Fixation and creativity in concept development: The attitudes and practices of expert designers

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Interviews were conducted with thirteen professional designers to understand their attitudes towards fixation and the practices they adopt to address it. Fixation was thought to be encouraged and discouraged by a wide range of factors related to the project, the client, the design team, the organisational culture and the design activities employed. The experiences that designers accumulate during their professional lives were associated with fixation in different ways. The experience of prior design failures was thought to encourage fixation whilst the experience of varied solutions was thought to discourage fixation. Recognising fixation episodes and reflecting on them was described as the means by which designers could guard against such episodes in the future and thus be more creative.

Keywords: creativity, innovation, engineering design, design fixation, qualitative research

The development of new products requires creative work to be done by engineers, designers and technologists. Design processes, whether systematic or intuitive, are often claimed to unlock this creativity by discouraging premature commitment to a particular representation of the design problem or to possible solutions to that problem. Despite this, it is often stated that designers do, in fact, become 'set', 'blinkered' or 'blinded' when developing ideas. The term 'design fixation' is often used to refer to this broad set of phenomena, or is used more narrowly to refer to the way in which designers inadvertently carry over specific and unhelpful features from a previous example when they are designing something new (Cardoso & Badke-Schaub, 2011a; Jansson & Smith, 1991; Purcell & Gero, 1992; 1996). These fixation effects have been described with respect to many areas of design practice, including not just engineering design, architecture and industrial design (as discussed later), but also, for example, software design (Goddard, 1976), interaction design (Hassard, Blandford, & Cox, 2009) and service design (Moreno, Hernández, Yang, Linsey, & Wood, 2014).

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Researching fixation is important for developing an understanding of what the barriers are to creative design and how those barriers might be avoided

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or overcome. Much experimental research has been conducted over the last few decades, providing valuable insights into how fixation is induced and how its effects might be mitigated. However, to gain experimental control, this research has often eliminated many of the factors that characterise real design projects, including long time scales, multiple stakeholders, team work, concurrent projects and design expertise.[1] There is still a lack of in-depth qualitative research on fixation and so the concept has not been framed with respect to the real-world settings that the experiments simulate. To provide a more contextually rich account of design fixation in practice, this paper reports on an interview study with professional designers working in innovation consultancies. The resulting analysis enriches our understanding of designers' attitudes towards fixation and the practices they adopt to overcome it. This provides a firm grounding for the planning of future fixation research and for developing tools and training that might mitigate fixation effects.

The paper is structured as follows. Section 1 reviews the literature on creativity and fixation, primarily with a view to establishing the relevant concepts and methods that might inform research on fixation in design practice. Section 2 outlines the methodological approach taken in the study reported here, describing the designers involved and the nature of the data generated. Section 3 presents the findings from the study, focussing on the designers' attitudes towards fixation and the practices they adopt to tackle it. Section 4 discusses the implications of these results for design research, practice and education and proposes further related work, both qualitative and experimental.

1 *Creativity and fixation*

Although creativity is often freely spoken about, it can be difficult to conceptualise clearly and many different definitions have been proposed (Sternberg & Lubart, 1999, p. 4; Taylor, 1988). However, what these definitions often share is the joint requirement that the creative idea be both novel (to an individual, a group or the world[2]) and appropriate (Runco & Jaeger, 2012). It is sometimes additionally required that the idea be non-obvious, surprising or efficient (e.g. see Howard, Culley, & Dekoninck, 2008). These different features of creative ideas are elegantly combined in Newell, Shaw and Simon's (1962) multi-part definition of creative thinking, a definition that is particularly well-suited to considering the role of fixation in design work:

> '1. The product of [creative] thinking has novelty and value (either for the thinker or for his culture).
>
> 2. The thinking is unconventional, in the sense that it requires modification or rejection of previously accepted ideas.

3. The thinking requires high motivation and persistence, taking place either over a considerable span of time (continuously or intermittently) or at high intensity.

4. The problem as initially posed was vague and ill-defined, so that part of the task was to formulate the problem itself.' (pp. 65–66)

In reviewing this definition, we can see that the first part describes an idea or approach that overcomes the conventional view described by the second part. The third part indicates that this breakthrough is not trivial and the fourth part describes the types of problems that are characteristic of design (Simon, 1996). Creative design thus involves the active modification or rejection of previously accepted ideas, ideas that might otherwise block progress.

The term 'fixation' is used by psychologists to describe the variety of blocks that can impede insight, often resulting from the counterproductive effects of prior knowledge (Smith, 1995).[3] This phenomenon and its variants have been demonstrated in a number of now-classic experiments, including Maier's (1931) and Duncker's (1945: Ch. 7) demonstrations of how people's fixation on the conventional function of artefacts inhibits their capacity to see new possible functions.[4] Related to this are Luchins' (1942) demonstrations of the Einstellung effect, where people become mentally set in a particular approach to solving problems. The concept of 'design fixation' was developed from these studies, with the term initially being used to refer to 'a blind adherence to a set of ideas or concepts limiting the output of conceptual design' (Jansson & Smith, 1991: p. 3).[5] Over time, 'design fixation' has often been used in a more narrow sense to refer to an over-reliance on the features of pre-existing designs (Youmans & Arciszewski, 2014). This narrower conception of fixation corresponds with the experimental paradigm that is used to induce fixation and measure its effects.

Whilst the concept of design fixation is often explicitly connected to psychological work on functional fixedness,[6] mental set and the Einstellung effect, Purcell and Gero (1996) note that fixation might exist in a number of forms and that 'we as researchers need to be wary of becoming fixated on our conception of what fixation is' (p. 381). In line with this, various types of design fixation have recently been suggested. For example, Hatchuel, Le Masson, and Weil (2011) classify fixation as it relates to examples, learning processes, other people's ideas and the design process itself. More formally, Youmans and Arciszewski (2014) suggest that researchers categorise fixation as relating to either design concepts or to domain knowledge, and then orthogonally, as being an instance of unconscious adherence, conscious blocks or intentional resistance.[7] In the complex commercial settings in which design takes place, this broader range of concepts might all be relevant and the boundaries between them might be difficult to discern. As such, this paper does not adopt a narrow experimentally-oriented perspective on fixation, but

instead admits any inadvertent or unknowing limitation of the spaces that are explored during design work. Such limitations need not necessarily have negative consequences but fixation is considered here in a negative light because it increases the possibility that useful ideas will be overlooked.

In its broader interpretation, the concept of fixation can be related to the way in which a specific frame of reference enables skilled performance within that scope whilst severely inhibiting creativity beyond that scope (Perkins, 1981, pp. 178–181).[8] This can be applied not just to individual psychological phenomena, but also to accounts of how ideas become 'entrenched' in organisations, where social factors such as hierarchy, expectations, norms, status, risk, incentives and leadership are influential (Dane, 2010: p. 585; Stempfle, 2011). Related to this is Kuhn's (1962) model of scientific progress, which is often used as a basis for understanding the process of conceptual development in general and design development in particular (Crilly, 2010; also see Addis, 1990; Vincenti, 1990). This model describes the formation of a dominant paradigm, the paradigm-induced blindness that results and the struggles by which new ideas are generated and accepted. Of particular note here is that in technology studies, Kuhn's work has given rise to the concepts of 'dominant designs' and 'normal technologies' which might remain largely unquestioned until they are displaced by sudden 'technological discontinuities' or 'technological revolutions' (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Constant, 1980; Dosi, 1982; Tushman & Anderson, 1986).

Just as the fixation concept can be extended from individuals to organisations, it can also be extended from short term experiments to episodes that span months or years. Supporting this is the real-world account of design progress that French (1971/1998) offers for the development of early aircraft gas turbines. He describes this development as involving an 'arbitrary decision' which was carried over from standard practice in steam turbines (the product predecessor). Despite being problematic in its new application, this repetition of a previous design element seemingly went unchecked for over a decade until engineers designed in features that were specific to gas turbines rather than steam turbines.[9] In considering this development, French advises us to 'notice the role of established ideas … in obscuring an important freedom of choice' (p. 202). It is this 'obscuring' of design options that research into design fixation has sought to study since Jansson and Smith brought the concept to prominence in the early 1990s. This research is reviewed below, first with reference to the experimental work and then by collecting the various existing fragments of qualitative research that are related to design fixation.

1.1 Experimental studies

Empirical research into design fixation has typically involved experimental studies that intentionally induce fixation by exposing designers to stimuli that might limit their thoughts. Participants are set a design task in which a

problem is posed and an example solution is provided to some of the participants (e.g. as an annotated sketch). Researchers then identify the repetition of features from these examples in the design solutions that are proposed by the participants. What is often observed is that exposure to example solutions is associated with a reduction in the variety, quantity and quality of solutions that designers generate in response to a brief (e.g. Jansson & Smith, 1991; but also see Purcell & Gero, 1992). When considering a qualitative study of design fixation in professional practice, four questions might be asked of the existing experimental literature: First, what is it that designers become fixated upon and why? Second, what design methods might be used to mitigate fixation? Third, how might accumulated design experience influence the occurrence of fixation? Fourth, how aware are designers of fixation events and thus how amenable is the phenomenon to study by self-report? These questions are considered in turn below.

