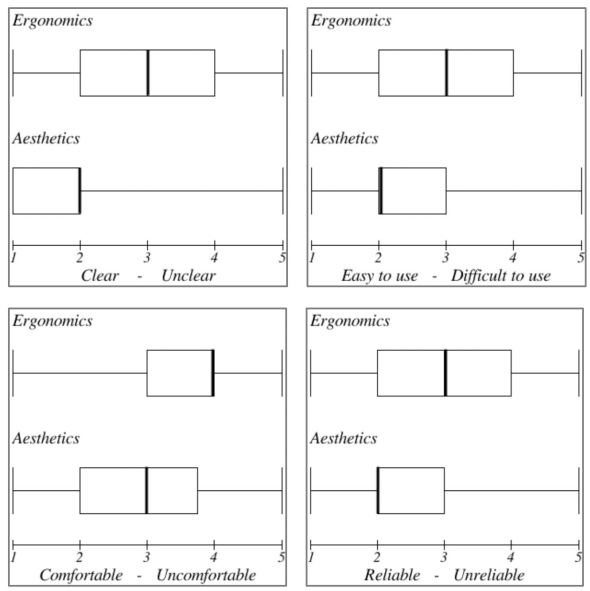

Figure 7 Differences between design outcomes, four *Usability* response items

Further, qualitative user responses indicated participants considered products of the aesthetics group similar to those that they generally thought of and had used. For example, Expert #2 suggested, *"It looks a little ordinary, but it looks like a very well-made and luxurious product."* On the other hand, the difference from the typical design shown by the ergonomics group's pursuit of usability improvements, resulted in confusion in how the designs may be used, together with uncertainty around their effectiveness. In contrast, it was the typicality of the aesthetic concepts that stimulated more positive response towards usability.

3. 2. 2. Quality of Form

The comparative analysis of design concepts also showed significant differences between four *Quality of Form* response items (Figure 8).

Participants assessed design concepts derived from the *Aesthetics Group* as significantly more *elegant (M=2.1, SD=0.9, conditions; t (82) =4.3, p=.000), organic (M=1.7, SD=0.4), asymmetrical (M=3.6, SD=2.2)* and *high-class (M=2.3, SD=0.9)*. While design concepts from the *Ergonomics Group* were evaluated as significantly more *inelegant (M=3.3, SD=1.0), geometric (M=2.5, SD=1.4), symmetrical (M=2.8, SD=2.7),* and *low-class (M=3.1, SD=1.1)*.

This result indicated more positive responses towards the aesthetic derived concepts (i.e. *elegant* and *high-class*) compared to the Ergonomic designs. That is, in line with expectations, the user evaluation identified the aesthetic driven scoop concepts as more elegant and high-class, indicating the relation between guidelines proffered at the start of the aesthetic design sessions (i.e. the design should be high-value and beautiful). As expected, the user evaluation study indicated these requirements were translated to inform scoop design compared to the ergonomic design outcomes.

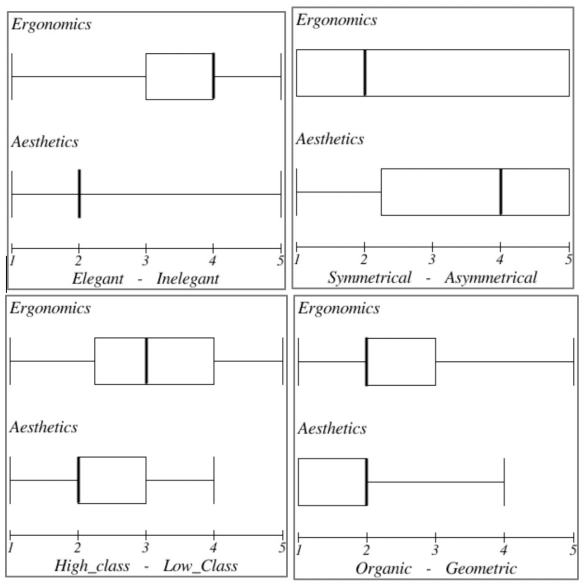

Figure 8 Differences between design outcomes in terms 4 Form response items

3. 3. Expert Concept Evaluation

3. 3. 1. Overall Evaluation

We asked two design experts to rank the six refined design concepts derived from the design workshop sessions. In line with user evaluations, The *Ergonomic* concepts were found to receive a lower ranking compared to the *Aesthetic* derived designs (Table 5).

able 4 Analysis result of SD responses using (*t–test, two–tailed*)

Design						
	Aes Scoop D	Aes Scoop F	Aes Scoop B	Ergo Scoop C	Ergo Scoop E	Ergo Scoop A
Rank	01	02	03	04	05	06

Overall, the design experts ranked the aesthetic derived outcomes higher than the ergonomic designs (Table 5). This result indicated that the designs derived from the aesthetic design constraints were assessed as better than those from the ergonomic workshop as judged by the expert designers. It would have been interesting to compare these results with those from expert ergonomists. However, this was not part of the current study design.

