An investigation into multidimensionality of Tactile Perception: Is the perception of roughness influenced by other modalities such as Vision?

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Abstract

The haptic sense gives individuals the ability to be able to find out information about the properties of a material or an object. The main aspects of object properties that are extensively studied are roughness smoothness and friction. Roughness is defined as a material that possesses an uneven irregular surface texture. Most research investigating haptic perception has not practically explored the multidimensionality of touch as a whole and studied with purely just exploration of the finger over various surfaces. This research attempts to extend theoretical information about haptic perception by studying the influence of Vision as a sensory modality on tactile perception. This is to provide empirical evidence that Haptic perception is multifaceted. In this study, Absolute magnitude estimation (a procedure that allows participants to numerically rate roughness on a scale of their own) was used. The assumption would be the higher the estimates the rougher the participant judges the 3D blocks. This estimation was used on 7 3D models of textile blocks of varying roughness displayed on a lazy Susan turntable. Participants had to give an estimated rating of roughness in three conditions Visual where participants-based estimations on sight alone, visual-haptic where the participants are not blindfolded and can touch the samples, haptic conditions where participants are blindfolded. The hypothesis explored was there will be a significant difference in the AME ratings of roughness across all three conditions and there would be higher mean AME ratings in the visual haptic condition. This would indicate that vision exerts an influence on roughness perception. Results displayed a significant main effect of visual modalities on roughness perception and a larger mean average rating in the Visual Haptic condition. Although unable to find significant interactions between conditions the hypothesis was partly supported as with the significant main effect found there is a clear difference in the way different modalities such as vision process tactile discrimination which establishes that Haptic Perception is solely refined to touch as a sensory modality. These future considerations could made be made studying other dimensions such as finer textures (smoothness), and other cases where vision isn’t readily accessible in Blind individuals.

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Introduction

Touch is a significant part of the five senses and haptic perception, in particular, refers to the ability to perceive and identify specific characteristics of objects like texture, vibration, temperature, or pressure. Buried under both hairy and hairless skin are biological mechanisms otherwise known as cutaneous mechanoreceptors that facilitate haptic perception. The four cutaneous receptors found across the body (Merkel disc, Pacinian capsule, Ruffini endings, and Meisner Corpuscles) are divided into two categories - slow adapting receptors which produce responses to sustained pressure, and fast adapting receptors which produce fast responses to skin deformation. These receptors play a key role in the haptic perception of texture which is best exemplified by SA1 receptors which are slow adapting and the perception of surface roughness. Research into the field of haptic perception has focussed on these specific receptors and has produced evidence that proves the isolation of specific touch receptors. (Klatzky and Lederman 1985) highlighted that these receptors are implicated in the “What System” which processes surface objects and properties. This system is the main focus of this research with the objective to understand how it is influenced by visual modalities.

There has been extensive focus on key characteristics of texture within the field of tactile perception. (Okamoto et al’s 2012) review of current research into tactile perception provides a salient overview of studies that have investigated subjective ratings of materials with a specific focus on macro vs fine roughness, hardness vs softness, and friction. Key in this study is (Tanaka et al 2008’s) roughness, moistness, hardness, and warmness examination of thirteen textiles including cotton and silk. In this study, twenty-one participants were blindfolded and instructed to rate textiles according to seven adjective pairs - this is known as the Classification Method wherein ranking is based on similarities between materials. This methodological design as well as a focus on roughness is a prominent feature of studies in Okamoto's research summary and is indicative of a research methodology within a haptic perception study that only establishes textures that belong to one class. In doing so, there is oversight of subclasses of texture which can impact the classification between textures.

