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Considering Confirmation Bias in Design and Design Research

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Abstract Confirmation bias is an innate and pervasive human tendency to preferentially attempt to validate beliefs instead of invalidating them. However the design community, which is increasingly concerned with the cognition of designers, has largely overlooked this phenomenon. This paper discusses the relevance of confirmation bias with respect to its potential to influence designers and design researchers. The existing literature suggests that confirmation bias is present among designers and can contribute to undesirable design outcomes. Our emphasis is placed on the role of confirmation bias in fixation and the misapplication of biological analogies in design. We discuss the results of our experimental study that suggest confirmation bias may skew data evaluation in design research, contributing to deviations from scientifically accurate conclusions. We also discuss possible methods to mitigate confirmation bias.

Keywords: Cognitive bias, conceptual design, design creativity, design evaluation, design methodology

1. Introduction

As early as Sir Francis Bacon's Novum Organum, an inherent bias in human information processing has been observed. Referred to by psychologists as confirmation bias, this involves a tendency to give more weight, or attend more acutely, to information that validates hypotheses or beliefs than to similarly diagnostic and relevant information that invalidates them (Spedding *et al.*, 1863). While confirmation bias does not categorically result in poor decision-making outcomes, failing to consider decision-relevant information is certainly a deviation from normatively optimal decision-making. It is when these deviations systematically result in erroneous conclusions or perpetuate fallacious beliefs that understanding and mitigating confirmation bias is a priority.

The aim of this work is to investigate whether designers and design researchers are subject to the influence of confirmation bias. It is worthwhile for the design community to consider how confirmation bias may account for observed design biases and poor decisions among designers, and to ensure that confirmation bias does not detrimentally influence design researchers themselves. This paper begins with a review of the literature describing the effect of confirmation bias across domains, and its potential to contribute to undesirable decision outcomes. The discussion then shifts to exploring how confirmation bias could influence the design process, including its relation to known design biases. We hypothesize based on this previous literature that confirmation bias may skew data evaluation in design research, contributing to deviations from scientifically accurate conclusions. We present an experiment that aims to study whether confirmation bias has the potential to influence design research. The results suggest that confirmation bias is present in the intuitive evaluation of design hypotheses even among individuals with research experience.

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Finally, a summary is presented which discusses research conclusions and approaches to mitigate confirmation bias.

2. Confirmation Bias

The earliest empirical research on confirmation bias in modern academic journals seems to come from Peter Wason (1960; 1968), who reported a series of experiments on the subject in the 1960's. Wason demonstrated that individuals engaged in simple logic and rule-deduction tasks have an innate desire to confirm beliefs rather than disconfirm them. However, Johnson-Laird *et al.*(1970) replicated one of Wason's (1968) experiments and found that individuals were less prone to confirmatory bias when the stimuli evaluated represented a realistic relationship as opposed to an arbitrary one. While the results of Johnson-Laird *et al.* (1970) imply that confirmation bias is less prevalent in real-world decision-making, Nickerson (1998) presents a review of the literature on confirmation bias, providing evidence of its influence on cognition in several practical contexts.

2.1. The prevalence of confirmation bias

Confirmation bias has been observed to influence human judgement in seemingly every domain in which it has been studied, including: formal logic, medicine, politics, systems design, management, science, information analysis, law, and personal judgement (Burke, 2007; Cheikes *et al.*, 2004; Dunbar, 1997; Isenberg, 1988; Lehner *et al.*, 2008; Nickerson, 1998; Silverman, 1992). One possible reason for this pervasiveness is that individuals find it easier to think of information that supports their beliefs than information that refutes them (Koriat *et al.*, 1980). This explanation relates to a reliance on cognitive heuristics, specifically the availability heuristic (an overreliance on the most available information in memory when making judgements (Tversky & Kahneman, 1982). Fiske and Taylor (1984) propose that humans have an innate desire to conserve cognitive effort during cognitive processing, which leads to a reliance on cognitive heuristics to simplify information processing. Similarly, Klayman and Ha (1987) argue that confirmation bias provides a framework which makes searching for decision-relevant information more efficient than a random search.

Other researchers theorize that confirmation bias may reflect a pragmatic decision-making approach that serves to minimize errors in real-world tasks (Friedrich, 1993). In this sense, confirmatory test strategies may have arisen due to their benefit to fitness from an evolutionary perspective, a theory that Cosmides (1989) suggests explains individuals' enhanced performance on these tasks when they can be perceived as social contracts. Therefore, confirmation bias may be inherent in the way human beings process information, without being limited to any specific information-processing task or domain. While some researchers argue that confirmation bias is adaptive in real-world decision-making tasks, there has been significant research demonstrating that it can also lead to objectively poor decisions and outcomes in a host of real-world and experimental tasks.

2.2. The influence of confirmation bias

Nickerson (1998) reports that confirmation bias can lead individuals to: fail to use disconfirming evidence to adjust their beliefs, accept confirming evidence too easily, misinterpret disconfirming evidence, and improperly assess the diagnostic weight of evidence. Logically, when these tendencies result in erroneous conclusions, confirmation bias has a negative influence. However, as previously mentioned, these tendencies may be part of pragmatic and adaptable decision-making strategies (Friedrich, 1993). Therefore, the influence of confirmation bias is best characterized in relation to the goals of the decision-maker (e.g., efficiency, accuracy, practicality, error minimization). One way to define this influence may be through the use of decision models that quantify the costs and benefits associated with decision outcomes (e.g., expected utility theory (Bernoulli, 1738), signal detection theory (Green & Swets, 1966)). However, it is often difficult or impractical to accurately define these costs and benefits. In addition, proponents of descriptive decision-making models argue that individuals often deviate from normative or rational models while still arriving at "good" decisions. For example, Katsikopoulos (2012) discusses the value of both rational and heuristic decision models in engineering design, i.e., multi-attribute theory and the Pugh process, respectively.