The experimental literature suggests that designers can become fixated on prior solutions unless they gain exposure to the right kinds of stimuli at the right time (Tseng, Moss, Cagan, & Kotovsky, 2008). These stimuli include alternative representations of the problem (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010; Linsey et al., 2010; Linsey, Wood, & Markman, 2008) and example solutions that are represented in the right modality (Sarkar & Chakrabarti, 2008), are at the right level of detail (Cardoso & Badke-Schaub, 2011b), are relatively novel (Perttula & Sipilä, 2007), are partially obscured (Cheng, Mugge, & Schoormans, 2014) or that are atypical relative to ideas that might otherwise be generated (Agogué, Kazakçi, Hatchuel, Le Masson, Weil, Poirel, & Cassotti, 2014). There is also strong support for the idea that designers should be exposed to ideas that are an appropriate 'distance' from the design domain that is otherwise being considered (Chan et al., 2011; Fu et al., 2013; Gonçalves, Cardoso, & Badke-Schaub, 2013; Tseng et al., 2008). This distance serves to promote the construction of analogies (Linsey et al., 2010; Moreno, Hernández, Yang, Linsey, & Wood, 2014; Moreno, Hernández, Yang, Otto, et al., 2014) but even cross-domain stimuli (e.g. in bio-inspiration) can lead to fixation on specific features rather than general principles (Helms, Vattam, & Goel, 2009; Mak & Shu, 2008). To be stimulated by examples (rather than becoming fixated on them) is thought to require abstracting from those examples prior to ideation (Goldschmidt, 2011; Zahner, Nickerson, Tversky, Corter, & Ma, 2010).

Although most design fixation studies focus on the effects of visual or verbal stimuli, experiments have shown that fixation can be reduced through dissecting physical products (Toh, Miller, & Okudan Kremer, 2013) and by constructing physical models or prototypes (Kershaw, Hölttä-Otto, & Lee, 2011; Youmans, 2011; also see Christensen & Schunn, 2007; Jang & Schunn, 2012). However, this might only be the case where these models do not require the investment of too much time or effort as such investment could

give rise to a sunk cost effect that inhibits change (Viswanathan, Atilola, Esposito, & Linsey, 2014; Viswanathan & Linsey, 2013). Beyond design methods that permit interaction with physical objects, there are also those that relate to how designers interact with each other and with the design problem. Fixation can seemingly be avoided or reduced by working individually rather than sharing ideas in groups (Kohn & Smith, 2011; but see Youmans, 2011), taking a break from the task (Kohn & Smith, 2011; Koppel & Storm, 2014; Smith, 1995; Smith & Linsey, 2011; but see Wiley, 1998) and using design heuristics such as those codified in TRIZ and SCAMPER (Yilmaz, Seifert, & Gonzalez, 2010).

Design fixation effects are thought to vary with the designer's age and experience (Agogué, Poirel, Pineau, Houdé, & Cassotti, 2014; Bonnardel & Marmèche, 2004). Fixation has been observed in school children's design work (McLellan & Nicholl, 2011; Nicholl & McLellan, 2007) and this may actually increase with educational attainment (Genco, Hölttä-Otto, & Seepersad, 2010).[10] However, it has also been suggested that because expert designers are better at problem framing than novice designers, experts are also more attached to their initial concepts in comparison to novices (Kim & Ryu, 2014). In a different context, studies on chess players showed that moderate levels of expertise did not prevent fixation on known (but inferior) solutions, but very high levels of expertise did (Bilalić, McLeod & Gobet's, 2008a). These findings fit with more general accounts that domain expertise can give rise to a lack of flexibility (Dror, 2011; Frensch & Sternberg, 1989) but also suggest that 'super-experts' can acquire an awareness of the pitfalls of expertise and learn to overcome them. When considering the effects of experience in the experimental studies, it is important to recognise that there are differences between mental blocks that are the result of domain knowledge (such as that which experts bring to problems) and blocks that are the result of recent exposure to stimuli. Low-knowledge subjects can combat fixation on stimuli by distributing their efforts over a prolonged period (when priming effects fade), whereas high-knowledge subjects demonstrate more flexible thinking when they engage in continuous effort (allowing the more active suppression of prior knowledge) (Wiley, 1998: p. 727; also see Smith and Blankenship, 1991).

Studies have shown that people may be unaware that they are fixated at the time of fixation (Linsey et al., 2010; also see Bilalić, McLeod, & Gobet, 2008b), may not in retrospect believe that they were fixated (Bilalić & McLeod, 2014)[11] and may not have insight into the cause of defixation (Maier, 1931).[12] Furthermore, explicit instructions to avoid reproducing the features of example stimuli have sometimes been ineffective (Jansson & Smith, 1991; but see Chrysikou & Weisberg, 2005). Despite this, Luchins (1942) found that having subjects write 'don't be blind' on a piece of paper sometimes helped to reduce the prevalence of fixation effects. Going further, Lane and Jensen (1993) showed that knowledge of fixation can help prevent

it, with subjects given a hint about the fixation effect moving more easily (than other subjects) from a rehearsed complex method to a new simpler one.[13] There is also more recent work indicating that receiving education about fixation has the potential to mitigate its effects (Howard, Maier, Onarheim, & Friis-Olivarius, 2013). This is consistent with studies in which designers have been shown to recognise the restrictive frames of reference that they are imposing on a problem and then identify the explicit design moves that they employ to break out of those frames (Akin & Akin, 1996).[14]

1.2 Argument for a qualitative approach

Design fixation research often claims that the various phenomena observed in experimental settings are relevant to real-world design practice.[15] However, the experimental settings differ from typical professional design contexts in a number of ways. For reasons of convenience and control, fixation studies typically exclude many factors that shape design work in commercial settings, including the effects of organisational culture, project timescales, project management and workload (e.g. see Carkett, 2004). Fixation studies also often use student participants working in isolation, tackling relatively simple problems over short time periods (but see Moreno, Hernández, Yang, Linsey, & Wood, 2014). As is often the case in experimental research, there is the risk that the setting for these studies is itself influential, potentially reducing both ecological and external validity (Cash, Hicks, & Culley, 2013; also see Christensen & Schunn, 2007). For example, developing concepts in a limited time may cause stress for the participants, reducing their creativity and thus giving rise to (or exacerbating) the fixation effects that the studies measure.[16]

Perhaps a particular concern for fixation research is the risk of introducing 'demand characteristics', cues from which participants infer the intentions behind the experiment and thus act so as to be a 'good subject' (Nichols & Maner, 2008; Orne, 1962). In reporting on his classic experiments into the Einstellung effect, Luchins' (1942) presents qualitative data that reveals the possibility of demand characteristics in fixation research. In his three water jars study, where the participants were seemingly fixated on the complex (three-jar subtractive) 'E' method and failed to see the possibility of the simpler 'D' method, they afterwards explained their motivations: 'I thought I had to subtract'; 'I thought I had to use all three jars'; 'I thought you wanted to see how well I knew the old (E) method'; 'I saw that (the D) method but thought it was too easy and it might be wrong to use it.' (p. 48).[17] Luchins also reports on the participants' apparent understanding of the experiment: '"I am not a fool"; "I am not that dumb"; "Trying to catch me?"' (p31) and '"I think I see the point of the experiment—I was supposed to become mechanized."' (p. 39). Later experimental studies have seldom reported participants' interpretations in this way, even though these quotations show the potential influence of participants developing an understanding of the experimenters' intentions (whether or not that understanding is correct).

Separate to the issue of experimental artefacts is the matter of how fixation research has more generally been shaped by the experimental method. Fixation research has so far seemingly focussed on investigating issues that are amenable to experimentation rather than necessarily considering the most interesting or pressing research questions that might be asked about fixation (irrespective of what methods might answer them). One focus for fixation research that would be complementary to the existing experimental work would be to understand how fixation is experienced and addressed in practice. To investigate such issues, many different kinds of study could be performed, but there is good precedent for the use of qualitative approaches in creativity research. In particular, there are strong arguments for the value of studying individual lives (Wallace, 1989), conducting concurrent or retrospective think-aloud studies (Perkins, 1981) and collecting multiple interviews for synthesis and comparison (Csikszentmihalyi, 1996; Shekerjian, 1991). More specifically focussing on creative design activities, there is a long history of reporting on interviews and case studies with individual designers, some of which have provided reflections on fixation-like effects, even if that was not the main research objective. These accounts are now provided here as they have not previously been collected and related to each other in the fixation literature.