Included in Okamoto’s research summary are other critical ways of investigating subjective ratings between materials such as the semantic different method (Osgood et al 1957) and the similarity estimation method. These methods share some similarities with the Classification Methods as they place an emphasis on ranking based on adjective labels while eschewing the focus on subjectivity. The Similarity Estimation Method involves a triad of group ratio judgments, grading a method evident in(Cho et als 2001) research into reliability judgments on visual textured stimuli, visual analog scaling, and numerical scaling, and the Semantic Different Methods allows participants to rate materials on a continuum one by one using a scale that has rough on one end and smooth on the opposite end. Despite both methods embrace of some quantitative methodology, the process is often convoluted and difficult to explain to participants, taking away focus from the experiment. The Absolute Magnitude Estimation Method (Stevens et al 2017) combines subjectivity, numerical value, and ease for haptic perception research. It is a psychophysical procedure in which participants make subjective judgments about the magnitude of stimuli with their own numerical scale. Research by (Verillo et al 1999) utilized AME with subjective judgments of eleven sandpaper samples to investigate whether there is a significant difference in ratings of roughness between the thumb and the finger. In this research, the stimulus was rectangular in the shape of standard sandpaper which was attached to plates of steel. The samples ranged from 16 to 905mm in terms of particle diameters and were presented to the participants three times in random order to prevent the order effect. The geometric mean for each participant which is described as Ms was then divided by the grand geometric mean for all the participants for all the grit sizes of the samples. This created the normalized responses for each participant to be analyzed using Repeated Measures ANOVA. The same procedure will be adopted where participants were asked to graze the 3D sample and rate the roughness with any scale they choose. The ratings were then normalized by calculating the mean making it easier to analyze. For the reasons relayed above, this research will incorporate absolute magnitude estimation method into the results.

The use of sandpaper to test roughness as evident in (Verillo et al 1999) research has been replicated through the research into haptic perception. However, (Weber et al 2013) suggested that samples like sandpapers often vary significantly among different manufacturers and the raised grits will not be similar in shape and size. The use of 3D manufactured raised patterns was encouraged in (Tymms et al 2018) research as it allowed “precise surface geometry “which gives the researchers more control over the arrangement of textons in a quick process of printing. This will be incorporated into this research as an improvement on previous studies into tactile perception.

Within Okamoto et al’s research summary paper, it is clear that research into haptic perception focussed on participants’ ability to distinguish between materials solely using touch. Examinations into the multidimensionality of touch, that is the influence of the other four senses on haptic perception is fairly rare. (Heller et al 1982) analyzed the influence of vision on haptic perception in sighted and non-sighted participants. The experiment involved four Japanese abrasive sharpening stones with sighted participants instructed to point to the stimuli which would be the smoothest of the four abrasive stones. Participants in the sight condition were given noise-canceling headphones to cancel out auditory variables and told to pick objects that were smooth. Participants in the touch condition were asked to pick the objects they thought were smooth.

Results showed that individuals performed better in the touch condition than in the vision condition. It was then concluded that sight was not sufficient for detecting smoother textures and perhaps touch may be superior to visual modalities in tactile perception. Whilst this is concluded it is further suggested by (Heller et al 1982) that coarser surfaces with larger textural features can be detected by sight, but finer surfaces may be difficult. Nevertheless, there is an influence of visual modalities on detecting textural features which will be explored further in this research experiment. This study will incorporate surface roughness as opposed to smoothness in (Heller et al 1982) study and use this information to find out how other modalities influence the detection of textures. There is some neurological evidence that could provide further support for the influence of visual modalities on tactile processing. This is evident in (Sathian et al 2002)who indicated that visual imagery is necessary for tactile processing of properties of certain objects. Participants were asked to determine the orientation of plastic gratings that was applied to the finger pads. They were asked to report whether the gratings were orientated along or laterally across the finger. TMS (Transcranial Magnetic Stimulation) was applied to the occipital areas of participants and the results indicated a disruption in performance in the orientation task. This led to the conclusion that visual processing is necessary for tactile discrimination further established participants reported that they could feel the gratings but were unclear on the orientation of the gratings during occipital TMS. This reinforces the thesis that tactile perception isn’t unitary and other modalities such as vision could interact with tactile systems which establishes a multidimensional system.