Another approach is to consider how confirmation bias contributes to undesirable outcomes from a worst-case scenario perspective. For example, confirmation bias may result in physicians inaccurately diagnosing patients' symptoms (Krems & Zierer, 1994; Pines, 2006), information analysts inaccurately weighting information in accident analyses (Cheikes, *et al.*, 2004), and prosecutors failing to consider alternative suspects (Burke, 2007). These types of cases all suggest that it is worthwhile to consider and mitigate the influence of confirmation bias, at least as a pre-emptive measure, when the results of individuals' decisions have serious implications.

2.3. Confirmation bias in design

Given the universal nature of confirmation bias, and that decision-making is a key component of the design process (Gero, 1990) it seems logical that design cognition is also subject to confirmation bias. However, there has been little previous research specifically examining this phenomenon in design.

Silverman and Mezher (1992) argue that confirmation bias contributes to misconceptions held by designers and contribute to human error in the evaluation of systems design. They suggest that under time constraints, confirmation bias could lead individuals to overly rely on evidence that confirms designs are complete and error free. In addition, they argue that a design case from NASA (Silverman, 1985) reveals confirmation bias has contributed to errors in spacecraft system design. In other research, Silverman (1992) found that a design critic embedded within CAD software could effectively mitigate confirmation bias while enhancing the speed and accuracy of participant performance. Silverman's research suggests that confirmation bias (as well as other cognitive heuristics and biases) can lead to errors in information acquisition or processing during systems design, but also offers possible methods to mitigate it.

In related research, Busby (1999) examined factors that contribute to obstacles to design reuse in mechanical design. He suggests that differences of opinion between designers and design clients present opportunities for confirmation bias that lead designers to not respond to feedback incongruent with their own beliefs. This has the potential to result in failures to reapply successful design solutions when the designer wishes to adopt an alternative approach. This behaviour could be interpreted to suggest that confirmation bias contributes to failures to adopt feasible and appropriate design strategies.

Otto and Wood (1999) address the possibility of designer bias when sorting customer needs statements into an affinity diagram, and develop a method to understand and represent design function with decreased bias. Maxwell *et al.* (2002) identify cognitive distortion and learned biases as human contributions to complexity in design. Yan and Zeng (2011) identify cognitive conflicts as those that involve "relations among different designers in the context of collaborative design and concurrent engineering." Nguyen and Zeng (2012) consider designer cognitive states and resources in identifying an inverse U shaped relationship between designer's mental stress and design creativity. Using similar methods, Aurup and Akgunduz (2012) aim to reduce the effect of participant bias in the elicitation of user preferences through bio-signals. Luh *et al.* (2012) include consumers' cognitive structures in developing an empathic design method for customer-centred products.

Our past research suggests that engineering students exhibit a confirmatory bias when referencing their own design ideas. Specifically, Hallihan *et al.* (2012) presents two studies that examined the role of confirmation bias. The results of the first study, a protocol analysis involving novice designers engaged in a biomimetic design task, indicate that confirmation bias is present during concept generation and offer additional insights into the influence of confirmation bias in design. The results of the second study, a controlled experiment requiring participants to complete a concept evaluation task, suggest that decision matrices are effective tools to reduce confirmation bias during concept evaluation.

In the observational study, 30 engineering students from a 4th-year design course were split into 9 groups of 3-4 students to work on a biomimetic design problem. Group discussions were recorded and transcribed to generate verbal protocols, which were then qualitatively coded (Cheong *et al.*, 2012; Hallihan, *et al.*, 2012). The authors found that the students were more likely to make statements that confirmed their beliefs than to make ones that disconfirmed them (i.e., of 107 statements from 9 groups, 83% were coded as confirmatory, while only 17% were coded as disconfirmatory [SD = 12.1%]). The results indicate that individuals engaged in a design task are more likely to consider why their concepts are appropriate than why they are not. A possible result of this, supported by other design research, is that designers may fail to see the shortcomings of their own solutions (Silverman & Mezher, 1992) or will fail to attend to the feedback of others (Busby, 1999).

In addition to research directly examining confirmation bias in design, there has been recent research examining other cognitive heuristics and biases. For example, Foster (2012) suggests that reliance on the availability heuristic during failure mode and effects analysis leads designers to over report the probability of the most recent failure mode. Shu *et al.* (Hallihan & Shu, 2011; Shu, 2012) hypothesized that a reliance on the availability heuristic could contribute to the misapplication of biological analogies in biomimetic design and contribute to design fixation. The relevance of this, as previously identified, is that confirmation bias may be a product of the availability heuristic. Individuals that rely on the availability heuristic in the evaluation of design beliefs may also be prone to exhibiting confirmatory bias.

Viswanathan and Linsey (2011) argue that sunk-cost bias may contribute to fixation during physical prototyping. Sunk-cost bias refers to a tendency to maintain a course of action due to previous investment (e.g., money, action, time, etc.) despite the fact that the prior investment should no longer logically be influencing the decision (Arkes & Blumer, 1985). This work is especially relevant as it supports the argument that cognitive biases can contribute to known design biases (i.e., design fixation) in conceptual design. Hallihan, *et al.* (2012) have also suggested that a host of cognitive heuristics and biases likely influence designers and may contribute to biased design cognition. The following sections explore the possible relationship between confirmation bias and known design biases in more detail.

