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How designers think creatively: an exploratory study in the use of visual and emotional mental imagery

Ian Marcus Edgecomb ✉, Ross Brisco and Andrew Wodehouse

University of Strathclyde, United Kingdom

✉ ian.edgecomb@strath.ac.uk

Abstract

Mental Imagery is a focus for design cognition research, with most research focusing on visual mental imagery, it has been highlighted that mental imagery encompasses more aspects than visual, including emotion known as multimodal mental imagery. So as researchers and educators we need to understand the cognitive process and how to best stimulate it. This paper looks at design students use of visual and emotional mental imagery and its impact on their ability to produce creative outcomes during the ideation stage of the design process.

Keywords: design cognition, product development, conceptual design

1. Introduction

When designers ideate and conceptualise, what are the cognitive processes that are involved? Research has revealed one of these cognitive processes as mental imagery (Goldschmidt, 1991; Hay et al 2017, Hart and Hay, 2022; Kavakli and Gero, 2001). Within engineering design research, there is a lack of consensus to define mental imagery. From the works of Kavakli and Gero (2001), Athavankar (1997), and Goldschmidt (1991) mental imagery can be defined as pictorial like objects in the mind recalled from memory which are transformed and manipulated to create the desired outcome.

Research by Vellera and Gavard-peret (2016) highlights that mental imagery is a factor that influences creativity during the ideation and conceptualisation stages of the design process, though their study only focuses on one aspect of mental imagery, visual mental imagery. Andrade (2013) highlights that mental imagery encompasses more than just than visual mental imagery, and states that the cognitive process has many forms, including auditory, tactile, gustatory and emotion. Nanay (2017) elaborates further and defines this as multimodal mental imagery. Leading to ask ourselves, does the use of multimodal mental imagery enhance creativity? And what is creativity within this context? Walia (2019) defined creativity as the act that leads to original ideas and generates possible options. Towards this, Lee and Trimi (2016) define creativity as key factor and driver for innovation; and in a modern world featuring increasingly complex challenges, known as 'wicked problems', engineering designers need to be able to innovate effectively and innovation relies on creativity.

As engineering design researchers and educators, it is imperative to understand the behaviours and cognitive processes associated with creativity both at the individual level and within a team dynamic, to ensure academics can better educate, stimulate, evaluate, and allow the next generation of engineering design students to be able to innovate effectively. This paper explores the use of multimodal mental imagery, primarily visual and emotional mental imagery, within design students and the impact this has on their creativity.

2. Literature review

2.1. Research into visual mental imagery

Visual mental imagery research is vast across an array of disciplines. Within engineering design research there is an interest on a designer's vividness when using visual mental imagery (Hart and Hay 2022; Palmeiro et al, 2016), their sketching ability when paired with mental imagery and ways in which to help stimulate mental imagery to aid designers during the design process (Andrade, 2013; Dahl et al, 1999; Goldschmidt, 1999; Tedjosaputro et al, 2018). Research has also been conducted to determine the relationship between mental imagery and the designer, such as Bilda and Gero (2008) who concluded that mental imagery can enhance idea generation during the design process. Hay et al (2017) talks about the way in which designers handle and treat mental images where they believe that designers use them just as much as external representations such as sketches and can even produce satisfactory results based on mental images alone.

Hart and Hay (2022) explored the vividness of visual mental imagery during concept generation and its effect on designers overall creative performance, where they proved that there was a significant and positive relationship with people using mental imagery and their creative output and suggests that individuals who do not use mental imagery in their creative process may be at a disadvantage. However, there is a lack of research into visual mental imagery and its impact on creativity (Cyrielle and Gavard-perret, 2016).

2.2. Research into multimodal mental imagery

Researchers have begun looking into multimodal mental imagery. researchers such as Macfie et al (2023) presents an extensive literature review on multimodal mental imagery. They highlight the role emotional mental imagery (empathy) plays in a designer's experience and its importance within the design process. Alongside this review Alzayed et al (2021) found that a designer's use of empathy improves productivity but cannot definitively assert that a designer's use of empathy improves their creativity. Showing a gap in knowledge, therefore it is important to understand the role empathy / emotional mental imagery plays alongside visual mental imagery in the design process and its impact on creativity.