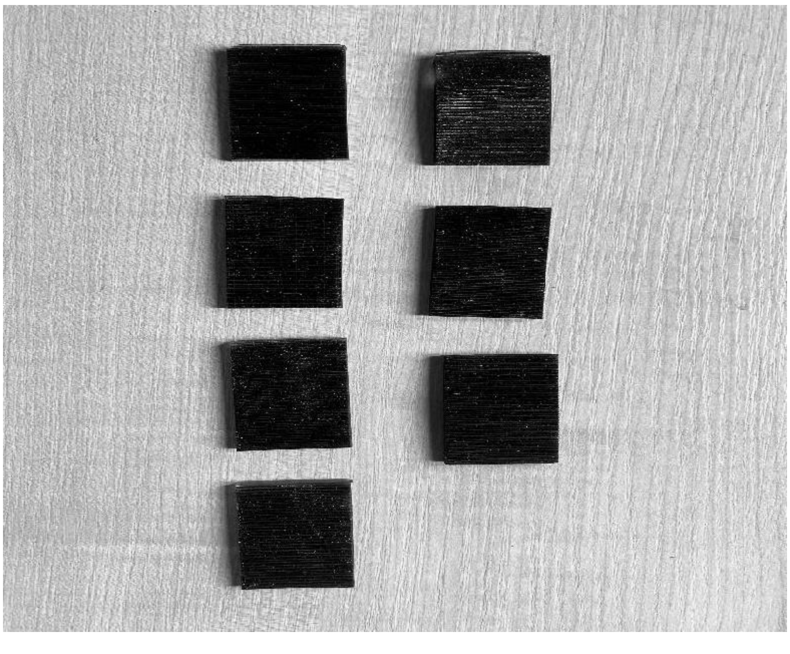
The aim of this study is to establish whether vision has an influence on tactile perception which would be investigated in conditions where vision is isolated and where vision and tactile perception is present. Thus, the outcome would be to observe whether perceptual discrimination of textures is dissimilar across conditions. The importance of this is indicated in amputees who are unable to feel senses of the world around them with prosthetic limbs. The information of the combination of haptic information and visual information and how that can improve prosthetic technology could help aid the tactile perception of individuals with missing limbs. To further provide support for future implications for this research (Timm et al 2020) indicated a mechanical glove that could initiate plasticity at the fingertips to improve tactile discrimination. The glove induced frequency-specific stimulation to fingertips that improved performance in tactile orientation tasks and two-point discrimination. The prediction of the study is that there will be a significant difference between the AME ratings of the visual condition, visual Haptic condition, and tactile condition and there would be a higher mean AME rating in the Visual haptic condition. The methodology of the research draws on some principles of psychophysics which is the study of determining the mathematical relation between physical stimuli and human tactual sensory experience. The method will include three conditions, one condition will be that participants will be blindfolded and touch the samples, another condition will involve participants subjectively judging material solely based on visual observation, and another will be visual- haptic where they see the stimuli whilst touching them

Methods

Participants and Design: Participants included 12 participants (5 males, 7 males, range 20-21) from the University of Birmingham. The exclusion criteria were suggested in the consent form advertised as only right-handed people were selected which is the inclusion criteria for right-handed participants. The informed consent form is included in appendix A. There were no finger injuries and all participants had to use their index fingers to graze the samples. Appendix A contains the general information about the consent form and safety screening questionnaire. All participants gave informed consent and ethical procedures were adhered to according to the British Psychology Association. The design was set up as 3(sensory conditions) X1(Absolute Magnitude estimation).

Materials: The stimuli included 3D printed texture blocks (fig 1) all different textures ranging from numbers displayed on the back to signify this. The rectangular blocks were measured 3.9cmX 2.5cm which was all identical for all the blocks. The experiment made use of a Lazy Susan turntable fig 2. The 3D printed surfaces are mounted on the Lazy Susan and there is a micro-controller (ATmega168) within this machine that allows quick selection of the correct sample. The turntable turns clockwise with the code uploaded to the machine. This in turn reduces the order effect so participants don't select the same samples. The program used to power the lazy Susan was Arduino Idea coding program on Windows Computer. These programmed serial numbers (see Appendix B) corresponded with the order in which the 3D samples were selected by the participants. An opaque Blindfold was used in the Haptic condition.