2.4. Confirmation bias and design fixation

Design fixation has the potential to restrict diversity in the concept generation process even among experienced designers (Linsey *et al.*, 2010) warranting further exploration of the underlying cognition. Cardoso and Badke-Schaub (2011) describe three causes/types of fixation in design, 1) the inappropriate reuse of previously seen features or principles, 2) the adherence to a constant frame of thought (referred to here as strategy adherence, and 3) the inability to retrieve prior knowledge from memory. Our discussion focuses on confirmation bias and strategy adherence.

Confirmation bias will lead individuals to integrate information in a way congruent with their existing beliefs. This is supported by research indicating that confirmation bias can lead designers to over rely on information that supports their designs are error free (Silverman & Mezher, 1992), fail to accurately consider belief-inconsistent perspectives (Busby, 1999), and fail to realize biological analogies are being applied improperly during biomimetic design (Hallihan, *et al.*, 2012).

Previous observational reports suggest that confirming beliefs may also prevent designers from attending to group feedback and contribute to overconfidence in design solutions (Hallihan, *et al.*, 2012). Interestingly, Jermias (2006) reports that overconfidence and a preference for confirmatory information contribute to a resistance to change commitment to strategies. Overconfidence may also contribute to, and be a product of, confirmation bias (Nickerson, 1998). Therefore, confirmation bias and confidence may create a positive feedback cycle, enhancing designers' resistance towards belief-inconsistent information.

Confirmation bias likely contributes to design fixation by inhibiting designers' ability to consider or accurately weight information that would prompt strategy change. The logic is that a designer has no motivation to abandon a strategy if they are not presented with, or attentive to, evidence that adopting a new strategy would better serve their goals. Certain design strategies may not be consciously accessible to the designer, for example Jansson and Smith (1991) demonstrate that designers may not be aware of the source they are fixated on. However, other more explicit design considerations, such as how the physical structure of a biological entity is analogous to a design feature, may be more representative of the types of decisions influenced by confirmation bias. However, further research is required to determine whether confirmatory tendencies are statistically more likely to contribute to fixation on design strategies.

2.5. Confirmation bias in biomimetic design

After a decade of research in biomimetic design, Shu (2012) reports that engineering students engaged in the application of specific provided biological analogies tend to:

(1). Fixate on particular words and phrases in text descriptions of biological phenomena that do not represent the overall biological analogy, with words familiar to engineers being the most likely cause of fixation.

(2). Develop the same concept multiple times in response to different biological analogies intended to elicit different solutions.

(3). Match provided analogies with existing (and sometimes widely known) solutions, rather than develop new solutions from the given analogy.

Similarly, Shu (2012) observes that students given access to a keyword search tool, developed to help identify relevant analogies from a natural-language corpus, have a tendency to:

(1). Select already familiar phenomena for application, as opposed to new or unfamiliar phenomena.

(2). Develop solutions that pre-exist the biological analogies that are claimed to inspire them.

Hallihan and Shu (2011) propose that in both these types of biomimetic design tasks, the biased detection and application of analogies is a result of pre-existing mental models. These effects are framed in terms of a reliance on cognitive heuristics, such as the availability heuristic.

However, in a protocol analysis by Hallihan, *et al.* (2012), similar behaviours were observed to be perpetuated by confirmatory strategies (i.e., searching for ways in which selected solutions were similar to the source analogue and failing to consider differences). For instance, in the 107 design statements identified (84 confirmatory and 23 disconfirmatory) 26 confirmatory cases were labelled as attempts to verify how design solutions were similar to the biological phenomenon, and only two cases were identified where designers considered how their solutions were different from the biological phenomenon. This tendency is not correlated with specific performance outcomes in biomimetic design, but suggests that designers are more likely to try to find how their solutions are analogous than how they are not. This tendency could contribute to fixation, as discussed, and the perseverance of solutions that misapply analogies or are overly influenced by existing engineering knowledge.

2.6. Section conclusion

At this point, the prevalence of confirmation bias in design, as well as its potential to contribute to counterproductive design behaviour (i.e., failures to consider design-relevant feedback, overlooking design errors, overconfidence, design fixation, the misapplication of biological analogies) seems supported by a limited amount of research. However, further research is required to demonstrate whether confirmation bias has the potential to definitively contribute to negative design outcomes. Another concern worthy of additional research is the influence of confirmation bias on those who study design; the following section explores this possibility.

3. Confirmation Bias in Design Research

Much of the literature on confirmation bias discusses its contribution to deviations from scientific hypothesis testing, however debate surrounding the issue remains. For example, Wickens and Hollands (2000) argue that confirmation bias during the evaluation of well-defined hypotheses may lead to cognitive tunneling, in which individuals fail to encode or process hypothesis-inconsistent information. However, Klayman and Ha (1987) argue that positive test strategies, often mislabeled as confirmation bias, are actually adaptive for determining the truth or falsity of a hypothesis. Therefore, the purpose of this research is to explore how confirmation bias influences hypothesis evaluation in design research.