1.3 Existing qualitative fragments

With a focus on the creative work of architects, Darke (1979) and Rowe (1987) describe case studies that examine the way in which designers bring 'primary generators' and 'organising principles' to a problem. This allows designers to make sense of a problem, impose an interpretation on it and thus make progress with a project. However, as Rowe acknowledges, these impositions can mean that design involves 'moments of "blinding" followed by periods of backtracking' (p. 35).[18] Considering both Darke and Rowe's work, Cross suggests that 'It is as though the designer adopts a blinkered approach, overly focussed on a particular solution concept, and doggedly "pressing on" when a more considered and reflective approach, and consideration of alternative solution concepts, might save time and effort in the long run' (Cross, 2011: p. 36).[19] Considering their own interview studies with race car engineering designer Gordon Murray, Cross and Cross (1996) say that Murray insists on keeping experience 'at the back of your mind, not the front' so that the designer is always designing things as though for the first time (p. 98). This reflection on the potentially negative effect of accumulated knowledge was also evident in Roy's (1993) comparative case study of expert designers. Reporting on James Dyson's work, he says that Dyson believes that when developing a new design 'it is often better to be relatively uninformed at the early concept stage so as not to be hampered by prior solutions' (p. 440; also see Candy & Edmonds, 1996).[20]

Busby and Lloyd (1999a; 1999b) report on interview- and observation-based research that focuses on the way in which organisational factors and experience influence the reuse of design knowledge. Although they do not provide firm evidence for fixation phenomena (if defined narrowly), they do describe the way in which organisational contexts provide candidate solutions upon which designers could become fixated (Busby & Lloyd, 1999a: p. 169). However, they also give examples where designers are seeking to avoid rather than replicate known solutions (e.g. avoiding patent infringement), and they list various aspects of good practice that the designers undertake to avoid fixation-related biases. These practices include formal concept evaluation processes, eliciting cross-domain critique and separating the roles of idea generation and idea implementation (Busby & Lloyd, 1999b: p. 141). Herring, Chang, Krantzler and Bailey's (2009) interview study with professional designers also briefly describes the practices that firms adopted to avoid fixation, such as bringing in people from outside the project to keep the team from being 'so entrenched in the process that they can't think outside the box' (p. 90).

Reporting on interviews with designers in several engineering companies, Eckert, Stacey, and Earl (2005) state that when looking for solutions to specific problems, designers need to know about past designs and prior solutions (pp. 13–14). One consequence of this is that the identification and adaptation of prior work imports more into the new design than just a solution principle. It also carries assumptions about physical properties, materials, manufacturing processes and context of use. Whilst some of these assumptions may be required, others may be inappropriate, having been unintended in the new context and going unrecognised as the project progresses (Eckert et al., 2005).[21] Also studying engineering design, Robertson and Radcliffe's (2009) participant observation study revealed some negative effects of CAD systems on creativity, including premature fixation, circumscribed thinking, and bounded ideation. Where the development of CAD models acted to discourage making major design changes, 'a resistance developed to ideas which would lead to too many changes to the model, even if these changes would solve numerous problems or make other improvements such as reducing overall project risk' (Robertson & Radcliffe, 2009: p. 137).[22] Results from a follow up questionnaire study showed that designers seek to reduce this effect through the delayed implementation of a highly structured model (Robertson & Radcliffe, 2009: p. 141).

The fragments of qualitative material collected above indicate that non-experimental methods can effectively contextualise the concept of design fixation. However, this has mostly been from studies that were not exclusively focussed on fixation (but just touched on it). As such, we still have very little information about whether designers recognise the concept of fixation, what their attitudes are towards it or how consciously they adopt practices to address it. Methodologically, there remains a question as to whether fixation

is amenable to introspection, but support for this comes from Sanger's (2012) study of 'entrenchment' in management practice. This involved interviewing Chief Marketing Officers (CMOs), showing that they experience both organizational and personal entrenchment, that they are alert to entrenchment traps and that they deploy various disruptive strategies to break free, sometimes with success. Sanger notes that 'the CMOs were unaware of their personal entrenchment until they got disrupted' but that they can describe these episodes in hindsight (p. 32).[23] On this basis, the study reported in this present paper takes fixation as its main focus, both in the enquiries that were made of designers and the analysis that was conducted on the resulting data.

2 Method

A semi-structured interview study was undertaken to provide information on designers' experiences of fixation and their attitudes towards it. This is discussed here according to the sample involved in the study, the method of data collection and the processes of data handling and analysis.

2.1 Sample

Using a combination of direct communication and chain referral sampling (e.g. see Biernacki & Waldorf, 1981), thirteen participants were recruited into the study. All participants were drawn from five UK-based consultancy firms focussing on design, innovation and product development. The participants self-identified as engineers, designers or inventors (or some combination of those titles), but are hereafter collectively referred to as 'designers' because of the roles they played in the concept development projects that were discussed. The designers all held post-school qualifications relevant to their work, typically bachelors, masters or doctorate level degrees in design or engineering. Overall, the designers had an average of 21 years of professional experience and had worked in various capacities on projects spanning a broad range of industrial sectors. The projects they spoke about varied greatly in duration and team size, but most typically ranged from one to three years in length and involved five to twenty people at their peak size (see Table 1).

The consultancy firms with whom the designers worked are all highly respected leaders in their fields, and their services are often sought when other teams have failed to solve the problems at hand (e.g. in the client organisation or in other consultancies). In the five-year period preceding the study, the consultancies collectively won over a dozen high-profile national and international awards for design, engineering, innovation and technology projects; they were also shortlisted for many more. The consultancies are all loosely related to each other, offering similar services and serving similar sectors and clients. Individual designers are known to move between these consultancies during their career and in this study no distinction is made between them. For reasons of confidentiality, the designers and the consultancies are not named in this paper, nor are the projects they discussed or the clients those

Table 1 Basic educational and professional details for each participant in the study and basic information about the main project they discussed in the interview

Participant ID code	*Highest educational qualification*	*Professional experience (years)*	*Role in project (self-identified title)*	*Market sector for project*	*Problem-solution type for project*	*Duration of project (months)*	*Size of project team (number of people)*
1A	Doctorate	20–25	Lead engineer	Consumer products	Thermal	36	14
2B	Masters	5–10	Designer	Medical products	Electrical, pneumatic	18	8
3B	Bachelors	20–25	Project lead	Medical products	Mechanical, thermal, pneumatic	36	5
4B	Bachelors	15–20	Project lead	Industrial products	Mechanical, electrical	24	5
5C	Doctorate	15–20	Director	Digital systems	Business process	96	70
6D	Masters	40–45	Director	Industrial products	Packaging	6	4
7A	Bachelors	40–45	Project lead	Medical products	Mechanical, fluidic	60	15
8E	Masters	10–15	Project lead	Product packaging	Fluidic	6	6
9E	Bachelors	5–10	Design engineer	Consumer products	Mechanical	12	5
10E	Masters	15–20	Technical lead	Medical products	Mechanical, fluidic	42	40
11E	Masters	20–25	Design engineer	Consumer products	Mechanical, fluidic	18	10
12D	Bachelors	10–15	Designer	Medical products	Mechanical, fluidic	24	8
13A	Diploma	35–40	Innovation consultant	Consumer products	Mechanical, experiential	24	10

projects served. Instead, a participant identification code is associated with each designer, composed of a number that reflects the sequence of the interviews and a letter associated with the consultancies they worked with (e.g. '3B').

2.2 Data collection

Over an eight week period in 2014, the designers were recruited into the study with a request to discuss technological innovation projects. Each designer was interviewed individually at their place of work (except for one interview which took place at the participant's home). The interviews had an average duration of 50 min, excluding briefing and debriefing. Each interview was preceded by a standard process of establishing informed consent, with all participants permitting audio recordings to be made.

Each interview was conducted using a semi-structured protocol (see Breakwell, 2006) and was broken into two main parts. In the first part of each interview, the researcher asked directed questions about the designers' experiences of projects they had worked on. As the discussion progressed, emphasis was placed on projects which had 'changed direction', resulted in 'breakthroughs' or involved people becoming 'blinkered' or 'blinded' to alternatives. Participants typically described one recent project in detail (see Table 1) which was referred to throughout. In the second part of each interview, the researcher described the concept of fixation. This involved a brief account of Jansson and Smith's (1991) experiments with the bike rack problem and a qualitative summary of the findings. Participants typically responded to the fixation concept spontaneously, relating it to the projects that had already been discussed in the first part of the interview. Throughout the interviews, the researcher did not use the term 'fixation', instead adopting, wherever possible, those terms that were uttered by the participants (e.g. 'tunnel vision', 'bias').