Figure 1: Seven 3D oriented blocks all arranged in order smooth to rough



Procedure: This is a Within measures Design as all participants experience all three conditions. The three conditions were all counterbalanced to avoid the order effect and a typical trial is displayed in figure 3. One condition is the Haptic condition where the participant is guided to press the red button which randomizes the selection of the seven stimuli displayed in fig 1. This condition requires the participant to be blindfolded to isolate the experience to haptic perception only. The participants were asked to graze vertically up and down the textile and the amount was three times for standardization. This block is repeated three times with different orders of the sample presented. The participant was then asked to give an absolute magnitude estimation of roughness which is a numerical estimate based on any scale of the participants choosing as evident in Verrilli et al research. Condition B is the Visual condition in which participants were asked not to touch the samples and judge roughness based on vision alone. The same AME was asked of this participant in this condition as well. Condition C is the visual haptic condition where the participants did not need to be blindfolded and they were asked to give an AME rating after touching the randomly selected samples. All conditions had 3 Repetitions. All AME were recorded in an excel spreadsheet (Appendix C)

Figure 2: Dissected Lazy Susan Turntable with USB and Button programmer attached

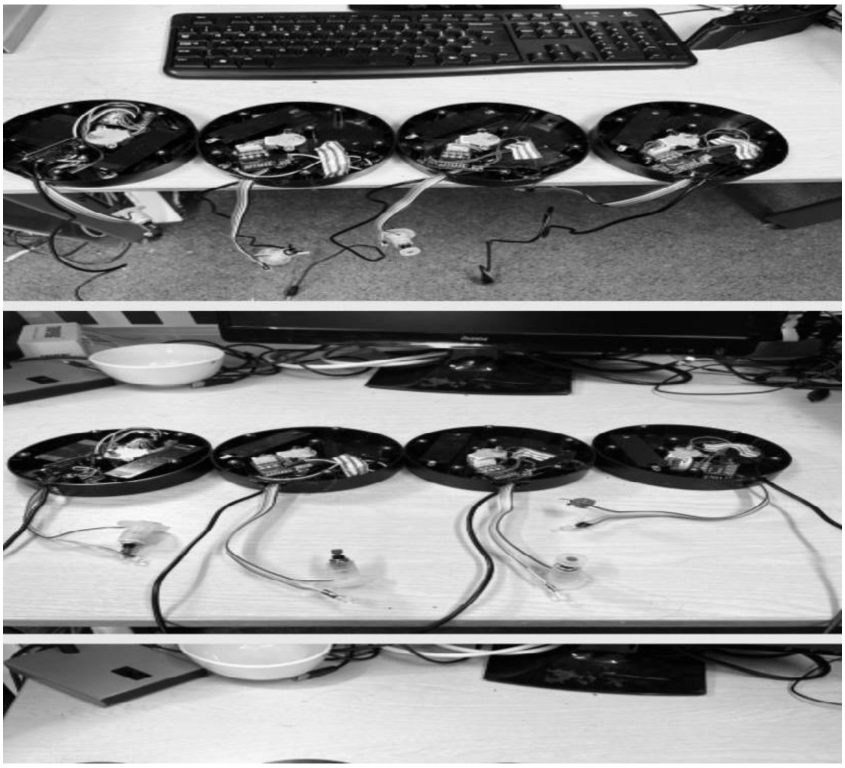
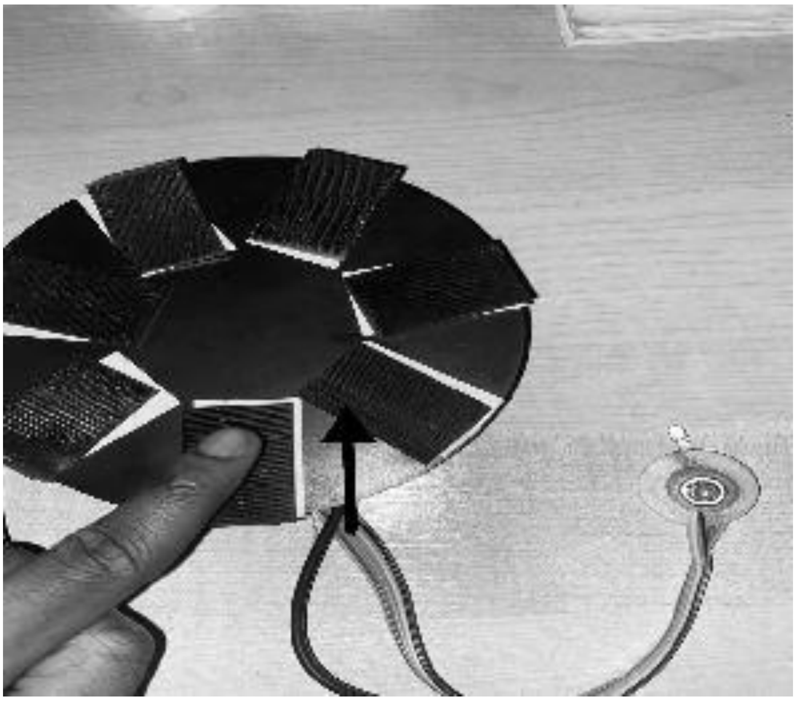