3. 3. 2. Newness of Ergonomic Outcomes

In providing their qualitative evaluation of the six design concepts, a dominant theme discussed by the experts in terms the ergonomic group's outcomes were the characteristics of *newness* and *freshness*. This newness was discussed in relation to both form and product use. In terms form, experts described *Ergo Scoop C* as a design radically departing form the form and shape of the product archetype, *"This scoop is a design reminiscent of a pepper grinder, or flute?"(Expert# 2). "If you look at Scoop C, the recorder comes to mind." (Expert# 1).*

Figure 9 Ergo Scoop C design (left) Grip Design of Scoop E (right)

Ergo Scoop E was most often mentioned in relations to newness in terms use. According to its designer, it was designed to easily convey the strength required for the scooping action without wrist deformation, unlike a traditional scoop requiring users to twist their wrist. However, this also appeared to result in a scoop design judged as radical in its form, *"Scoop E looks like it has something special. I wanted to use it quickly because it appeared miraculous from the first moment I saw it." (Expert# 2) "There seems to be something new in terms of usage than existing products such as the way to grip it." (Expert# 1).* This finding indicated how ergonomic derived designs, in their pursuit of use improvement, also resulted in stimulating responses indicative of novelty.

The experts also indicated how more radical ideas derived from the *Ergonomics Group* had the potential to provide seeds to apply to other product domains, *"The shape of the Scoop E handle is likely to be applicable to the grips of a variety of products ..." (Expert#2) "(Looking at Scoop C) Other kitchen utensils should be kept vertically in this way. It seems that the concept of standing vertically is innovative." (Expert# 1).* It appeared the ergonomic derived design concepts, in their pursuit of use improvement, also influenced evaluation in terms their provision of newer solutions. If this was the case, the result provided evidence to suggest how radical use changes, resulting in departures from the product archetype, may have stimulated feelings of novelty. On the other hand, the same newness identified within the ergonomic derived designs also appeared to increase the risk of critical use failings, which resulted in their overall lower ranking by experts.

3. 3. 3. Critical Failure and Unacceptable Error

The design outcomes derived from the ergonomic design constraints appeared to influence raised expectations from the expert evaluators. However, after actual use, expectations were not met due to functional limitations. For example, *Ergo Scoop E* which was initially well received, having the advantage of use without wrist rotation, was subsequently assessed as a critical failure. The distance between the scoop and the grip was so short that when used fingers touched the surface of the ice cream contained in the bulk container (Figure 10).

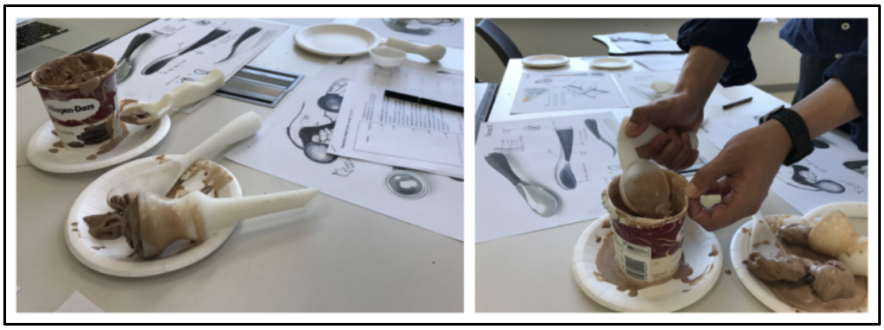

Figure 10 Critical failures in use: *Ergo Scoop C* (Left) and *Ergo Scoop E* (Right)

These critical use failures were found throughout the ergonomic design concepts. For example, *Ergo Scoop C*, which was considered new, effectively scooping ice cream, but was identified to have the fatal drawback in dropping the ice-cream into the bowl due to its heavily hemispherical, concave scoop head, *"When I first saw it, I liked it. But I'm disappointed about the usage of the product..." (Expert# 1).*

The frequent occurrence of use errors lead to disappointment founded upon the experts' expectations in terms scoop functionality and use. This result appeared to indicate how heightened initial expectations lead to greater disappointment after the experience of a critical use failure founded upon functional expectations. In this sense, although the ergonomic driven outcomes were, in fact, seen to be more novel than those of the aesthetic group, issues with usability impaired their appropriateness for the activity of scooping ice-cream. If this was the case, the use of ergonomic design constraints stimulated concept deliverables that were assessed as radical compared to aesthetic derived designs.