In an experiment by Hallihan, *et al.* (2012), a group of graduate students were asked to evaluate the hypothesis that designers fixate on example solutions for design problems they are solving. The participants were asked to evaluate the validity of the fixation-on-examples hypothesis using design concepts as a data set. This experiment was originally intended to examine the effectiveness of decision matrices in mitigating confirmation bias in a concept evaluation task. However, it is revisited to examine how confirmation bias influences individuals engaged in the analysis of design research data and hypothesis evaluation. The results suggest that confirmation bias may skew individuals' acquisition or interpretation of research data, however many participants still form reasonable conclusions regarding the hypothesis.

3.1. Participants

Sixteen graduate students (2 female, 14 male) from the University of Toronto participated in the study. Participants were recruited from a University of Toronto graduate residence and the department of Mechanical and Industrial Engineering. The sample consisted of students from various faculties, with Law and Engineering constituting a majority (see Table 1). We believe that the concepts were simple enough that participants did not require extensive engineering knowledge. All the participants were graduate students with experience conducting academic research.

Table 1. Participant demographic information

Participant No.	Age	Faculty	Gender
1	25	Zoology	Female
2	25	Genetics	Male
3	25	Sociology	Male
4	25	Medicine	Male
5	23	Law	Male
6	27	Law	Male
7	28	Law	Male
8	25	Law	Male
9	27	Engineering	Male
10	31	Engineering	Male
11	27	Engineering	Male
12	25	Engineering	Male
13	25	Engineering	Male
14	25	English	Female
15	26	Law	Male
16	25	Engineering	Male

3.2. Procedure

Participants were provided with the following background information and instructions:

> There has been a significant amount of research demonstrating that designers often become fixated by examples of successful design solutions. The research indicates that when designers see an example solution for a design problem they are working on, they often incorporate elements of that example into their own design solutions. This effect has been observed even when designers are instructed not to fixate on examples, and even among experienced designers.
>
> An experiment was run to test the hypothesis that designers fixate on examples. The design problem and example solution given to participants can be seen at the bottom of the page. Six participants generated solutions for the problem; their concepts can be seen on the next page. Your job is to look at the results of the experiment (the participant concepts) to evaluate the validity of the fixation hypothesis, stated as: "The presence of an example solution causes designers to fixate and incorporate elements of the example into their own solutions".

The design problem involved generating an automated watering system for a houseplant; the problem and example solution are from Perttula and Liikkanen (2006). The six design concepts shown to participants were solutions for the automated watering system problem (see Fig. 1). Participants were provided with brief functional descriptions for each concept and the example. The participants were told the six concepts had been generated by individuals from a previous study who had been exposed to the example solution. Two of the concepts (1 and 3) were developed by the lead author to ensure they incorporated multiple elements of the example solution. The others (2,4,5,6) were from a previous design-fixation experiment (Hallihan & Shu, 2011) and were scored by independent raters as relatively low in fixation on the example solution. This was done to establish the ratio of "evidence" available for evaluation as roughly 66% disconfirmatory and 33% confirmatory. The participants' task approximates evaluating a design research hypothesis using realistic research data.

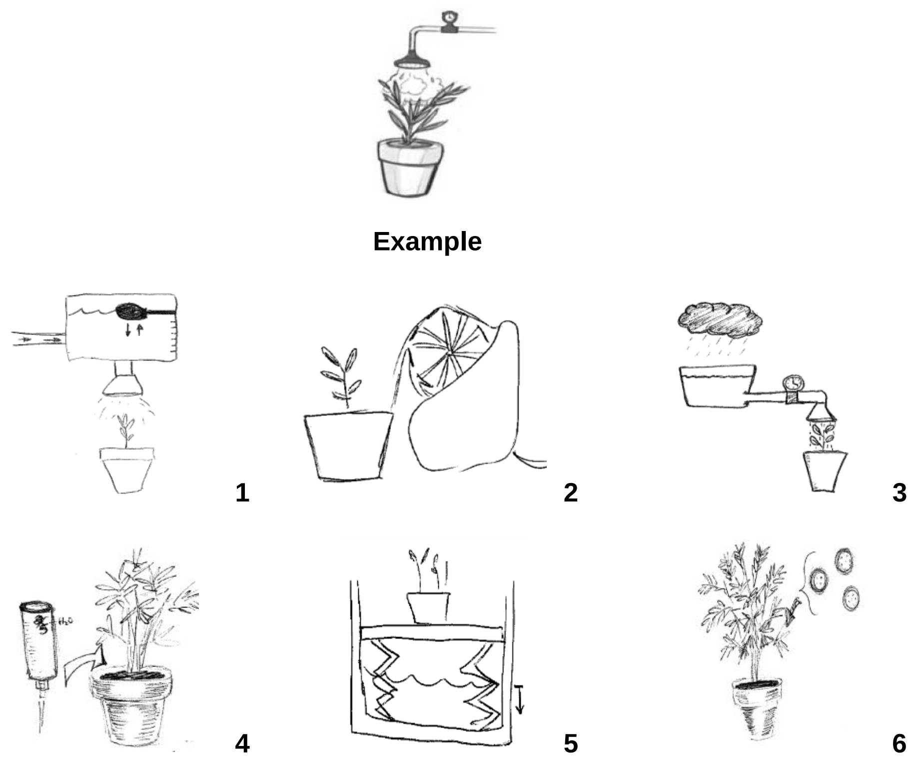

Fig. 1. Evaluation concepts 1-6 (Hallihan et al., 2011) and example concept (Perttula and Liikkanen, 2006). Functional descriptions not shown in figure.