Figure 3: Display of a trial with participant grazing the sample vertically as signified by the arrow



Analysis:

All Data was analysed using SPSS 27 a statistics package and with it, a Repeated Measures ANOVA was applied to the data using Sphericity assumed correction if needed. The Absolute magnitude estimations were normalized using the equation from Verillo et al (1999)`s study which is stated as the MS (geometric mean) of ratings of all three blocks divided by the grand mean (MG). The normalization was done for all the conditions, and this was the data that was put through Repeated Measures ANOVA. The reason for normalization is evident in (Moskowitz et al 1971) who pointed out in magnitude estimation procedures normalization is necessary when some participants give a large number estimate and others give a smaller range of estimates. A test of normality was applied to the data before analysis to indicate whether the data fit parametric assumptions and this, in turn, allowed for Repeated Measured Anova to be ran.

Results

The SPSS output shows the within-subjects factor was the Sensory Modalities which is the conditions of Visual, Visual Haptic, Haptic. The results from the Repeated measures ANOVA indicates F(2,22)=4.882, p=.018,etap2=.307 The significant value for sphericity was 0.444 which is greater than 0.05. Thus, sphericity could be assumed in the data and as reported the ANOVA result was referred to in the sphericity assumed row. The result was significant which supports predictions made in this current experiment. The pairwise comparisons suggested there wasn't a significant interaction between Visual, Visual Haptic, and Haptic conditions. This is indicated as the p-value between Visual and Haptic conditions was reported as p=0.535 and the p-value between haptic and Visual haptic was p=0.065. Fig 4 shows the mean absolute magnitude estimations against the sensory three conditions. The mean and standard deviation of the ratings in all three conditions are reported in Table 1 It is reported that the mean of AME in the Visual Haptic condition is 8.3 which is higher than the other conditions that report 5.3(haptic) and 6.4 (Visual). All in all, the Results partly support the hypothesis that there will be a significant difference in ratings between the three conditions of Visual Haptic and Visual Haptic.

Fig 4: Figure depicting means of AME against Visual, Haptic, And Visual Haptic (error bars represent standard errors)