Alongside these studies, Maciel et al (2021) studied the use of multimodal mental imagery in design students and concluded that designers who have visual impairment are better suited to designing for real world problems as they cannot rely on their vision, and subsequently used their visual mental imagery and rely on other sensory inputs as found in multimodal mental imagery. Maciel et al (2021) also highlights that this may prevent designers from fixating on the existing designs of a product allowing them to produce creative outcomes, raising an important question, does design fixation impact a designer's creativity when using mental imagery?

Wu et al (2023) explored design fixation's impact on creativity. Concluding that a designer's use of visual aids to help generate concepts has a negative impact on a designer's creativity. This raises the question, does the use of visual mental imagery function as a visual aid?

This can be answered by understanding the Geneplore model (Finke et al, 1992). Gilhooly and Gilhooly (2021) and McTeague et al (2020) have summarised this a mental process that involves two reoccurring processes that use mental synthesis to create parts and assemblies of an idea.

Comparing this by are previous definition of mental imagery and Arhiem's (1993) claim that mental imagery is "fugitive recollections of visual perceptions". It can be assumed that designers who use visual mental imagery, use this as a visual aid during the design process. And further, from this it can be extrapolated that designers who use visual mental imagery, use these as visual aids during the design process, alongside this,

2.3. Gap in knowledge

From the literature above, It can be concluded that little is known about a designer's use of visual and emotional mental imagery and its relationship with creativity. Furthermore, few studies have investigated design fixations relationship with visual mental imagery exists or multimodal mental imagery.

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This leads to the aim of this research, to investigate the relationship between multimodal mental imagery with creativity and the influence of design fixation on this relationship. Towards this aim, two research questions were created:

RQ1 Does the combined use of visual and emotional mental imagery improve creativity?
RQ2 Does design fixation have a relationship with the use of mental imagery?

3. Methodology

To answer the research questions the following experiment was created. The methodology followed university ethics guidance.

44 final year design students (referred to as P1-P47) took part in the study, these students have been completing a product design course over the past four years, final year design students were chosen due to the knowledge in the design process and are more likely to be like that of a designer in industry. The exercises took place in a studio environment, no restrictions on how participants were to complete the task were provided.

Participants conducted 3 activities as part of the study:

1. Participants were required to complete two, ten-minute concept generation activities, where exercise one asked participants to design a radio and exercise two asked participants to design an alarm clock. These products were chosen as they are products the students would either have direct lived experience with or, if not, would have sufficient understanding of the basic function of the two products.
2. Once the participants completed the concept generation exercise, participants were asked to fill out a Plymouth Sensory Index Questionnaire (PSI-Q) developed by Andrade et al (2013). The PSI-Q asks participants to self-report their use of visual and emotional mental imagery on a Likert scale from 1 (No imagery at all) - 10 (as vivid as real life).
3. Once the participants had completed the PSI-Q they were provided with a comment sheet where participants would have five minutes to comment on their thought processes for both exercises.

Once all data has been collected a creativity assessment was conducted with four PhD students (Known as Assessors) who have knowledge in the design process, these assessors were selected from an open call and a look into their educational background was conducted to ensure they have experience and knowledge in the design process. The evaluation was conducted in a face-to-face environment to allow for collaborative discussions to take plan and ask any questions which may arise during the exercise. Assessors were provided with eleven concept sheets in a randomised order. Assessors used the Decision tree for originality assessment in design (DTOAD) developed by Kershaw et al (2019) to determine a participants creativity score. The DTOAD can be found in Appendix A.

The DTOAD rates concepts on a scale of 0 to 10 in increments of 2.5. Once Assessors had completed their evaluations, they had a collaborative discussion to ensure their scores were accurate and was an attempt to eliminate as much bias from the exercise as possible.

Once participants completed their involvement within the study, the authors of the study conducted a thematic analysis, determining a coding schema based of the reoccurring themes that appeared throughout the participants comments, comparing these with the results from the self-reported PSI-Q and the creativity assessment to determine answers from the research questions. This processes followed a grounded theory approach.

Both quantitative and qualitative data have been collected for this study, however a more qualitive analysis approach has been adopted to understand deeper meaning and insights into the data collected.