2.3 Data analysis

All audio recordings were transcribed verbatim and augmented with any handwritten notes made during the interviews (e.g. relating to sketches, gestures or context). The transcripts totalled 92 000 words and were imported into qualitative data analysis software (ATLAS.ti) to permit the iterative coding processes associated with a general inductive approach (see Braun & Clarke, 2006; Thomas, 2006). On the first iteration, the transcripts were divided into 350 segments, coded against 80 unstructured themes. After several coding cycles, the analysis had stabilised on the main themes and sub-themes that are presented in this paper. The categorisation of the themes was intended to represent the voice of the designers who participated in the study rather than to satisfy the requirements of classification theory.[24] Throughout the analysis, emphasis was placed on identifying themes for their *relevance* to the concept of design fixation (e.g. exposure to earlier designs) rather than their *prevalence* within the transcripts (e.g. general discussions about designer-client relationships).

Although the analysis was conducted on full verbatim transcripts that reflected pauses, broken sentences and repetitions, the quotations provided here are edited for ease of comprehension. Any additional editorial additions or substitutions are enclosed in square brackets. Otherwise, the language used is entirely that of the participants. Note that in the second part of the interviews the designers often mentioned the car-mounted bicycle rack example that the researcher had previously referred to in explaining the fixation concept (see Jansson & Smith, 1991). This is evident in the quotations presented in this paper where the participants refer to the 'bike rack' or 'car rack'. In each case, this is followed with an inserted citation (J&S) to be explicit about the reference that is being made. To distinguish between quotations taken from the first and second parts of the interviews (i.e. whether the fixation concept had yet been discussed) the participant identification code is followed by '(i)' for the first part of the interview and by '(ii)' for the second part (e.g. '3B(ii)' would indicate a quotation from the second part of the interview with participant 3B.)

3 *Thematic analysis*

The main themes that resulted from the analysis are here described under four headings: (1) the nature of fixation; (2) factors that encourage fixation; (3) factors that discourage fixation; and (4) the effects of experience on fixation. Each theme is divided into sub-themes and these are illustrated with quotations that reflect the particular way in which the designers accounted for their experiences. There is no logical order in which to present the themes but the relationships between them are discussed in a thematic overview (Section 3.5).

3.1 *The nature of fixation*

Even in the first part of the interviews, the designers made spontaneous references to the risks of acquiring 'tunnel vision', of 'regurgitating' prior solutions or of becoming 'blinded' or 'blocked' to alternatives. In the second part of the interviews, the designers almost universally recognised the phenomenon of fixation as described by the experiments. However, the ideas upon which designers might fixate, were not just possible design solutions (e.g. examples of existing products), but also perspectives on the problems being addressed and the processes of addressing those problems. Avoiding premature commitment to these solutions, problems and processes was seen as a key factor in maintaining a successful design project.

> *'It's foolish to believe that your initial idea is the good one and your process or your plan or the methodology or approach that you're following is the correct one. As you start, you become familiar with the programme, you identify challenges, risks, problems. Or [the] requirements themselves emerge or change. That is when you have to shift or adapt or move or completely replan, redesign, change the concept, change the idea. I think the ability to identify that as soon as possible [is critical]'* — 8E(i)

Although a blind and unreflective adherence to a limited way of thinking was generally acknowledged as problematic, the designers also considered some aspects of fixation-related behaviour to be essential to their work. This centred on recognising an inherent contradiction: designers must remain *open* to the possibility that their ideas are limited or misdirected whilst also being *persistent* in developing their nascent ideas in the face of negative feedback. This persistence is critical because new concepts always have problems and some commitment to them is required unless they are to be prematurely abandoned for other concepts that will in turn prove to also have problems.

> *'It's human nature to have these built in preconceptions and you can channel down and go down this path … your blinkered view. But [although] that's got its bad side, there's a good side to that as well. Because if you weren't single minded enough to be tenacious then you wouldn't keep going. So sometimes the worst thing you can do is to ditch what you have got and jump ship for some other concept that looks more appealing, it only looks more appealing because it hasn't been built yet! … So yes, … there is that biasing and blinkered view, and … in some ways it's bad but in some ways you have got to persist down an avenue, … be tenacious in the belief that the principles that you created were probably okay'* – 10E(ii)

3.2 Factors that encourage fixation

The designers described various factors that increase the risk of fixation or increase the severity of its effects. In particular, five sub-themes were identified: exposure to *precedents;* commitment to *initial ideas*; project *constraints*; a *blame* culture; and the role of the *briefing* in inducing fixation.

3.2.1 Prior art

A restricted view of the solutions that are applicable to a project was associated with exposure to prior art. This might be in the form of design solutions already available on the market or those having been developed by the team for previous projects. Such precedents were thought to give rise to a conflict between the motivation to explore these precedents (for information) or to avoid them (for independence). Especially where the problem is technically challenging and where promising concepts might still prove to be infeasible, learning from prior solutions might save considerable resources. However, this was expected to have negative consequences if genuinely innovative products were required.

> *'You can do the [technology and product] research first and see what's out there, but by doing that you are polluting your mind. So you have to be aware of that, and if you do go looking [at what's out there], you're polluting what you might come up with. You're seeing these ideas and thinking: "Oh, that's how you do it then." … You've got the advantage of seeing what people have already done so that you know that these are potentially robust solutions. But then you've got the risk that you actually may have cut off some other ideas you might have come up with. … It's kind of tunnel vision.'* – 9E(i)

'It's very unusual to start a design from a completely blank sheet of paper. … So you're always starting from what's known and what works or what's reputed to work, whether it's internal or external to the company. So, you're always starting from your example of the bike rack [J&S] which might be a good bike rack or it might be a faulty bike rack but you're not starting from a blank sheet … And I think that sometimes quite poor designs, can just get marched on and on and on through subsequent upgrades and never really get sorted.' – 7A(ii)

3.2.2 Initial ideas

Just as solutions that precede the project were identified as a source of fixation, so too were the solution concepts developed in the early stages of a project. The initial ideas that designers generated were described as having a limiting effect on later ideation as effort was expended on defending the early direction rather than exploring new ones. This problematic effect of initial ideas could be manifest as individual designers fixating on their own work or fixating on work developed by others in the design team.

'It's definitely very important to make sure that people realise that when they come up with an idea they should consciously know that it's just one idea. You know, there's many more available, there's always more than one solution to a problem, so keep thinking, basically [laughs].' – 9E(ii)

'I think there quite often is a feeling that people have that they actually know the best combination of solutions pretty early on. And most of their effort will be going to prove that that works, rather than exploring the full range of options. I think the pragmatic mind-set [staying safe] is pretty strong, [as is] going towards the path of least resistance.' – 2B(ii)

3.2.3 Constraints

One of the recurring themes in the interviews was the cost of thoroughly exploring the solution space. These costs might be incurred directly, by billing for the time required for thorough exploration, or might be incurred indirectly, by delaying the completion of the project and the launch of the product. In these cases, an acceptable solution (one found quickly and inexpensively) might be preferred over a superior solution (one that took more time to develop and incurred greater costs). The negative consequences of limited concept exploration were well known, but in projects that are very budget-constrained or risk-sensitive, these consequences are offset by the need for expediency and pragmatism.

'We might come up with a solution, … a solution that's really good. And, … we might stick with that, maybe because of costs and time. Because it costs [the client] money for us to look at other options. … And if we really believe that [our concept is] a good option we may say: "Yeah, we could keep exploring some other ones, but if the client hasn't got any money [then

let's not]" … So even though we know we can do it, and it might be the best thing to look at the other [options], we won't.' – 3B(ii)

'You think of an idea. A week later you think of a better way of doing it, so you scrap the original idea. You never get anywhere. It often takes you three or four times longer to [get to] market. And the cost involved in bringing that product to market at a later date can sometimes be horrific. … I don't think there is any product [of mine] where there wasn't a better way of doing it.' – 13A(i)

3.2.4 Blame

Some of the participants referred to organisational culture as an influence on fixation. Settings in which there was 'permission to fail' were considered to be beneficial because the exploration and development of new ideas was encouraged, even when risky. In contrast, those settings in which ideas were 'owned' by their originators were claimed to encourage fixation because the individual owners of an idea could be protective of it and resist alternatives. In general, the designers celebrated the working culture in their current organisations, and contrasted this against their experiences with previous employers or with client companies where there was risk of blame.