Participants were told that the average completion time for this task was 15 minutes, but that they would have as much time as they wanted to reach an optimal conclusion. Their performance was timed to examine the influence of time spent evaluating. Timing began once participants read and indicated they understood the instructional materials and began problem solving. After participants completed the evaluation, they were asked what their conclusion regarding the hypothesis was.

3.2.1. Experimental conditions

Participants were evenly divided into two groups; the *matrix group* was provided with instructions to use a formal decision matrix to evaluate the experimental data relative to the hypothesis, the *intuition group* received no formal instructions. The instructions given to the matrix group were adapted from the *Analysis of Competing Hypotheses* (ACH) methodology. ACH was developed by Heuer (1999) as a decision-making tool to improve the forecasting accuracy of information analysts. The 8-step method directs analysts to create a matrix that facilitates the comparison of alternative hypotheses and the evaluation of the relevance and diagnostic value of available evidence. It has been demonstrated to reduce reliance on cognitive biases, including confirmation bias, in complex decision-making tasks (Brasfield, 2009). Participants in the intuition group were not given any specific evaluation directions and were only instructed to record considerations relevant to their evaluation as point form notes on a blank sheet of paper. Participants in the matrix group recorded relevant considerations within the matrix itself.

3.3. Coding confirmation and disconfirmation

Participants' self-generated records were analysed to determine the ratio of confirmatory to disconfirmatory evidence they identified and evaluated. A note indicating the consideration of evidence, or argument for, confirming the fixation hypothesis was counted as one instance of confirmatory evidence. Similar documentation that did not support the fixation hypothesis was counted as one instance of disconfirmatory evidence (Figs. 2 and 3 show examples of coded data, matrix and intuition, respectively).

Degree of Fixation	Features of Design From Example	Features of Design from Outside Sources
Concept 1 High Fixation	- Overhead release of water(C) - Fed by water line(C) - Sprinkler head(C) - Periodic release at intervals (requiring timer)(C) - Valve of some kind(C)	- Ball float valve(D)
Concept 2 Medium Fixation	- Fed by water line(C) - Overhead release of water(C)	- Water wheel release(D) - Continual release of water at fixed tempo (no timer required)(D)
Concept 3 High Fixation	- Overhead release of water(C) - Sprinkler head(C) - Fed by water line(C) - Periodic release at timed intervals (requiring timer)(C)	- Natural cloud source / fed by rainwater(D)
Concept 4 Low Fixation	- ? [sic]	- Dripper release(D) - Continual water release at natural tempo(D) - Soil fed stream(D) - No water line(D) - No timer required(D)
Concept 5 Low Fixation	- Timer required(C) (based on functional description)	- External movement brings plant to water (instead of bringing water to plant)(D) - Hydraulic lift required(D) - No flow of water stream(D) - Higher relative energy required(D)
Concept 6 Low Fixation	- ? [sic]	- No water stream(D) - No timer required(D) - No external movement(D) - Sponge fed(D) - Soil fed hydration(D)

Fig. 2. Coded participant matrix: 12 confirming(C) and 18 disconfirming(D) instances.

Top Left: incorporates water line^(C)^ and a similar looking sprinkler head^(C)^
Top Middle: incorporates a house water line^(C)^
Top Right: incorporates many elements^(C)^, except the water line^(D)^
Bottom Left: seems to incorporate no elements^(D)^
Bottom Middle: incorporates predetermined intervals^(C)^
Bottom Right: seems to incorporate no elements^(D)^

Fig. 3. Coded participant notes: 5 confirming(C) and 3 disconfirming(D) instances.

3.4. Results

Three participants exhibited behaviour that was believed would confound the comparison between the experimental groups. Participant 7 was assigned to the matrix group but failed to follow the directions provided and instead relied on intuition. Participants 6 and 12 were assigned to the intuition group, however they utilized matrices to formalize their decision process in a way that simulated the treatment condition. Therefore, these participants were evaluated in the group that more accurately reflected their decision-making procedure, resulting in two groups (Matrix:No-Matrix). Table 2 shows the data collected.

Table 2. Conditions, data, and participant conclusions

Participant No.	Matrix	Confirm	Disconfirm	Proportion (%) (Confirm – Disconfirm)	Time (min)	Conclusion
1	Yes	8	10	44.4 - 55.6	15.7	Conditional
2	No	4	4	50.0 - 50.0	6.3	Conditional
3	Yes	7	8	46.7 - 53.3	14.4	Conditional
4	No	3	1	75.0 - 25.0	6.8	True
5	Yes	9	9	50.0 - 50.0	20.2	Conditional
6	Yes	12	18	40.0 - 60.0	20.5	False
7	No	1	2	33.3 - 66.7	9.7	Inconclusive
8	Yes	4	1	80.0 - 20.0	10.2	True
9	Yes	11	16	40.7 - 59.3	35.9	Inconclusive
10	No	8	6	57.1 - 42.9	19.3	True
11	Yes	5	11	31.3 - 68.8	17.9	False
12	Yes	6	18	25.0 - 75.0	22.8	Inconclusive
13	No	5	3	62.5 – 37.5	11.8	False
14	No	7	11	38.9 – 61.1	11.6	False
15	No	4	2	66.7 – 33.3	5.3	Inconclusive
16	No	2	3	40.0 – 60.0	15.2	True

3.4.1. Comparisons to ideal

Two single samples t-tests were used to compare the proportion of evidence evaluated in the matrix group and the no-matrix group to a hypothetical ideal group. Based on the concepts provided (see Fig. 1 and Sec. 3.2) the ideal proportion of evidence available was believed to be 33.3% confirmatory and 66.7% disconfirmatory. Because the proportion of disconfirmatory cases for both groups is calculated by dividing the number of disconfirmatory cases by the total number of cases, once this proportion is known, the confirmatory instance is not free to vary, therefore only one t-test per group is required. The single sample t-tests compared the proportion of disconfirmatory evidence evaluated in the matrix group, and the no-matrix group, to an ideal population mean (M = 66.7%) (see Fig. 4).