4. Results

Table 1 displays the processed data from both exercises and the DTOAD evaluation. The Mental Imagery score represents the combined use of between both exercises. Participants could score a maximum of 20 for each modality (Visual or Emotional). The creativity score is the percentage of the total creativity in both exercises. The equation used is shown below.

$$\text{Creativity Score} = \left(\frac{\text{Exercise 1 Creativity Score}}{(Concept\ Count \times 10)}\right) + \left(\frac{\text{Exercise 2 Creativity Score}}{(Concept\ Count \times 10)}\right)$$

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Table 1. Overall participant results

ID	1	2	3	4	5	6	8	10	11	12
Visual MI	11	14	13	10	16	8	11	9	16	17
Emotional MI	13	12	12	7	12	12	6	9	14	16
Creativity Score	21%	16%	27%	7%	36%	0%	0%	0%	0%	0%

ID	13	14	15	16	17	18	19	20	21	22
Visual MI	12	9	13	11	13	10	14	11	9	11
Emotional MI	9	5	12	12	11	8	13	12	7	10
Creativity Score	0%	5%	0%	18%	19%	6%	3%	2%	0%	0%

ID	23	24	26	27	28	29	30	31	32	33
Visual MI	14	17	13	12	12	17	9	13	12	16
Emotional MI	12	18	6	10	20	16	7	12	8	16
Creativity Score	0%	43%	0%	0%	0%	22%	16%	13%	3%	13%

ID	34	35	36	37	38	39	40	41	42	43
Visual MI	14	8	10	12	12	2	7	10	13	10
Emotional MI	12	3	11	9	11	2	5	9	10	8
Creativity Score	14%	0%	0%	0%	0%	0%	5%	0%	8%	0%

ID	44	45	46	47
Visual MI	9	14	14	15
Emotional MI	10	12	9	11
Creativity Score	0%	0%	15%	0%

From table 1, 52% of participants scored 0% overall creativity from the DTOAD throughout both exercises, 20% of participants were creative in one of the exercises and 27% were creative in both exercises, though most participants' creativity varied throughout both exercises. An example is P1, who was 39% creative during exercise 1 but only 2% creative during exercise two.
86% of participants provided comments that were suitable for thematic analysis, comment sheets that were not analysed included comments such as P17 who simply stated, "I wasn't doing enough concepts". The comments were analysed, and a theme and sub-theme was assigned to each comment. The results of the thematic analysis can be found in Table 2.

Table 2. Outcomes of the thematic analysis

Percentage of Population	Theme	Sub-theme	Percentage
41%	Fixation	Existing Products	57%
		experience	25%
		environment	11%
25%	Creativity	Factors effecting	23%
		Collaboration	2%
20%	Cognitive Process	mental imagery	23%

Examples of comments that were assigned fixation and existing products, are "shapes usually used on the product" from P6 and "thinking of products I already know and brands such as Braun." From P11. Examples of fixation and experience are "had been working on another uni project focussed on

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designing a retro futuristic product so inspiration was taken from that" from P10 and "thinking of the design emotion class I am pretty sure I sketched some the concepts I sketched then". Examples of fixation and Environment are "looked around the room for inspiration" from P23 and forms based on some of the objects I saw in the studio around me" from P19. Creativity and factors effecting include comments such as "the environment in which we were in, I was having fun" from P8. Creativity and collaboration are from comments such as "ran out of ideas so discussed with peers" from P5. Cognitive process can from comments such as "didn't visualise these ideas before" from P10 and, " negative emotion attached as alarm clocks are not a favourite thing generally" from P11.

5. Discussion

This section discusses the results found in table 1 and table 2, a deeper look into the extreme examples along the distribution of results have been provided to help justify the claims made in this paper. The result of this study suggests that when designers employ both vivid levels of visual and emotional mental imagery, aided by their ability to take inspiration from their environment and/or their prior experience, a likely to achieve higher levels of creativity than those who do not experience vivid levels of both forms of mental imagery. Designers who do not employ both vivid levels of visual and emotional mental imagery are likely going to experience a lower level of creativity during ideation. One likely reason, as highlighted by this study, is their fixation of existing designs / concepts for the exercise in which they are designing for, put in layman's terms, a mental form of tunnel vision.
The remainder of the discussion presents the outcomes of the research as it relates to the research questions.