'[Our company is] very good like that, … we are very non-judgemental; people are allowed to make mistakes. And that's one of the beauties of this place actually, because if you're allowed to make mistakes you'll be very creative, you'll be prepared to take risks. And if you don't have that, if there's fear there that you're going to get blamed you won't take those risks, you won't be creative you won't be innovative, or you'll be limited, you'll be self-limiting.' – 3B(ii)

'[In another organisation I used to work at] you could suggest stuff and it wouldn't go in because [the other designer] had ownership of [the design] and it was taken as a personal criticism if you criticised the design in any way. … and I think that kind of attitude can lead to blinkered designs.' – 12D(ii)

3.2.5 Briefing

In the preceding discussion, the concept of fixation is related to the restricted thinking that the designer might exhibit, but designers are not the only ones susceptible to fixation. The designers in this study often referred to their clients as becoming set on particular ideas during the project briefing. This was described in at least two ways, either as the client being fixated on a possible solution prior to approaching the consultancy, or as the client becoming fixated on the initial concepts that the designers shared with them. As such, just as fixation was seen as something that had to be managed within the design team and the design process, it was also seen as something to be managed during interactions with the client, especially when establishing the brief.

'In some ways, the [example] car rack [J&S] will be what the client comes to us with. And quite often they're really looking for us to embody that, and we will be pretty blinkered with that and just implement some of the features.

And quite often I'm sure they'd love us to point out real reasons why they're not good, but … if a client comes to us with that, quite often we will, depending on the project, take that and try to engineer it into a solution [laughs]. … So I think that the blinkered thing is probably true to some extent.' – 2B(ii)

'[Sometimes] the industrial designer shows something [to the client] and if they love that then [the client says]: "That's what we need, that's what needs to be made." And … they're driven by that emotional feeling that that sketch or that concept produced. Usually it's because the guy that made that sketch or that concept is very good; he's also verbally [good at] presenting it. He's very charismatic and, he makes [the client] fall in love with his idea and [the client] just blindly says: "Oh, this is great, that guy is great and his design is great". … And whatever you put down later it's difficult to get them distracted from [that first idea] … The client manager and the client might love the concept and then you as the designer need to struggle to move them away from that concept' – 8E(ii)

3.3 Factors that discourage fixation

The designers often described themselves and their organisations as fixation-aware and fixation-resistant. This is described here by five separate sub-themes: the role of *teamwork* in preventing fixation; the use of systematic design *methods*; the role of *facilitation* in managing others; the *making* and testing of models and prototypes; and the influence of working under the *expectation* of developing concept variety.

3.3.1 Teamwork

Isolated unstructured work by individuals was considered to increase the risk of fixation or the severity of its effects. This was attributed to the limited perspective that a single designer can have on a problem, the limited knowledge that they can bring to bear and the limited experiences that they have of alternative methods and solutions.

'Probably the worst thing to do is just work on a problem on your own. … Because you have your own skill set, you're very experienced in a certain area, you're very interested in working on a certain thing and it's quite easy if you just work on your own, to think: "I'm going to come up with ten different concepts for this." [But] you look at them and think: "Well, five of them share the same core principle!" And then you sit down and you think: "Well, right, I'm going to think a lot harder about this and come up with some more concepts." And [now] seven of them have the same core principle [laughs]. You get to a certain point and then you can't see any further.' – 1A(i)

To combat the effects of isolated design work, the designers mainly described two team design methods that brought different perspectives to bear on a given problem: brainstorming and design reviews. Brainstorming was mentioned by many of the participants, often referring to a formally

facilitated process that was both an environment in which fixation effects were observed and an environment in which those effects were questioned or resisted. The uncritical free-thinking encouraged in brainstorming can be contrasted with the structured process of conducting design reviews for concept evaluation. However, in both cases, what was valued was the introduction of new ideas from other people, people distinguished by their different backgrounds, different experiences or their different levels of involvement with the project.

> *'I think sharing is good … If you've got more minds, people with different knowledge and experiences. That's why in brainstorms here we tend to grab people from different backgrounds, so we'll grab a physicist or an electronics person into a mechanical problem, because they all look at it differently, which can help.'* — 9E(ii)

> *'We do peer reviews, technical peer reviews where you bring in somebody who's not related to the project to challenge you as a project leader, say: "Oh, why have you done it like that?" Or: "Show me your rationale for how you've done it." They're acting a bit like the client really, … they capture anything or they could stop [the project] before it reaches the client.'* — 3B(ii)

3.3.2 Methods

In addition to the team processes of brainstorming and design reviews, the designers also repeatedly described systematic design methods as the means by which fixation was tackled. Morphological charts were almost universally praised as a method by which designers were required to systematically break down a problem and work through each of the options available, thus allowing them to detach themselves from their initial ideas.[25] (To a lesser extent, TRIZ and related methods were also cited as productive ways to encourage a change of perspective on a problem and ensure the consideration of alternatives.)

> *'It [the morphological chart approach] forces you to go away from what you naturally want to do, which is solve it quickly in one swoop. It forces you to analyse it in depth in lots of different aspects.'* — 3B(ii)

> *'[You] build a matrix that forces you to consider, all of the various different options, forces you to fill out alternative approaches. So you had to break out of that particular column [of the matrix (a particular solution)] you may have got stuck in. You were forced to consider other types of techniques and columns and so on. Which actually was quite a good approach. … It becomes quite useful to push you out of that box.'* — 5C(ii)

3.3.3 Facilitation

The designers often described fixation as a challenge that they knowingly tried to manage in themselves and in others. This management was described at the level of individual projects and also at the level of the larger organisation. The relatively non-hierarchical and project-driven nature of the consulting practices meant that the participants had generally been managed by

others and had managed others themselves. As such, they had experiences of observing and managing fixation and of observing other people's management of fixation. The role of expert facilitation was described as the key to such management in idea generation sessions, where the potentially negative effects of group behaviour (with respect to fixation) need to be controlled.

> *'If you're a project leader for something, sometimes you can see it in the team, you get some guys who will be very sort of focussed on the way they want to do it, they want to do it [one particular way] because they've got previous experience of that'* – 4B(ii)

> *'Some people will fight for their idea almost aggressively, not aggressively but quite passionately. What you have to do is usually just give it a minute, sometimes you can actually just let them have their say and move on, and just carry on going and then come back to it, just a few minutes later even, and present an alternative. … I think it lifts up the tunnel vision thing, the walls, kind of, fall away a bit and I suppose their guard's down maybe. And then you can explain another idea and they can see the light, see that: "Oh yeah, that idea too could work." … I think, the more that that happens, then the more those people actually become open to other people's ideas.'* – 9E(ii)

3.3.4 Making

The designers often insisted that model making was an essential means by which they could test their ideas. In the technically challenging design work that they performed, sketched concepts were seldom accepted as feasible unless supported by computational or physical models that demonstrated that the design would satisfy the requirements. The feedback that the designers received from their prototyping activities would serve as an external source of critique, allowing them to detach from ideas that were not satisfactory and move on to explore the alternatives.

> *'The easiest way to learn … is to build things, test them, see how they perform. That's the point at which your ideas meet reality and one of the core questions is: "How different is reality to what I thought it would be when I was designing it?" And it's seeing and understanding what it [the design] does or doesn't do. And being open to that is one of the things that then enables you to make the next step, whether it's in the right direction or not.'* – 1A(i)

> *'I'm sure there is all sorts of biasing that happens in design. I think that is one of the challenges, to try not to be too blinkered. But frequently, if you are designing something that's new technology that has got some fundamental technical challenges to overcome, then you can have all those biases but they won't really [hinder] you because you make some prototypes, you find they don't really work very well and then you have to work out why*

…. So, in the end the reality will kick you in the face and help you along …. Typically, in a brainstorm, people fire off the immediate ideas in their head … I can imagine they would be biased by things they have seen recently or whatever, but I think when you actually come to build things, then the physics of the world kicks in, and you can't really cheat that stuff. You can try your best but it's something that either will work or won't [laughs].' – 10E(ii)

3.3.5 Expectations

The designers' clients were previously described as a possible source of fixation, but the clients' requirements for concept variation also has a defixating effect. In some of the designers' accounts, even the anticipation of presenting to the client encouraged broader thinking as the client was assumed to expect variety. The designers worked so as to meet or exceed these expectations, thus generating the variety of concepts that they thought would be well received.

'I think the whole point of the way we're set up is to try and avoid that [fixation]. A client comes to us with a question, a problem, and wants us to brainstorm around it. I think if we fed back ten purely mechanical problems all involving gearboxes and cams, for instance, they'd be pretty disappointed. So it's our job to think outside the box a little bit and come out with some crazy ones, aspects of which can be taken forward.' – 12D(ii)

'We're having to present to clients. … They want to see that we've explored a lot of areas. So, I think it is on people's mind, from the point of view that we have to present to the client, we're going to need more than that one idea: 'What have we missed? There must be other ways to do that … ' – 2B(ii)

3.4 The effects of experience

The experience that designers accumulate through their professional work was understood to influence the risk of fixation in different ways. In particular, three sub-themes were identified: the way in which the *experience of variety* (of concepts or solutions) opens up the space of exploration; the way in which the *experience of failure* (of concepts or solutions) makes that exploration less likely; and the way in which the *experience of fixation* (in previous projects) raises the designers' awareness of fixation risks and thus helps them to guard against it.