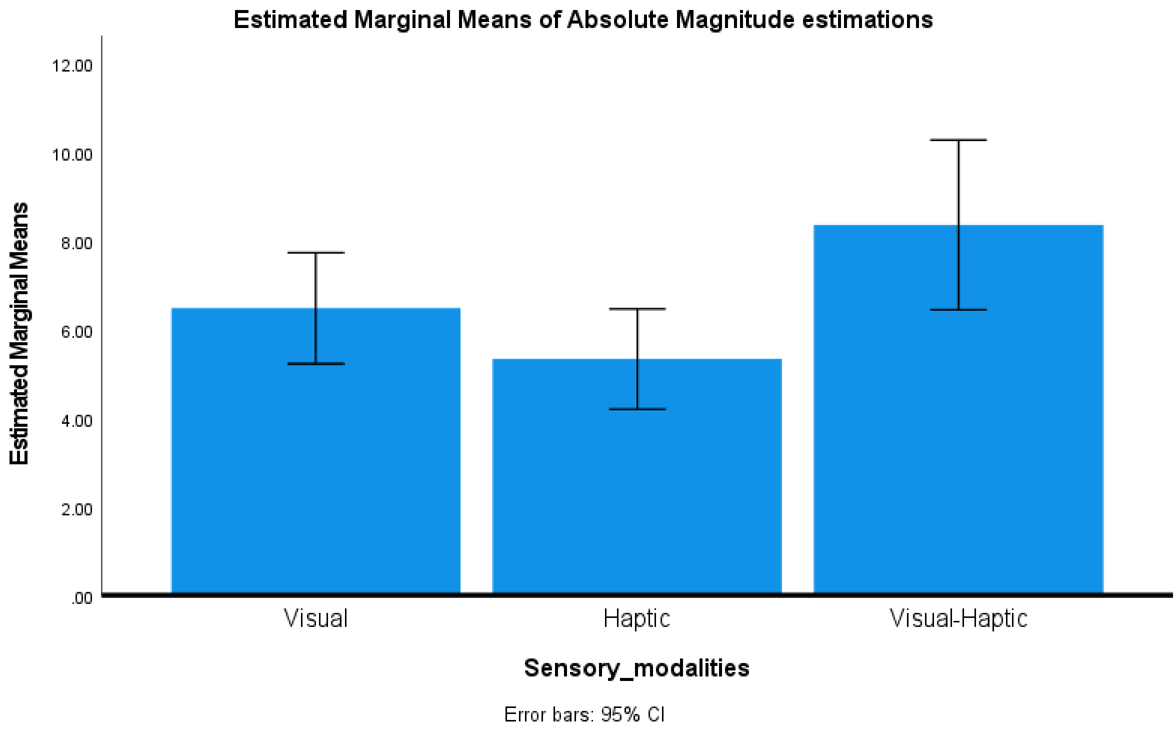


Table 1: Table showing Mean of AME ratings for all three conditions (Visual , Haptic, Visual Haptic)

Estimates

Measure: MEASURE_1

Sensory_modalities	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	6.481	.569	5.229	7.733
2	5.333	.512	4.205	6.461
3	8.362	.872	6.443	10.280

Discussion

The aim of this current research was to investigate whether visual modalities had an influence on Haptic perception and therefore establish that Haptic Perception is Multifaceted. The hypothesis that stemmed from this is that there will be a significant difference in the AME ratings of the three conditions of VH, Visual, and Haptic. The results partly support the hypothesis as a significant main effect was found. This in accordance with the higher mean AME ratings in the visual haptic condition could suggest that there is a mechanism in Visual modalities that interferes with individuals' discrimination of rough textures. The surface characteristics and the outward appearance of the 3D samples are what perhaps produced the higher mean ratings observed. The results support the conclusions made by (Heller et al 1982)and (Sathian et al 2002) that visual modalities do influence tactile perception as it interacts with discrimination of certain textural features highlighted such as surface roughness, and the overall appearance of ridges displayed on the 3D printed samples. The dominance of visual modalities displayed in the VH condition has been explained by the modality appropriateness hypothesis (Welch et al 1986) and the directed attention hypothesis (Posner et al 1976). MAH explains that individuals rely on the modality that is specific for a task and in this experiment, it was to describe numerically the level of roughness of the samples. DAH indicates that individuals direct their attention to the visual modality on a usual basis and this concentration takes away from less attention to modalities such as touch.

.The paired comparison results were unexpected and deviates from the ANOVA result as it was not significant. It revealed there isn't a significant interaction between the mean AME ratings. The reason for this may be down to certain methodological drawbacks. The study involved a rudimental explanation of absolute magnitude estimation to participants before the actual procedure began and this may be a limitation as it could explain the similarity in ratings between all three trials as it was observed participants has a specific range and subconsciously stuck to that range for the subsequent trials. The similarity in range occurred across all conditions and it could be the reason for the lack of significance of ratings between the conditions. Research by (Collins et al 2012) made us of absolute magnitude estimation in investigating loudness in children and before the actual procedure had participants undergo training in estimating line lengths. (Stevens et al 2017)posited that line estimation is a task that which participants can get a quick grasp of AME. This was also explored in(Verillo et als 1999)as the original testing included participant estimating line lengths. This could perhaps be an improvement in ratings given in the experiment and perhaps go towards producing more significant differences between the conditions as there is more of a range in numerical estimates.