5.1. RQ1 Does higher levels of visual and emotional mental imagery improve creativity?

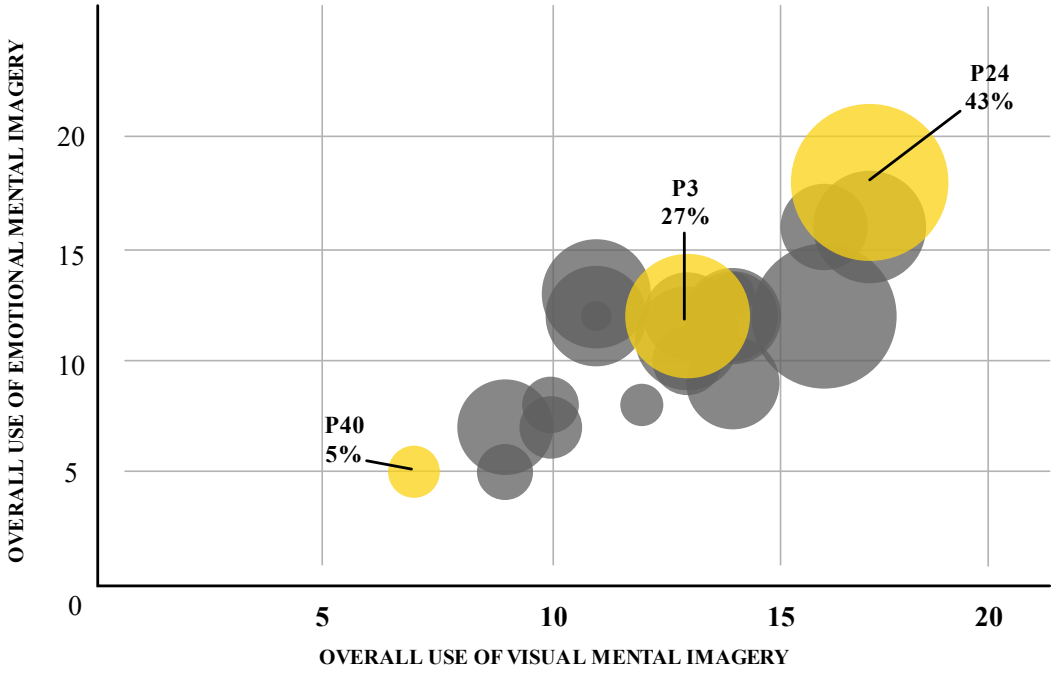

Figure 1. Bubble graph of participants overall use of multimodal mental imagery and creativity

When looking at the quantitative data from Table 1 plotted on a bubble graph in Figure 1, where the X-axis represents the participants use of visual mental imagery, the Y-Axis representing the participants use if emotional mental imagery and the size of the bubble is their creativity score, there is a positive trend, the more designers employed visual and emotional mental imagery, the more creative outcomes

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were produced. However, a detailed look into the data on a participant-by-participant basis allows focused examples in response to RQ1.

P24 had a high creativity score for exercise one with 54% overall creativity, the participant also showed vivid emotional and visual mental imagery, scoring nine on the PSI-Q for each category. Comparing P24's exercise two outputs they comment on the inability to not focus on existing technologies. This is concurrent with the lower creativity score of 31%, however they did rate their use of mental imagery for both categories as nine, meaning they experienced vivid emotions and designs in their mind.

Considering P34's vividness of mental imagery, they reported vivid visual mental imagery (7) and low emotional imagery (2). Comparing this to exercise two where they experienced high levels in both visual and emotional mental imagery (7) they were more creative (21% overall creativity). This leads to the conclusion that with high levels of both visual and emotional mental imagery it can significantly improve the level of creativity of a designer.

The above conclusion is further support by the 50% of participants who scored 0% in their overall creativity across the exercises, such as P8 who states they had 70% vivid visual mental imagery and 20% vivid emotional imagery, P39 who experienced 10% vividness in both visual and emotional mental imagery throughout both exercises and maintained a creativity score of 0% and, P28 who claimed to have 100% vivid emotional mental imagery but only 20% vivid visual mental imagery. Therefore, it can be stated that designers who employ only one or no forms of mental imagery during idea generation are significantly less creative.