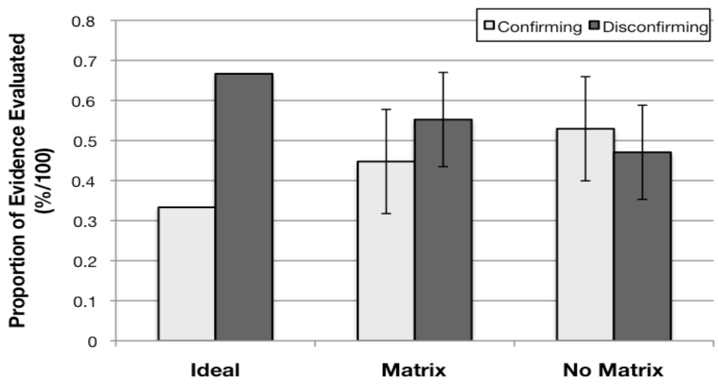

Fig. 4. Proportions of confirming and disconfirming instances evaluated between matrix and no matrix conditions relative to hypothetical ideal (error bars: 95% CI).

The matrix group did not significantly underestimate the proportion of disconfirming evidence (M = 0.55, SD = 0.16) relative to the ideal, t(7) = 1.971, p = 0.089. However, the no-matrix group significantly underestimated the proportion of disconfirming evidence (M = 0.47, SD =0.15) relative to the ideal t(7) = 3.73, p = 0.007. The inverse is necessarily true when considering the proportion of confirmatory cases evaluated (i.e., the matrix group did not significantly over-report the proportion of confirmatory cases, the no-matrix group did). However, there was no statistically significant difference in the proportion of evidence evaluated between the matrix and no-matrix groups. If the matrix and no-matrix groups are combined into a single group, the proportion of disconfirmatory evidence evaluated overall (M = 0.51, SD = 0.16) is significantly lower than the ideal proportion t(15) = 3.96, p = 0.001.

3.4.2. Effect of time

Hallihan, *et al.* (2012) noted a strong and statistically significant correlation between the amount of time participants spent solving the problem and the quantity of evidence evaluated: confirmatory (r = 0.72, p < 0.01), disconfirmatory (r = 0.76, p < 0.01). Additional analyses revealed a moderate correlation between the proportion of evidence evaluated and the amount of time spent on task: disconfirmatory (r = 0.49), confirmatory (r = -0.49) t(14) = 2.1, p = 0.054 (see Fig. 5). There were no significant correlations between time and the proportion of evidence evaluated when examining the groups separately.

3.4.3. Participant conclusions

Participants were asked to provide a final conclusion regarding the fixation-on-examples hypothesis. Conclusions fell into one of four categories (see Table 3):

(1). True – the data indicate the hypothesis is true
(2). Conditional – the data indicate that the hypothesis is true sometimes
(3). Inconclusive – there is not enough data to support or reject the hypothesis
(4). False – the hypothesis is not supported by the data

The sample size is too small to make meaningful statistical comparisons between participant conclusions and other variables (e.g., condition or time spent evaluating). However, certain trends stand out and may make for interesting future research. Three of the four participants who concluded the hypothesis was true were from the no-matrix condition; this group also spent the least time evaluating the hypothesis and evaluated the most confirmatory information. The inconclusive group spent the most time evaluating, however the average may be over inflated by participant 9 (35.9 minutes); there is substantially more variance in the time spent evaluating in this group than the others.

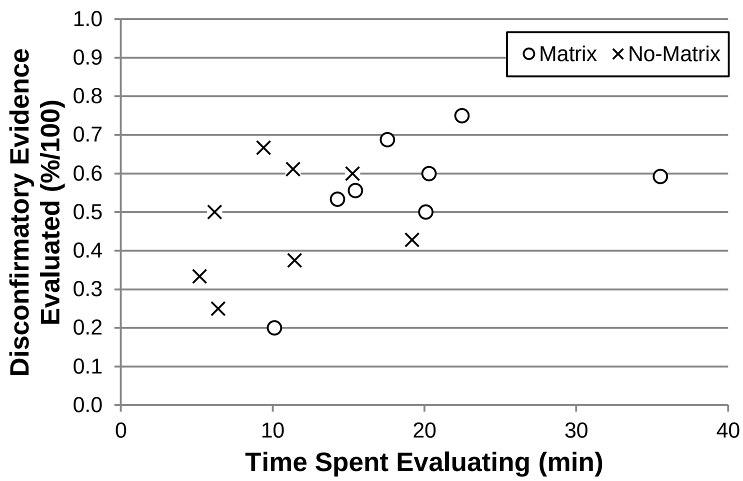

Fig. 5. Correlation between the proportion of disconfirmatory evidence evaluated and the amount of time spent on the evaluation task (r = 0.49).