The numerical estimates of roughness were solely on this dimension and future studies could implement other dimensions referenced in Okamamoto et als study (2012). This is an effort to distinguish if the same interaction of visual modalities influencing haptic perception remains the same across ratings of other dimensions such as surface texture, glossiness, and brightness. This would further establish the fact that Tactile perception in an everyday environment where a range of dimensions is explored requires the collaboration of other modalities such as vision. Research exploring other dimensions includes (Yoshida et al 1968) who investigated similar conditions of haptic only visual only and visual haptic. The study reviewed dimensions such as slippery sticky hard/soft and rough smooth. Thus, if a similar methodological design studied in this current experiment could be attributed to these dimensions, it could reveal if visual modalities influence tactile perception and produce different AME ratings in the three conditions. It could also reveal that perhaps for certain dimensions vision is inferior and tactile perception is more accurate in discrimination between textures.

Whilst this discrimination between textures is aided by Vision it is unclear whether Touch or Visual modalities produce confident ratings in conditions where the samples are not identical and clear cut. This is evident in research by (Fairhurst et al 2018) who investigated perceptual ambiguity where participants explored T-shaped samples that were inverted. In different blocks, the stimuli had either clear cut or ambiguous cases and judgments based on whether the vertical bar was shorter or longer than the horizontal bar. The confidence in rating was tested and results indicated more confidence in Tactile when the case was ambiguous but more confidence in Visual Modalities when the case was clear cut. This links to the earlier aforementioned point that for certain textures in which case finer textures vision is seen as more readily accessible to use but for more ambiguous textures it requires more exploration to discriminate. This is an avenue that could be explored In future considerations as from the results in the study it is only clear vision has an influence in AME ratings of similarly printed 3D Samples but one could attribute different conditions with various samples of varying ambiguity to see how extensive and multifaceted Haptic perception is as a whole across a range of textures.

Potential Follow up studies from the significant differences found in the three conditions could perhaps delve into the outcomes of tactile accuracy in the absence of blindness. This would perhaps provide more theoretical information about the interaction between senses and how that affects haptic perception. A key example is with blind individuals and how the absence of vision disrupts haptic perception which was created artificially with the blindfold in this current experiment in the haptic condition. Research by (Bhattacharjee et al 2010) found that blind individuals who experienced vision at an early stage and later acquired blindness perform better on tests of tactile discrimination than sighted individuals. The test required participants to distinguish between small taps and large taps on a small probe that produced vibrations. When the large longer tap followed a smaller tap it disrupted tactile discrimination, but it was found that blind individuals performed better in these trials. This establishes the malleability of tactile perception and its performance when vision is impaired. The ability of the brain to compensate for the absence supports the Multidimensionality thesis as if the tactile perception was solely reduced to touch alone then Blind individuals would not possess the ability of tactile discrimination. This Is further supported by research that indicated that visual cortexes are activated in tactile discrimination tasks which produces the conclusion that the brain can use systems associated with other modalities to aid the perception of textures.

In conclusion, the experiment further expanded on previous research into Haptic perception establishing that it is multifacetedly evidenced by the fact that Visual modalities influence Absolute Magnitude estimation ratings. Results partly supported the hypothesis that there will be a significant difference between the three conditions, whilst there wasn't a significant interaction between the three conditions. There are some methodological limitations in future studies could address and It provides enough information to aid tactile technology earlier mentioned and provide more information on how senses interact with each other to aid haptic perception when one modality is damaged.

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APPENDIX A

The following page below displays a copy of the information sheet, safety questionnaire, consent form that were presented to participants before the experiment.