3. 3. 4. Analogical Design Concepts

The designs derived from the aesthetic constraints were evaluated by the experts more positively compared to the ergonomic design outcomes, largely due to their ability to satisfy functional expectations. However, this assessment appeared to derive not only from the ability to meet expected usability requirements (i.e. scooping ice-cream), but also derived from design choices related to the use of metaphoric design. For example, the experts highly valued the use of analogy in the product outcomes where the chosen metaphor held for reasons of both form and function. As such, both experts evaluated *Aes Scoop D* as the best ice-cream scoop in terms of both aesthetics and usability.

Figure 11 *Scoop D* & Chick (left), *Scoop F* & Korean Traditional *Amboori* (right)

As Expert #2 indicated, *"(Looking at Scoop D) It is very impressive that the bird seems to have bowed his head to eat a meal. It's a very interesting design"*.

3. 3. 5. Similarity to Product Archetype

Both the experts mentioned that, compared to the designs derived from the ergonomics group, aesthetics outcomes were closer to the product archetype. This indicated that the *aesthetic* derived designs were seen to be less radical in their form and function than those of the ergonomic derived outcomes. However, and contrary to our expectations, the aesthetic designs (*Aes D, Aes F, Aes B*) showed superiority in terms usability. For example, user #4 indicated, *"It is so natural to use and more comfortable than the other one (indicating ergonomics group)."* Second, designs derived from the Aesthetics Group were assessed to perform well-enough. Expert #2 indicated, *"The design of the handle not only looks pretty, but it is also very easy when you actually hold it."* This result appeared to indicate a benchmark use expectation was achieved in the aesthetic design outcomes that was lacking in the ergonomic designs.

Ironically, pursuit of more radical use alternative did not translate into improved expert response due to critical function issues. In contrast, the Aesthetic derived outcomes both functioned well enough and appeared to hold value as emotional objects. In this sense, results confounded our expectations in that the more radical departures in product function, seen in the Ergonomic designs, did not translate into more positive user and expert assessment of the design concepts.

4. Discussion & Conclusions

The current study has investigated how the provision of different design constraints *(ergonomic* and *aesthetic*) influenced conceptual design outcomes through an approach that including design workshop sessions, refinement of product concept ideas and evaluation by both potential end-users and design experts. Two design constraints; ergonomics and aesthetics were selected as an experimental condition to understand influence of design constraints more generally. That is, we provide an account of how design constraints may influence outcome, through the use of the two ergonomic and aesthetic constraints.

The study resulted in six design outcomes: three derived from aesthetic (*Aes Scoop B, D, F*) and three from ergonomic constraints (*Ergo Scoop A, C, E*). User evaluation sessions employed a set of 12 bipolar SD (*semantic differential*) scales related to evaluation of usability and aesthetic dimensions (Khalaj and Pedgley, 2014). Eight of the 12 SD scales indicated statistically significant (*t-test, two-tailed*) differences between ergonomic and aesthetic derived designs outcomes.

Results of the user evaluation indicated design outcomes derived from aesthetic design constraints (i.e. *Aes Scoop B, D, F*) were assessed as significantly better in terms ease of use and design aesthetics. In contrast, the ergonomic derived designs attracted user response

indicating significantly reduced desirability and usability. We speculate that the radical departures in use and form, stimulated through the application of ergonomic considerations, resulted in user concern related to functionality (i.e. the ability to effectively scoop ice-cream). Likewise, the ergonomic derived concepts' novelty of form may have been due to the users' speculation that the same novelty in form and function may have been unacceptable in the radical departure from product archetype (i.e. the standard ice-cream scoop design).