Therefore, from the points above, it can be concluded that when designers do not use emotional and visual mental imagery or purely rely on vivid visual or emotional mental imagery this negatively impacts on their creativity, but when vivid emotional mental imagery is experienced alongside vivid visual mental imagery, designers can be more creative and able to produce innovative outcomes. This means designers must employ both types of mental imagery when creating to be able to produce more innovative outcomes. Those who do not employ both processes during idea generation limit the number of creative outcomes that become available to them. The specific reasons as to why they are not creative when they do not employ this process is unknown from statistical analysis alone.

5.2. RQ2 Does design fixation have a relationship with the use of mental imagery?

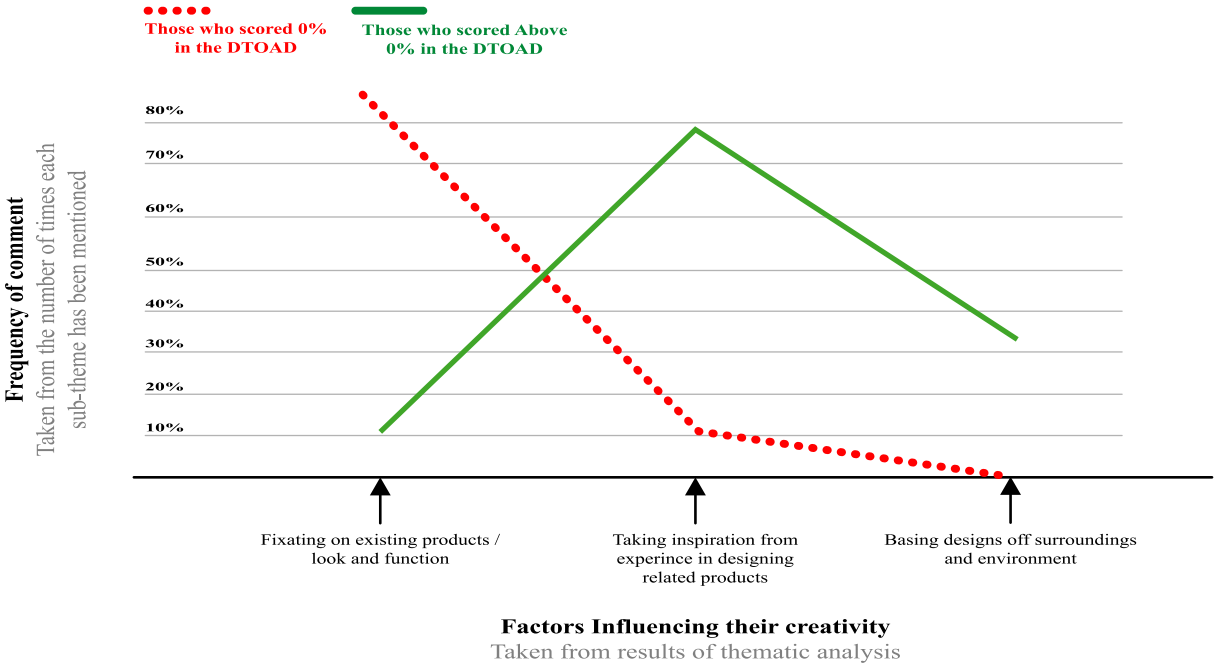

Figure 2. Comment frequency from participants on why they were or were not creative

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Figure 2 displays a visual representation of the data found in Table 2, the X-axis being the three sub-themes of fixation found during the thematic analysis. The Y-axis represents the frequency in which these themes occurred throughout the study. The dotted trend line represents the frequency in which these themes occurred in participants who scored 0% for creativity and the solid line represents those who scored higher than 0% for their creativity.

5.2.1. Those who were not creative

59% of the participants commented on a form of fixation as shown in Figure 2, and 65% of those who commented on fixation had a 0% creativity score across both exercises. Of the 65% of participants that commented on fixation, mentioned they were fixating on existing designs (88%), showing a negative relationship.

Participants such as P18 did however achieve a creativity score of 11% overall, though this came from exercise two alone and the comments on design fixation mentioning the inspiration from existing products were related to exercise one. This is not a solitary case in the data as this trend continues with P24, where they commented on exercise one, where they tried to avoid traditional outcomes of radios, which can help answer RQ2 with the terms of design fixation, by not fixating on existing designs of radios the participant was able to produce more creative outcomes. During exercise two, P34 comments on experiences with radios and existing designs which led to a high level of fixation and low creativity (7%). This trend does continue with participants 19, 32 and, 42 who all have one exercise that was creative with no mention of fixation on existing products and a non-creative exercise with mention of fixation on existing products, further supporting the study by Wu et al (2023).