3.4.1 Experience of variety

The designers often spoke of how their work exposed them to a great variety of design solutions that would develop into a resource that they could draw on to solve problems. This was described as an inevitable process of gaining exposure to the many products, processes and systems that they interact with in their personal and professional lives. Developing an awareness of the variety

of possible solutions to any given design problem had the effect of both making those same solutions accessible and reminding designers of the opportunities for concept variety.

> *'You build up a library of things you have seen and things you designed and things you have seen other people design. So, I think any designer or engineer is constantly looking at the objects around them and just absorbing little ideas and thoughts.'* — 10E(i)

> *'A lot of the younger guys, have never really tinkered and they've never mucked around in garages and just taken things to pieces and found out how they work. [But when they do], that can be enough to give them exposure to different solutions for fixing problems. And the more you see, the more options you have. … I think my concepts now [later in my career] probably do [include] a wider range of mechanical devices … than when I first started. So I think the range of mechanisms for solving problems has probably got better as I've picked up more experience of things.'* — 12D(ii)

3.4.2 Experience of failure

As designers accumulate experience of different projects, they develop experience of how certain approaches succeed and fail, with the experience of failure being particularly prominent in their minds. This accumulated knowledge can drive a trend towards increasing conservatism, with experienced designers accepting a restricted set of solutions. These solutions might be known 'to work' but adhering to them prevents the exploration of solutions that are unproven or that are related to those that have previously failed.

> *'I think a lot of [graduates], they're just straight out of university. They've obviously not got the experience of failure at that point, the frustration of failure. But the nice thing from that is you often get a lot greater breadth of creativity. … I think from my standpoint I'm very mindful of the fact that as I get older my thought processes become more rigid.'* — 11E(ii)

> *'The younger you are the more keen you are to be adventurous, to be exploring new things and also you don't know things that don't work because you haven't tried them. As you progress you know a few things don't work technically and you know the process of design.'* — 8E(ii)

3.4.3 Experience of fixation

Whilst experience of failure can lead to fixation, experience of fixation itself (and its negative consequences) is the means by which designers reflect on their biases and learn to resist them. As such, the designers in the study often described themselves as not just fixation-aware, but as fixation-averse. They had learnt to identify the situations in which fixation was a risk and to implement countermeasures.

> *'You do a project and think: "Oh no, that [pursuing one idea] was not the right thing to do." And then you think: "Right, remember that next time*

around." It really does make you stop and think. I'm doing it more and more now. It's thinking: 'Well, okay, I know that traditionally I would follow this layout, it seems like the right thing to do but I'm going to stop. I'm going to spend an hour or two and just see what happens if I move things around a bit and try it slightly differently.' — 11E(ii)

'You always think your idea's good, there's psychology in that, you come up with your first idea and you power it up and you go: "Yeah, this is a really good idea." And then you push other ideas to the side, mentally. This is what you do in your more basic and younger [days], when you're not as experienced. … The more projects you do then the more you … self-analyse. … I think if you do that [analysis] every time, eventually when you start another project you go: "Oh, I remember doing that [fixating] last time and at the end I had all these other solutions. Maybe we should just check to make sure that there aren't some more solutions there." So I suppose it's something that comes with experience' — 9E(ii)

3.5 Thematic overview

The hierarchical structure of the previous sections permits a linear reading of the analysis but mask some of the connections between the themes. In particular, design fixation was described in the context of a basic tension between two opposing characteristics that concept development requires of designers: remaining open to the possibility of other ideas *and* persisting in the belief that an idea is worth developing despite alternatives. Persistence and openness can thus be reclassified as factors that encourage and discourage fixation (respectively). Openness, whilst valuable, not only conflicts with the need for persistence but also consumes resources because it delays commitment. Of those factors that encourage fixation, three of them relate to the influential role of *precedents*: prior art, the briefing and initial ideas. Of those factors that discourage fixation, two of them relate to the influential role of gaining *feedback* on a design: teamwork and making prototypes. The expectation that critical feedback would result if there was insufficient variety in the concepts can also, less straightforwardly, be considered as feedback (even if that is only anticipated). The different roles that experience plays can also be reclassified, with the experience of failure encouraging fixation and the experience of variety discouraging fixation. Of particular importance is that the designers believed that the occurrence of fixation can also, with sufficient reflection, discourage the occurrence of future fixation episodes (see Figure 1).

4 Discussion

In contrast to the experimental literature, the interviews reported here give a perspective on design fixation that emphasises professional designers' attitudes and practices. As such, the study highlights a number of factors that are not typically emphasised in the literature. First, fixation need not just

relate to the solutions represented in prior art (provided as stimuli in many experiments) but also to the problems and processes that are being considered and to the initial ideas that designers develop. Second, designers need not sketch concepts in isolation from other people and other techniques (as is often the case in the experiments), but might actively seek fixation-breaking feedback from their team and from the 'physical reality' of making models. Third, although wide-ranging concept exploration may be desirable in design (and is often requested in the experiments) the constraints of commercial practice may mean that the cost of such exploration discourages conceptual breadth. Fourth, by accumulating experience of multiple projects (as has seldom been possible for the experimental participants), professional designers draw on their experience when maintaining a balance between openness and persistence.

Although this qualitative study offers new insights, some of the themes that emerge from the interview analysis support or contrast with the findings from the related experimental literature. For example, the designers emphasised the defixating effects of making models, which corresponds well with those fixation studies that have tested the effects of prototyping activities (e.g. see Kershaw et al., 2011; Viswanathan et al., 2014; Viswanathan & Linsey, 2013; Youmans, 2011). However, the designers also presented a reflective stance towards this practice and towards the problem of fixation generally. This is in contrast to the accounts offered in the experimental literature which shows participants being unaware of fixation effects (Linsey et al., 2010). This contrast suggests that an awareness of fixation might be developed over repeated projects and in response to feedback that reveals prior fixation episodes. If so, this would support the finding that learning about fixation has the potential to reduce its occurrence or mitigate its effects (see Howard et al., 2013).

Beyond adding context to the findings of the experimental work, this study also adds to the qualitative descriptions of fixation in the existing studies of design. For example, the designers' accounts show that they impose order on the problem and commit to a given direction, even if alternatives might be available. This corresponds well with the findings from earlier studies with expert designers (e.g. see Cross, 2011; Darke, 1979; Rowe, 1987; Roy, 1993). The various reasons given for these commitments are in agreement with more recent qualitative work that points to the influence of previous designs, sunk cost and client behaviour (see Eckert et al., 2005; Paton & Dorst, 2011; Robertson & Radcliffe, 2009). When those commitments need challenged, design reviews and other forms of external critique were considered invaluable, supporting the findings of earlier studies (see Busby & Lloyd, 1999b; Herring, Chang, Krantzler, & Bailey, 2009).

The thematic analysis in this study revealed a number of organisational and managerial factors that influence fixation, including company culture, client

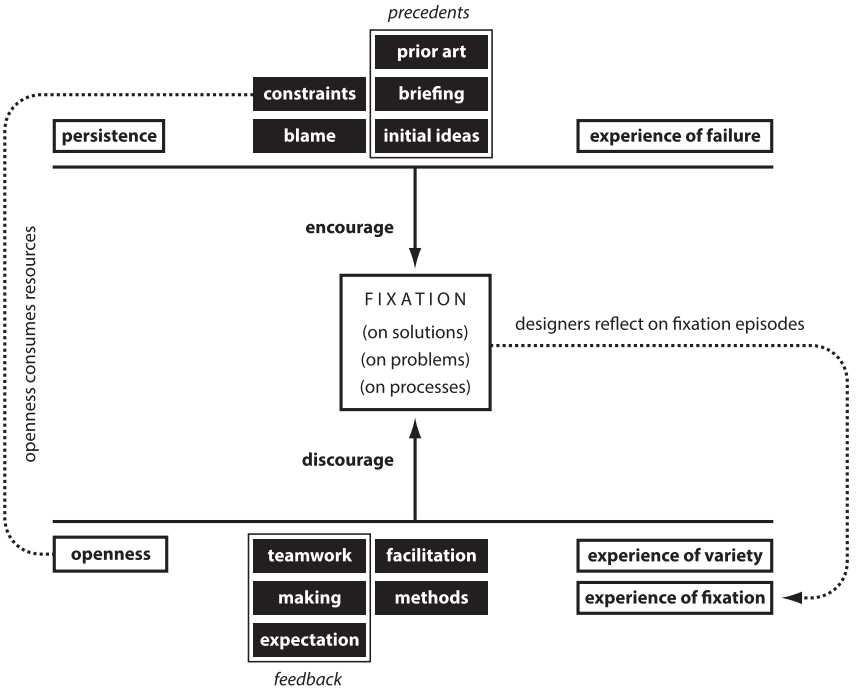

Figure 1 Factors influencing design fixation in professional practice

expectations, perceived risk and management (also see Carkett, 2004). Such factors have been considered in the study of 'organizational fixation' or 'entrenchment', and design research might look to this literature for guidance on studying these matters further (e.g. see Sanger, 2012; Stempfle, 2011). Similarly, although design expertise has not been a strong focus of the fixation literature so far, the accumulation of experience emerged as an important theme in the interviews reported here. This connects well to the study of fixation in other domains, where domain expertise is seen as a key factor in determining whether fixation occurs and by what approaches it might be mitigated (e.g. see Bilalić et al., 2008a; Wiley, 1998). However, what this present study might add to these accounts is the idea that reflection on previously experienced fixation episodes can be the means by which fixation itself becomes a subject of expertise.