Table 3. Participant conclusions, average time spent evaluating, ratio of confirmatory to disconfirmatory evidence evaluated, and number of participants in the matrix condition

	True	Conditional	Inconclusive	False
Participant No.	4,8,10,16	1,2,3,5	7,9,12,15	6,11,13,14
Average Time (min)	12.74	13.99	18.15	15.16
(SD)	(5.62)	(5.79)	(13.74)	(4.49)
Average Con/Dis (%)	63.0/37.0	47.8/52.2	41.4/58.6	43.2/56.8
(SD)	(18.2)	(2.7)	(18.0)	(13.5)
Matrix	1/4	3/4	2/4	2/4

3.5. Discussion

3.5.1. Interpreting participant evaluations

The comparison of the proportion of evidence evaluated suggests that individuals evaluating without the decision-matrix deviated significantly from the ideal ratio of confirmatory to disconfirmatory evidence. However, individuals in the matrix condition did not. In addition, the trends visible in Fig. 4 suggest that the matrix group was more similar in their evaluation to the ideal than the no matrix group. The caveat is that there was no statistically significant difference in the proportion of evidence evaluated between the two groups. Therefore, these groups could be combined to examine the overall comparison of participant evaluations to the ideal, in which case the total group significantly under-represented the proportion of disconfirmatory data and over-represented the proportion of confirmatory data.

This task required individuals to evaluate participant generated concepts in order to evaluate the validity of a design hypothesis, a method that directly generalizes to design experiments involving the evaluation of participant generated design concepts. In addition, the sample used in this study was entirely composed of graduate students, a representative sample given that graduate research assistants often conduct the data acquisition and coding process in academic research. Even though the participants were only briefly exposed to literature on design fixation, and had no vested interest in validating the hypothesis, they still over-represented the proportion of confirmatory information relative to the hypothetical ideal. These results suggest that design researchers should take care to avoid the overrepresentation of data that confirms hypotheses.

3.5.2. Interpreting participant conclusions

Although participants may have exhibited a confirmatory bias in acquiring or reporting data for evaluation, the influence of this bias on their final conclusions with regard to the hypothesis varied. The participants were generally sensitive to the fact that fixation may have occurred in some concepts and not others. Given that a phenomenon does not have to manifest in every possible instance to prove its existence (e.g., the fact that only a small proportion of individuals are schizophrenic does not mean that schizophrenia does not exist), participants who concluded the hypothesis was conditionally true or inconclusive arguably reached valid conclusions. However, these groups differed in how they responded to the presence of confirming and disconfirming evidence. The conditionally true group concluded that the hypothesis was true in some cases because there were some confirmatory data; the inconclusive group determined that in the presence of both confirmatory and disconfirmatory data, a firm conclusion could not be drawn. While the conclusions seem similar, the conditionally true group interpreted the results in order to validate the hypothesis, suggesting confirmation bias influenced their conclusions. In addition, 25% of individuals concluded that the fixation-on-examples hypothesis was well supported by the data, even when the majority of concepts provided showed very little evidence of fixation. Therefore, a confirmatory bias seems present in the conclusions of half of the participants in this study.

Of the four participants who concluded the hypothesis was true, 3 performed the evaluation without the matrix (see Table 3). The conclusions of participants 4, 8 and 10 seem logical considering they identified a greater proportion of confirmatory evidence than disconfirmatory. However, participants 16 identified a higher proportion of disconfirmatory evidence than confirmatory. This seemingly contradictory conclusion may be a result of failing to properly evaluate the diagnostic value of contradictory evidence with respect to the hypothesis, an effect observed in other information analysis tasks (Cheikes, *et al.*, 2004) and a known consequence of confirmation bias (Nickerson, 1998). Of the participants who concluded the hypothesis was false, two were in the matrix group and two were in the no matrix group. Although participant 13 identified more confirmatory evidence than disconfirmatory, all of these participants stated the hypothesis was only valid if it was always true.

3.5.3. Empirical limitations

These conclusions are based on the assumption that an unbiased or ideal evaluator would determine that the ratio of disconfirming to confirming evidence available from the six concepts was 2:1. This ratio is based on an evaluation of the six concepts along four functional elements identified by Perttula and Liikkanen (2006) in rating fixation on the example concept: 1) water source, 2) regulation of flow, 3) water transfer, and 4) energy source. The four disconfirmatory concepts were independently rated as the least fixated on the example solution out of 123 concepts from a previous fixation experiment (Hallihan & Shu, 2011). The two confirmatory concepts were designed by the lead author and incorporated three out of four functional elements of the example, and had high aesthetic similarity.

Another limitation is the relatively small sample size. Increasing the sample size would likely lead to decreased error variance and if the sample means are representative, both conditions would likely significantly deviate from the ideal. However, this decrease in variance or increase in power would also likely support the conclusion that the matrix group performed significantly better than the no matrix group. These possibilities, as well as the trends observed here, offer areas for future research with larger samples.

Finally, several participants (6, 12, 7) were included in groups for analysis that they were not originally assigned to. One option would have been to exclude these individuals from the analysis completely; if this were done the same trends are observed, the matrix group's deviation from the mean ($M = 0.15$, $SD = 0.17$) approaches significance $t(5) = 2.3$, $p = 0.07$, and the no matrix group's deviation ($M = 0.22$, $SD = 0.14$) becomes "less" significant $t(6) = 4.38$, $p = 0.005$.

3.5.4. Effect of the matrix

The analysis does not demonstrate that the use of formal decision matrices significantly improved the performance of the matrix group in direct relation to the no matrix group. This observation is consistent with research from Cheikes, *et al.* (2004) involving the use of the ACH procedure with individuals performing an accident analysis task. However, Brasfield (2009) observed that the ACH procedure did mitigate confirmation bias in participants engaged in a political analysis task. In addition, we (Hallihan, *et al.*, 2012) previously suggested that the use of the matrix facilitated an increased time spent on task, accounting for a significant difference in the amount of data evaluated between groups.