Related to the user evaluation result, experts assessed outcomes derived from ergonomic design constraints as more radical, but less functionally usable. In contrast, the experts were more impressed with the aesthetic design outcomes, due to their ability to achieve a required, benchmark practical goal (scooping ice-cream); while at the same time were evaluated as desirable in terms their appropriation and use of metaphoric design. Thus, the three ergonomic derived concepts attracted more positive expert response in terms of newness, although this positivity was, in the end, dampened by a frequent occurrence of critical use failures.

Confounding expectations, the ergonomics group's design outcomes also received lower expert scores than those derived from a focus upon design aesthetic in terms use and comfort. This unexpected result indicated design constraints biasing ergonomic considerations led to more radical design outcomes, through pursuit of improved usability. This then resulted in the Ergonomic scoop designs as being assessed as more novel. It is unclear to what extent the design-prototypes (in their ability to achieve the working functionality proposed by the design concept), or the designs themselves implicated an inability to satisfy performance expectations in terms use-function (i.e. scooping ice-cream). Perhaps, in pursuit of radical difference in use functionality, the expression of intent as working prototype became more critical. However, qualitative data from the expert evaluation of design concepts did also indicate the designs themselves as limited in their ability to reach expectations related to use and function.

In contrast, it may have been that the three design outcomes derived from the aesthetic design workshops did not suffer from issues related to usability, and were thus evaluated more positively in terms form aesthetic. More interestingly, the designs derived from the workshop providing aesthetic design constraints were notable in their use of metaphor as inspirational drivers for design ideas. It may be that design constraint that focus upon aesthetic considerations resulted in a kind of thinking that promoted a more qualitative, expressive approach, compared to the ergonomic designs. This was evidenced in, for example, embedded references, within the concept designs, to existing objects (*Aes Scoop F*) and nature). Future studies may wish to explore, for example, how provision of aesthetic-driven constraints may foster inspirational approaches (i.e. references to existing objects and nature).

Overall, the ergonomic constraints have influenced the creation of new designs that were much more radical in their use. This then had implications for their form, which may help to extend ideas towards product design innovation. Rather than conceptually splitting use and form driven approaches to innovation (Rampino 2011), researchers may wish to explore

relations between innovation-in-use and resulting change in product form-aesthetic. Results indicated how perusing radical functional change, drove aesthetic difference. Further studies may wish to explore the extent to which product type (i.e. ice-cream scoop, speaker, drinks tumbler) influences any relationship between pursuit of ergonomic improvement and radical change in product aesthetic. Experts showed great interest in these new designs in their methods of use. However, when they did not achieve functional requirement as expected (Ice-cream scoop), satisfaction declined rapidly. This would agree with existing works on relations between innovative change and functional expectations (Pahk and Self, 2015).

Although the current study has provided insight into how different design constraints (broadly termed *Ergonomic* and *Aesthetic*) may have implicated conceptual design outcomes, we see limitations in our approach in terms understanding the influence of design constraints as drivers to direct a process of new product development. We acknowledge that in the real world, the design brief, and constraints contained therein, must consider a myriad of other issues (i.e. manufacture, costing, materials, supply, marketing etc). Controlling for these influences, while allowing focus upon particular constraints, also moves our lab-based approach further away from the complexities of real world design contexts. Therefore, it would be meaningful for future studies to adopt approaches to the study of design constraints as used in real world cases through, for example, observational of their use in practice and/or interview as means to understand how designers may appropriate constraints, their attitudes towards their application and the role of various stakeholders in the provision, appropriation and use of constraints.

A further limitation of our approach is that we focused on conceptual design ideation, rather than looking at the ways in which the use of constraints may, for example, evolves over the entire new product development process. Following studies may wish to explore the role and use of design constraints across the new product development process, from product planning, system level-design, through to detail design and manufacture (Ulrich, 2012).
Further, in setting our target product as *ice-cream scoop* we attempted to select a product type for which both aesthetic and ergonomic design considerations are considered to be important. However, products that have been used for a long time, such as ice-cream scoops, without significant changes in form or function can be affected by the aesthetic convention that exists in people's perception in the process of evaluating aesthetic satisfaction. Relatedly, the function of such well-established products may have incrementally evolved over time, thus optimising their use-function (i.e. results suggesting preference for the more archetypal aesthetic derived design concepts was a result of this). Therefore, future studies may wish to explore how other products and product-categories, with lower levels of aesthetic convention, may lead to difference. For example, it would be meaningful to compare how different design constraints may affect emergent/disruptive areas of product design, such as IoT (Internet of Things) products and their related systems.