4.1 Limitations and future work

This research study has particular features that should be considered when generalising from the findings and when planning future work. In particular, the designers studied were expert consultants with years of relevant education, training and professional experience. The projects that they worked on were typically conducted for external clients over many months, with teams composed of people from different disciplinary backgrounds and with new

team members being brought in to the project at different times. These factors might all be expected to influence the designers' reported awareness of fixation effects, their attitudes towards those effects and the steps they take to address them. Other types of designers working in other contexts on other types of problem might experience fixation in very different ways. Future studies might usefully focus on different aspects of design practice, including professional experience (e.g. novice, expert), design discipline (e.g. software, architecture), type of organisation (e.g. consultancies, in-house design) or problem type (e.g. inventive design, routine redesign). These distinctions and others could form the basis for valuable studies that permit comparative analysis, revealing the factors that affect fixation across design practices or those that are specific to different types of design practice (for example typologies of design practice upon which such work might be based see Buchanan, 2001; Von Stamm, 2008: p. 525).

Beyond the features of the sample studied, the methods used also imply certain limitations. The study is entirely qualitative and based on the self-report of the participants. In general, people's accounts of events and processes can be subject to a number of limitations, including lack of awareness, poor recollection, folk theories, acquiescence bias and self-presentation bias (Perkins, 1981, pp. 13–32; Podsakoff, 1986). More specifically, creative activities may also rely on unconscious processes (Dijksterhuis & Meurs, 2006) and people may be mistaken about where their ideas came from and how they were developed (Brown & Murphy, 1989). To address these limitations, future research should also attend to the different qualitative research methods that might be applied to understanding the occurrence of fixation in design. In particular, longitudinal observation studies of design projects could provide a basis for identifying periods of fixation in light of the breakthroughs that follow. Such studies might usefully focus on (or at least include) meetings between the design team and meetings between designers and other stakeholders. Such meetings have the benefit of requiring the explicit verbalization and explanation of the current design direction, making accessible to the researcher much of what might otherwise be left unspoken (e.g. see Dunbar, 1997; also see Christensen & Schunn, 2007; Wiltschnig, Christensen, & Ball, 2013). Recording what is said in these meetings along with any associated design documentation would provide the material for later analysis of the directions that design projects proceed in and the ways in which those directions change.

In addition to studies that are entirely qualitative, small qualitative components could also be included in future experimental research. For example, after an experimental intervention, researchers might present participants with initial observations or established theory. This could be used to elicit participants' responses to researchers' accounts of the fixation effects that were

observed. Additionally, participants might be presented with alternatives to the design solutions that they had proposed and their response to these alternatives might form the basis for further data collection. As described in Section 1.2 of this paper, Luchins (1942) provides an early example of how such an approach can offer additional information on the participants' understanding of the tasks they were supposed to perform and of their own performance on those tasks (also see Kim & Ryu, 2014). Adding such qualitative components to experimental work would permit a more nuanced analysis of the quantitative data, potentially permitting additional classifications of the participants or the explanation of outliers (see Nichols & Maner, 2008; Orne, 1962). Ultimately, we might most usefully take the view that for the study of creative acts, neither naturalistic nor laboratory studies are superior; both should be combined to give a more complete and robust account of the phenomena under investigation. In this way, observations from naturalistic enquiry and the results of controlled experiments can each inform the other (Dunbar, 2001, pp. 330–322; also see Levitt & List, 2007; Malterud, 2001a, 2001b).[26]

In addition to being used in the planning of future fixation studies, the analysis reported here might also assist in the development of tools and techniques to mitigate fixation in practice. Such an objective is often discussed with respect to software systems that provide designers with points of reference (for information or inspiration), such as in biomimetics and other analogical design approaches (e.g. Chakrabarti, Sarkar, Leelavathamma, & Nataraju, 2005; Deldin & Schuknecht, 2014; Shu, 2010; Vattam, Helms, & Goel, 2010). These tools and others might be better developed for and introduced to design practice by understanding how aware designers are of fixation and of the factors that encourage and discourage it. In addition, education and training activities might be developed to assist designers in actively reflecting on their previous fixation episodes. [27]This could then form the basis for designers themselves devising and implementing the processes that will best prevent such episodes from recurring.

4.2 Conclusion

Design fixation is a real problem in professional practice, one which expert designers are aware of and which they take steps to address. A broad range of personal, organisational and contextual factors influence the degree to which fixation occurs and the effects that it has on the resulting design. Perhaps most interestingly, when designers reflect on their experience of prior fixation episodes this can be the means by which fixation is effectively challenged. However, despite their awareness of the risks of fixation and the steps they take to guard against it, designers also recognise that fixation is a difficult problem to gain control of. In the creative work that is done to develop new products, commitment and persistence must be shown in the face of continued struggle and repeated

setbacks. It is thus difficult to maintain the levels of openness and flexibility that are required to challenge previously accepted ideas and to develop ideas that are both novel and valuable. To tackle this conflict it is important to gain a better understanding of the various creative behaviours exhibited in design and the barriers that block that behaviour. Such an understanding would allow us to develop the tools and techniques that effectively address fixation in the contexts in which it occurs and also better understand how such tools and techniques should be presented to those who might implement them.

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Notes

1. When researching design creativity, there is clearly a tension between the precision and rigour of controlled experimental research and the ecological validity of real-world enquiry. This is evident in the different views expressed by the board members of *The International Journal of Design Creativity and Innovation*:

   'The scientific method is demonstrably the best method for exploring and explicating any body of knowledge, including creative design. Those interested in research on design creativity must understand the most important elements of the scientific method, and insist that students and colleagues do the same. These critical elements include theoretically guided research, hypothesis testing, rigorous experimental design, clearly defined and validated measures' (Smith, 2013: p. 12).

   'Another problem is that empirical research on creativity is often conceptualized as experimental research. Most of these studies are producing singular results standing alone and are hardly mirroring the complexity of the "real world." These results do not provide further insights to nurture the development of theories or application models on creativity and innovation' (Badke-Schaub, 2013: p. 13).

   'More work needs to be done to define, develop, and demonstrate the effectiveness of novel research methods. We require approaches that can study a range of phenomena from individual cognitive mechanisms to innovation within a company. We need to be able to connect the data collected with multiple approaches ranging from highly controlled lab experiments to long-term observational studies' (Linsey, 2013: p 29).