At this point it is difficult to explicitly state whether formal decision matrices (specifically those resembling the analysis of competing hypotheses procedure) mitigate confirmation bias in information analysis. Perhaps one benefit of this procedure is that it encourages individuals to actively consider multiple hypotheses. In this way, it may make disconfirming cases or instances more salient and available, as that information may be perceived as "confirming" one of the identified alternate hypotheses. This would be congruent with other research suggesting that priming individuals to think counterfactually reduces confirmation bias (Galinsky & Moskowitz, 2000).

4. Conclusion

In this paper, it is argued that confirmation bias is a pervasive phenomenon in human information processing with the potential to influence the judgements of designers and design researchers. In some instances, the influence of confirmation bias has the potential to result in erroneous conclusions or undesirable decision outcomes. In the design process these outcomes may be a result of failing to see the shortcomings of design solutions. These failures may be perpetuated through the interaction of confirmation bias with other known design biases such as fixation or the misapplication of biological analogies, as well as failing to respond to design feedback and overconfidence.

We have also argued that confirmation bias has the potential to influence design researchers. In the experiment presented, it was argued that individuals have a tendency to over-represent evidence that confirms research hypotheses and under-represent information that disconfirms them. However, this did not directly translate into erroneous conclusions regarding the hypothesis. Further research is needed to tease apart the relationship between the quantity of evidence evaluated and actual conclusions. One confounding factor is the diagnostic weight individuals assign to evidence in the formation of conclusions. This too may be influenced by confirmation bias (Cheikes, *et al.*, 2004) but is unaccounted for in the present research. Even if participants identified more confirmatory information than disconfirmatory, how diagnostic that information is perceived to be with respect to the hypothesis likely had bearing on their final conclusions.

4.1. Mitigating confirmation bias

The value of using formal decision matrices to mitigate confirmation bias is not clear. While this research does not indicate they improve performance relative to intuition, there has been research to suggest otherwise. In addition, a significant and positive correlation between the amount of disconfirmatory evidence and time spent on the task was observed; the matrix group spent significantly more time evaluating than the no matrix group. Therefore, spending more time on the task may have been facilitated by relying on the matrix procedure, which in turn led participants to identify more disconfirmatory data relative to confirmatory, reflecting a closer to optimal evaluation.

Decision matrices may also reduce reliance on confirmation bias in another way. Jonas *et al.* (2001) found that when individuals evaluate information sequentially, they exhibit a stronger confirmation bias than when they evaluate information simultaneously. The researchers suggest that sequential information processing induces a focus on prior decisions, increasing commitment to them. Interestingly, in the ACH procedure and the instructions given to participants in this experiment, individuals list all the relevant information they can identify and then consider the diagnostic value of each piece of evidence relevant to alternate conclusions. In this way, these procedures facilitate simultaneous information processing.

Another method to mitigate confirmation bias involves educating and training individuals. Nisbett and Ross (1980) suggest that educating individuals about the nature of cognitive biases, and enhancing their awareness of the processes underlying them, is an effective approach to mitigate biased cognition generally. However, simply making individuals aware of the bias itself does not seem to be an effective method to mitigate it (Burke, 2006).

In addition, it is possible that increased accountability and negative feedback could mitigate confirmation bias. Negative feedback and increased accountability have been shown to decrease overconfidence and strategy adherence (Arkes *et al.*, 1987; Jermias, 2006) and as a result may similarly reduce confirmation bias. Accountability and negative feedback may be incorporated as part of the peer review process for design researchers, as well as into the design process. Silverman (1992) explores the use of a critic embedded within CAD software to mitigate human error in the design process, and methods such as this may be valuable if they could be effectively applied to encourage designers to think critically of their own ideas. Similarly, this process may also prime individuals to think counterfactually, which can also reduce confirmation bias (Galinsky & Moskowitz, 2000). However, Silverman (1992) suggests that shifting to a disconfirmatory strategy did not account for the effectiveness of the critique method he examined.

4.2. Publication bias

We may be resistant to the idea that confirmation bias influences the academic community, however evidence of publication bias (i.e., the over-representation of positive results in academic literature) indicates a preference for confirmatory information does exist (e.g., see Easterbrook *et al.*, 1991). Dickersin (1990) suggests this bias results from investigators', reviewers', and editors' preference to submit or accept papers based on the strength and direction of their findings. In design, this could manifest as an over-representation of studies that have been shown to prove the efficacy of interventions relative to studies that have found null effects for the same intervention. Or consider the over-emphasis of anecdotal reports regarding biological analogies as stimuli to inspire insight. Anecdotal examples are often cited to describe the instances when the serendipitous observation of a natural phenomenon inspired a solution for a design problem. However, those cases in which a relevant analogy was observed and failed to inspire insight fall by the wayside. Failing to consider when methods are ineffective may make a comparison between alternate methods less meaningful.

4.3. Summary

Future research is needed to more precisely characterize the influence of confirmation across a range of design processes. However, at this point it seems that confirmation bias has the potential to negatively influence design judgements and contribute to known design biases. Further research examining various methods to mitigate confirmation bias (e.g., formal decision tools, education and training, critical feedback and accountability) could provide valuable insights to enhance information processing in design and design research.

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