All participants who commented on fixation from existing products experienced vivid mental imagery (>5) of one aspect of multimodal mental imagery, further justifying the conclusions drawn from RQ1. Highlighting a factor that negatively effects a designer's ability to innovate and be more creative. Aligning with a study by Viswanathan and Linsey (2013) where they were able to determine that having existing products whether physical, pictorial, or imaginative, restricts a designer's ability to innovate. In the case of this study this is multimodal mental imagery.

5.2.2. Those who were creative

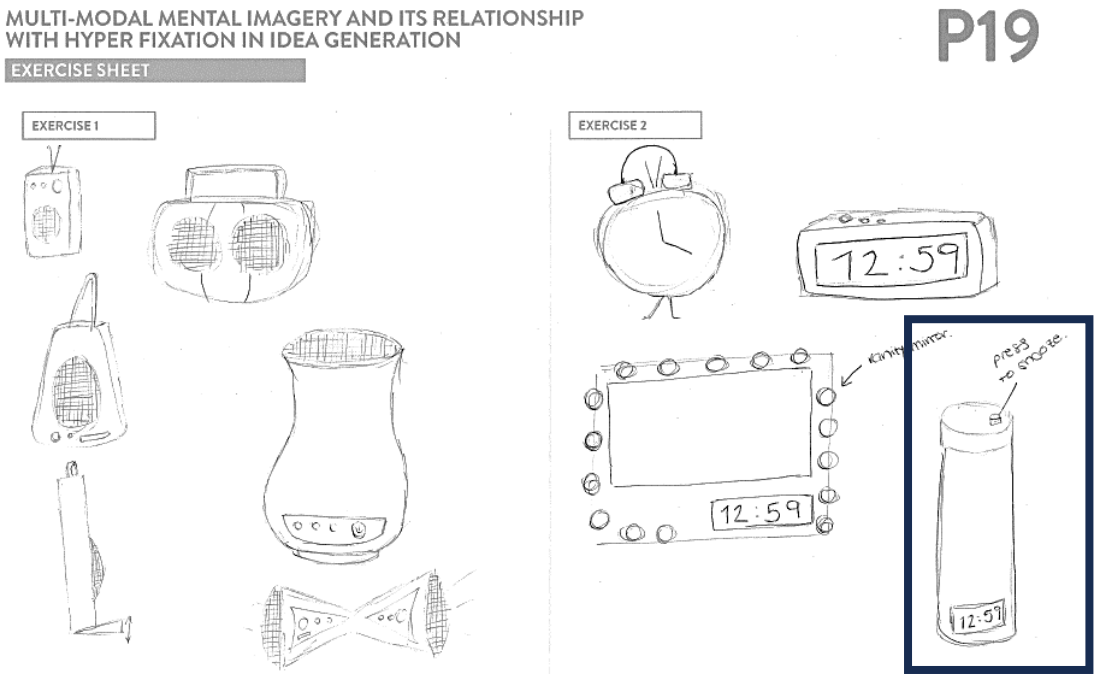

Figure 3. P19's concepts from exercise 2

Participants who commented on fixation and surrounding environments or fixation and experiences, achieved a higher creativity score between both exercises. Interestingly for those who based designs off

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their surroundings, took literal inspiration from surroundings, evidence of this can be seen in Figure 3 where P19 comments that they took inspiration from their surroundings, specifically a water bottle. However, this concept did allow for a higher creativity score overall, further justification of this can be found with participant 29, who had a high creativity score of 44% overall and mentioned their inspiration from a previous design project they worked on, they also had high levels of visual (7, 10) and emotional (6,10) mental imagery in both exercises, further highlighting the conclusions drawn from RQ1.

5.3. Summary RQ1 and RQ2

The result of this study suggests that designers who use both visual and emotional mental imagery, whilst experiencing vivid mental images and emotions can experience an enhanced form of creativity known as 'Innovative Thinkers', done using their prior experiences and / or their surroundings as inspiration to add innovation to an outcome.