GENERAL INFORMATION SHEET

Introduction to the Research:

You are a participant in this research study investigating Haptic perception which put simply is the ability to tell the difference between a range of textures and whether this includes other modalities such as Vision. The purpose of this investigation is to explore whether vision has an influence on Haptic Perception.

What Stimuli will be presented?

The stimuli will involve 3D printed Blocks and will involve a lazy Susan which is a motorized turntable and a blindfold.

What are the exclusion criteria?

The exclusion criteria are whether you are left-handed or if you have any injuries to your fingers i.e., a cut or etc

Will my data be Kept Confidential?

The data collected from this experiment are compliant with the Data Protection Act 1998. All information shared in this research will be kept strictly confidential.

Any Problems with the study you can contact Professor Max DI Luca who is the lead supervisor in this research study. The email is M.DiLuca@bham.ac.uk.

You will be given a copy of this information sheet to keep if requested, Thanks for your participation in this study and for taking the time to read this sheet.

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PARTICIPANT CONSENT FORM

Participant code (researcher use):

Please put an X in the box for the following information where it applies to you:

Gender	male	female	Prefer not to say	Non-binary
			________	

Age
(please specify years)

Dominant hand	Left	Right

Fluent English Speaker	Yes	No

Please initial each box to confirm the following:

I have read the information sheet.	
I have had an opportunity to ask questions and discuss this study.	
I have received satisfactory answers to my questions.	
I have received enough information about the study.	
Who have you spoken to?	
I understand that I am free to leave the study: - at any time - without having to give a reason for leaving	
I wish to be contacted about future research studies at the University of Birmingham	

I confirm that I have read the participant information sheet and have completed the above consent form. The nature, purpose, and possible consequences of the procedures have been explained. I understand that I may withdraw from the study at any time. I confirm that I have been through the safety screening procedures if applicable and that I am happy to participate in this study.

Please note: All data arising from this study will be held and used in accordance with the Data Protection Act (2018). The results if the study will not be made available in a way that could reveal the identity of individuals.

Name in capital letters:	
Signature:	**Date:**

Researcher witness (researcher use): Print Name: Signature:	**Date:**

Participant information sheet

This experiment is investigating whether vision has an influence on tactile perception to establish the thesis that Tactile perception is multifaceted and not unitary. You will complete three conditions with the same task of rating how rough the 3D samples are. The 3D samples will be presented on the Lazy Susan, and you will be asked to graze the sample with your index finger three times. Then you will be asked to rate the roughness of the sample presented on your own numerical scale, eg 25 for how rough the sample is.

Visual Condition:
You will be asked to report roughness based on the surface appearance alone without touching the sample

Visual Haptic condition:
You will be asked to graze the sample three times and report the roughness of the sample

Haptic Condition:

You will be blindfolded with consent and you will be asked to graze the sample three times and report the roughness of the sample.

APPENDIX B

```
21:44:47.890 -> 12345678
21:44:47.890 -> 263[illegible]47
21:44:47.890 -> 12345678
21:44:47.890 -> 1563247
21:44:47.890 -> 12345678
21:44:47.890 -> 1465327
21:44:47.890 -> 12345678
21:44:47.890 -> 5362417
21:44:47.890 -> 12345678
21:44:47.890 -> 5461237
21:44:47.890 -> -1
21:44:47.890 -> 2635147156324714653275362417546123 7
```

APPENDIX C

Participant	Visual 1	visual 2	VISUAl 3	Haptic 1	Haptic 2	Haptic 3	V/H 1	V/H2	V/H3
1	9	5	5	7	8	7	8	5	9
2	10	6	5	8	9	6	5	4	8
3	14	8	9	9	6	8	9	6	8
4	8	10	7	7	9	5	8	7	7
5	7	7	8	8	9	6	7	5	5
6	9	8	8	7	6	6	8	9	8
7	5	4	2	4	2	2	8	3	4
8	6	7	3	4	3	3	6	1	7
9	2	8	4	9	7	1	6	8	9
10	8	6	9	7	3	8	8	7	8
11	3	8	7	3	10	10	7	5	7
12	8	5	9	4	2	2	8	7	6

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