In terms the designers used in the current study, there can be many parameters that affect the quality of design outputs such as the personal backgrounds, interests, and experience. Although we attempted to limit for this effect (similar educational and experience backgrounds of the participating designers), the designers' personal characteristics and traits

may have implicated the quality of design outcomes. Future studies may wish to further control for this type of influence through, for example, more specifically profiling design participants, or recruiting a larger sample could lessen this limitation. They may also wish to explore how different types of designers use and apply design constraints with their ideation works and implications for designed outcomes.

Considering the relative size of our sample, we also see limitation in results in terms of the statistical analysis of responses. Future works may wish to increase sample size to provide more robust findings.

With the limitations outlined above notwithstanding, the current study has begun to explore how design constraints may implicate conceptual design ideation and the development of new products. More work is now required to provide a foundational framework for understanding relations between the proposition of various designconstraints and their influence upon design outcome. This understanding may also help provide understanding of the complex relationship between design problem framing, solution ideation and development.

References

1. Alessi. (2017). Alessi: Kitchen. Retrieved May, 2017, from https://www.alessi.com/us_en/product/kitchen.html.
2. Dempsey, P. G., McGorry, R. R., Cotnam, J., & Braun, T. W. (2000). Ergonomics investigation of retail ice cream operations. *Applied ergonomics, 31*(2), 121–130.
3. Hekkert, P., Snelders, D., & Van Wieringen, P. C. (2003). 'Most advanced, yet acceptable': Typicality and novelty as joint predictors of aesthetic preference in industrial design. *British journal of Psychology, 94*(1), 111–124.
4. IF World Design Guide. (2017). iF Design award 2016: Evaluation Criteria. Retrived April, 2017, from https://ifworlddesignguide.com/if-design-award-2018#/criteria.
5. International Ergonomics Association. (2014). What is Ergonomics. International Ergonomics Association. Retrieved November, 2017, from http://www.iea.cc/whats/index.html.
6. Khalaj, J., & Pedgley, O. (2014). Comparison of semantic intent and realization in product design: A study on high-end furniture impressions. *International Journal of Design, 8*(3), 80.
7. Nayak, B. K. (2015). *Study on Innovation in Product Design Considering Aesthetics and Ergonomics* (Doctoral dissertation). National Institute Of Technology, Rourkela, India.
8. Newlands, D., & Hota, M. (2017). Case Study 7: Häagen-Dazs China: The Luxury Icing on the Cream. In *Services Marketing Cases in Emerging Markets* (pp. 77–88). Springer, Cham.
9. Norman, D. A. (2004). *Three levels of design: Visceral, behavioral, and reflective*. New York: Basic Books
10. Onarheim, B. (2012). Creativity from constraints in engineering design: lessons learned at Coloplast. *Journal of Engineering Design, 23*(4), 323–336.
11. Pahk, Y., & Self, J. (2015). Knowledge of use and acceptability of typological innovation: A comparative study. In *Proceeding of the IASDR 2015*, Brisbane, Australia.
12. Rampino, L. (2011). The innovation pyramid: A categorization of the innovation phenomenon in the product-design field. *International Journal of Design, 5*(1).
13. Reddot. (2017). Red Dot Award: Product Design Adjudication Criteria. Retrieved May, 2017, from https://red-dot.de/pd/jury- 2015/adjudication-criteria/?lang=en.
14. Sadowska, N., & Laffy, D. (2017). The design brief: inquiry into the starting point in a learning journey. *The Design Journal, 20*(sup1), S1380-S1389.
15. Smart Design.(2017). Getting a grip A longtime partnership that changed kitchens everywhere. Retrieved May, 2017, from https://smartdesignworldwide.com/projects/oxo-partnership/.

16. Ulrich, K., T. (2017). Design: Creation of Artifacts in Society. Coursera course. Retrieved May, 2017, from https://www.coursera.org/learn/design#.
17. Ulrich, K., T. (2012). *Product Design and Development*. New York: McGraw Hill International Edition.
18. Verganti, R. (2009). *Design driven innovation: changing the rules of competition by radically innovating what things mean*. Harvard Business Press.
19. Zangwill, N. (2014). Aesthetic Judgment, The Stanford Encyclopedia of Philosophy, Stanford University, Edward N. Zalta (ed.). Retrieved November, 2017, from https://plato.stanford.edu/archives/fall2014/entries/aesthetic-judgment/.