Those who experience vividness in one of the forms of mental imagery whether that is visual or emotional were likely to not have enhanced creativity leading to lower scores, known as 'fixating thinkers'. One of the reasons for this is due to design fixation of existing designs already in place for the specific product in which they are designing for as shown by the thematic analysis of the comments provided by the participants in Table 2 and Figure 2. A summary of this finding is shown in Figure 4.

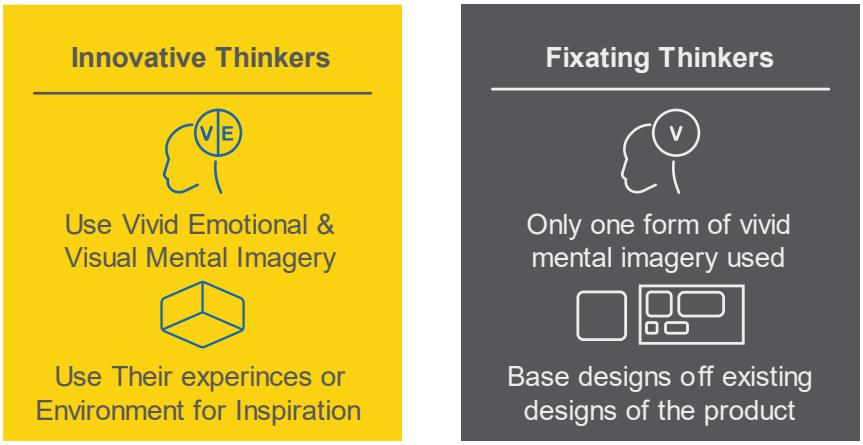

Figure 4. Type of designers that use multimodal mental imagery summary

These findings however are exploratory and not definitive, more research into the use of multimodal mental imagery is required. More research into multimodal mental imagery, its impact on creativity and the underlying reasons is required.

5.4. Limitations

Whilst conclusions have been identified it is important to understand a few of the other factors they may have impacted on the participants overall creativity. As stated in section 2, participants were made up of students from the University of Strathclyde and with 4 separate courses all specialising in different aspects of the design course such as the embodiment and function of designs, innovation and novelty of designs, the processes used to manage the design and manufacture process and the designs for a specific target user. Students' levels of creativity and specialities in the design process will vary drastically, therefore the participants focus on the designs were simply for function and general use rather than innovation and changing the way the product functions.

Another factor affecting the level of creativity is the simplicity of the design brief given to the participants, they were provided with products that have been extremely saturated and some could argue are no longer relevant in today's society, alongside this they were given no constraints to work against, this has been highlight by P35's comment, where they state "thinking of the object alone did not enhance or inspire creativity" which links back to RQ1 and RQ2 where the participant experienced 60% vivid visual mental imagery and 20% vivid emotional mental imagery and 0% creativity overall, therefore if

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design students cannot innovate on open design briefs or existing products how can educators expect them to innovate and solve for 'wicked problems'.

6. Conclusions

This paper explores the use of multimodal mental imagery, primarily visual and emotional mental imagery, within design students and the impact this has on their creativity. From the current state of the research, it has been highlighted that mental imagery encompasses more aspects that just visual, such as emotional (Andrade, 2013). Other researchers in the community have expressed the importance that emotional mental imagery has during the design process but have not been able to determine its direct impact on creativity.

This paper takes this gap of knowledge and begins to explore a designer's use of visual and emotional mental imagery and its impact on creativity. Using a Plymouth sensory index, decision tree for originality assessment and thematic analysis, the authors of the study are able to make claims on the types of designers that use visual and emotional mental imagery and, where their inspiration or way of think comes from.

From this study, it has been concluded that during the concept generation stage of the engineering design process, designers can use multimodal mental imagery to help improve their overall creativity.

It has been highlighted that there are two types of thinkers from this study. Innovative thinkers, who employ both visual and emotional mental imagery to help enhance their creativity, a way in which they may use these processes is by taking inspiration from their surroundings and/or from their prior experiences of designing similar products.

Fixating thinkers are those who only use one vivid form of mental imagery potentially impacting on their creativity during a design exercise. These types of thinkers are potentially created when existing products are heavily influencing their thought process, meaning they are unlikely to apply new or innovative solutions to a design.

From this study, it is believed that the conclusions can provide a basis to develop further research in multimodal mental imagery. It is believed that this study can help design educators and researchers focus their efforts to build an understanding of how to best stimulate and prepare these design students to enhance their creativity.

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