2. Boden (1990: pp. 32–35) famously distinguishes between individuals who are psychologically creative (P-creative)—having a more or less sustained capacity to produce ideas that are new to them, and those who are historically creative (H-creative)—having arrived at one or more ideas that are new to the world. Both types of creativity are initially defined with respect to ideas, but then these ideas are used to define the people responsible for them (for the application of these ideas to design, see Dasgupta, 1994: 18; Redelinghuys, 2000: 273).
3. In psychological terms, fixation has also been defined as 'something that blocks or impedes the successful completion of types of cognitive operations, such as those involved in remembering, solving problems, and generating creative ideas' (Smith, 2003: p. 16) or 'a potentially resolvable block or impediment to reaching the goal of one's mental activity, something that blocks completion of different types of cognitive operations, including many processes and structures involved in memory, problem solving, and creative ideation' (Smith, Linsey, & Kerne, 2010: p34).
4. Duncker also describes functional fixedness in relation to the function of mathematical 'solution-elements' (Duncker, 1945: Ch. 8). This connects the idea of functional fixedness for physical things to the problem of the Einstellung effect in computer programming (e.g. Goddard, 1976) and other non-physical problem domains. As an indication of its widespread relevance, German and Barrett (2005) have demonstrated functional fixedness in a technologically sparse culture (the Shuar people of Ecuadorian Amazonia), even though that culture has comparatively few single-function objects.
5. Fixation effects had previously been considered in computer programming, when, writing of the psychological pitfalls affecting problem solving, Tracz (1979) stated that 'the mind fails to see the shortest solution for a given problem because of a fixation to one approach of solving a problem of that type' (p. 133).
6. Although a connection is often made between design fixation and functional fixedness, there is a sharp distinction: functional fixedness describes how people struggle to imagine new possible functions for a given artefact; design fixation describes how people struggle to imagine new possible artefacts for a given function.
7. Even more generally, but still with relevance to design, Von Hippel (1989) argues that fixation limits the capacity of 'typical users of existing products' when imagining other products and other needs.
8. Although fixation is typically referred to as a negative aspect of design behaviour, people apply and maintain inappropriate constraints when solving problems because those same constraints facilitate the solution of similar problems, the dissimilarities are not apparent to them, and current problem solving attempts do not reveal the imposed constraints (Isaak & Just, 1995, p. 287). As such, Smith and Linsey (2011) point out that the processes that lead to fixation are, under other circumstances, usually quite useful and adaptive: 'The unconscious cognitive system that rapidly and reflexively reacts to stimuli and situations, enabling automatic responses for highly practiced activities such as reading, driving, or recognizing familiar faces and objects, provides the means for cognitive offloading of highly repetitive responses. … But, it is precisely because this adaptive implicit cognition is so useful and unconscious that its rare inappropriate use is so difficult to diagnose and repair' (Smith & Linsey, 2011).
9. More precisely, commenting on the attachment of the turbine blades to the turbine disc (by means of the fir-tree root), French (1998) states that 'The arbitrary decision which passed unnoticed' (p. 201) was that the fixing of the blade to the disc was at a radius just slightly less than the inner end of the blade's aerofoil (which was exposed to the hot gasses from the combustion ring). This resulted in high disc temperatures which in turn required the use of dense, expensive and unreliable austenitic steels for the disc. This 'arbitrary decision' was carried over from standard practice in steam turbines and seemingly went unchecked for over decade until engineers developed the 'extended root blade', which lowered thermal transfer to the disc permitting the use of lighter and more reliable creep-resistant ferritic steel discs.

10. Genco et al. (2010) report on a design fixation experiment in which, first year (freshman) engineering students are more innovative and less fixated than their final year (senior--level) counterparts.
11. When chess players were told that the quicker solution (to check mate) that they had just found in one board configuration was also possible in another configuration in which they had only found the slower well-known 'smothered mate' solution, Bilalić and McLeod (2014: p. 77) report that the players 'were shocked. "No, it is impossible," one player exclaimed. "It is a different problem; it must be. I would have noticed such a simple solution." Clearly, the mere possibility of the smothered mate move was stubbornly masking alternative solutions.' (Sheridan and Reingold (2013: p. 6) also report on the retrospective accounts of the chess players in their experiment but this is not in response to an explanation of the Einstellung effect.)
12. In Maier's (1931) famous two-strings experiment, physical clues to the solution were often quickly followed by success but were often not identified by the participants as the reason that they solved the puzzle. In summary, Maier suggests that 'When a solution appears suddenly and completely the very factor which sets it off may be lost to consciousness' (p. 192). Similarly, Metcalfe (1986) has shown that people might be misled as to how close they are to solving problems.
13. In Lane and Jensen's (1993) experiment, one group was provided with text that said: 'Hint for Solution. Under some circumstances, people who have developed a strategy to solve a series of problems are less likely to solve a subsequent problem. The subsequent problem, presented alone, is solved very easily.' Experimental subjects receiving this hint were three times more likely to solve the easy problem than were subjects in the other experimental conditions.
14. Akin and Akin (1996) here are reporting on verbal protocol studies. Chrysikou and Weisberg (2005) also report on verbal protocols; their data is primarily quantitative but does categorise the ways in which source information is used to solve a problem, e.g. instructions or examples.
15. For example, Gero (2011) states that "In the design domain, the majority of the discussion of these [fixation] phenomena is essentially anecdotal and not based on either principled argument or the results of empirical research" (p. 108). In contrast, Cheng et al. (2014) more explicitly connect the idea of fixating stimuli (product images) to the collections of images that some designers have available to them in their workplace (and that they might collect through their practice) (also see Doboli and Umbarkar, 2014).
16. Luchins (1942) reports on the negative effects of working under time pressure, the stress that this induces and the effect of that stress on the process of problem solving. Elsewhere, there is evidence that time pressure and performance incentives might decrease participants' ability to disregard salient features of an image whilst looking for other features (Berbaum, El-Khoury, Franken, Kuehn, Meis, Dorfman, et al., 1994; Fleck, Samei, & Mitroff, 2010).
17. Luchins (1942) also reports on participants giving accounts of their reasons for failing to see the direct path in a maze task after they had been trained to solve more difficult mazes that required a crooked path: 'After a minute's examination of the maze, most subjects noticed the direct path but two had to be shown it by the experimenter. The next question addressed to all was, "Why do you think you didn't see this easy way before?" Answer: "I looked for the crooked path and used it" or "I looked to see if the crooked path was connected with the goal, and then used it"' (p. 25).
18. According to Rowe (1987), this 'blinding' refers to conditions in which obvious connections between various considerations of importance go unrecognized by a designer.
19. As with the earlier example from French (1971/1998), Cross (2011) concludes by saying that there is a danger in clinging to design ideas whilst failing to see their inadequacies: 'It could be that designers have to invest some significant cognitive effort in generating these concepts, and so are reluctant to let go of them' (p. 36).
20. Whilst these expert interviews summarise the lessons learnt over years of practice, what they don't offer is an account of actual instances of fixation. However, in Sach's qualitative study of architecture studio practice, one of the students recalls a fixation episode:

> 'I was at this point and I was using the T (the shape of the letter,) to shape my space and to ah … you know and to create other spaces. And the T stopped working for me, there was only so much that I could do with it. And I was afraid to, well since I had started with the T and I like it a lot because I liked what I had gotten so far, I wanted to hold on to it but I could see clearly that I couldn't do much more with it, ah, and so that's where I was stuck.' (Sachs, 1999: p. 201).

Although not talking of fixation effects (but of the role of feelings in creativity), Perkins (1981) provides another example account of creative struggle that hints at the type of reflections that might be collected by interview:

> 'Let me describe an odd experience I've had several times in writing. I would be vaguely dissatisfied with something I had drafted. I'd acknowledge a few problems to myself, but proceed to edit the piece without any basic revision. But the feeling of unease would intensify. I'd begin to procrastinate. Finally, I would have to rethink the situation, discard considerable work, and proceed with a new plan.' (p. 114).

21. Defazio (2008) also conducts interviews with expert engineering designers (in addition to architectural and instructional designers) with a focus on their use of precedents. He is aware of the fixation concept (e.g. pp. 2–3) but neither his interview protocol nor his interview transcripts focus on fixation (also see Demian and Fruchter, 2006: p. 190).
22. Speaking of one particular 'critical incident' that was observed, Robertson and Radcliffe (2006) say '[an] externally driven change necessitated major changes to the CAD model. However, this had an unexpected positive implication, because it provided the design team with an opportunity to re-evaluate some earlier concepts and produce an improved design. These innovations had been avoided previously due to the premature fixation of the design team' (p. 4).
23. Related to this is Davies and Talbot's (1987) report on an interview study with 35 expert designers. Davies and Talbot find that the designers were able to offer retrospective accounts that included getting stuck and recognising that: 'sometimes there was a partial or mistaken illumination followed by incubation, when the designer slept on what he was convinced was the idea only to wake up to realise that it was wrong' (p. 20).
24. For example, a more formal analysis might strive to expand and reorganise the themes to ensure that they are mutually exclusive and collectively exhaustive (Bailey, 1994; Marradi, 1990). Such work might provide a useful basis for reanalysing existing data and for designing future studies.
25. When developing morphological charts, designers decompose the overall system function into sub-functions and then identify multiple solution principles that are applicable to each sub-function. In doing so, a number of different overall concepts can be considered, each being a different combination of various solution principles (e.g. see Pahl & Beitz, 1996).
26. A rare example of combining qualitative and experimental methods within a set of fixation-related studies is offered by Hassard et al. (2009). Reporting on interviews with interaction designers, they state that 'All participants discussed how the design they created was based, either intentionally or unintentionally, on an analogous within domain example.' (p. 143), an analogy they relied upon too heavily, later modifying it extensively to fit their problem rather than searching for a fresh direction. The validity of this qualitative observation (based on *post-hoc* reflection) was then studied quantitatively through a design fixation experiment.
27. Fixation-like effects can be seen in professional practices outside design, where reflection is prescribed as a countermeasure. For example, the diagnostic practices of medics have been studied from the perspective of cognitive errors (Kassirer & Kopelman, 1989), including the effects of premature decisions, prior expectations, confirmation bias, momentum effects, framing effects and inappropriate attention to sunk costs (Croskerry, 2003). Croskerry's recommended strategies to avoid these biases include developing an awareness of the biases themselves and a metacognitive focus on how problems are being worked out (Croskerry, 2003).

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