Manipulating perception: The effect of product similarity on valuations and markets[a]

Andreas Gotfredsen[b] Carsten S. Nielsen[c]
Alexander C. Sebald[d] Edward J.D. Webb[e]

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[b]agotfredsen@gmail.com, Department of Economics, University of Copenhagen, Øster Farimagsgade 5, building 26, 1353 København K, Denmark

[c]csni@star.dk, Department of Economics, University of Copenhagen, Øster Farimagsgade 5, building 26, 1353 København K, Denmark

[d]Corresponding author: alexander.sebald@econ.ku.dk, Department of Economics, University of Copenhagen, Øster Farimagsgade 5, building 26, 1353 København K, Denmark

[e]e.j.d.webb@leeds.ac.uk, Leeds Institute of Health Sciences, University of Leeds, Level 11 Worsley Building, Clarendon Way, Leeds LS2 9NL, UK

Abstract

We study the economic impact of perceptual limitations using experimental goods for which the difficulty of perceiving the difference between them can be manipulated by altering the similarity of their visual representation. In our first experiment, we found that subjects' willingness-to-pay for goods became more similar when it was harder to discriminate between them. Building on this result, we ran a second experiment where the same experimental goods were traded in a market with heterogeneous buyer preferences and seller market power. Buyers were less likely to choose the option which maximises consumer surplus when discriminating between products was harder, and buyer payoffs were lower. We find indications that buyers used a different method of constructing their valuations in the market than in individual choice, and there was weak evidence that using different methods were beneficial for buyers. Seller prices and profits were not dependent on how easy it was for buyers to discriminate between goods.

Keywords: Perception; similarity; bounded rationality; willingness-to-pay; posted offer market; experimental economics

JEL codes: D4, D8, D9

1 Introduction

Our perception of the world is limited: we are constantly bombarded by vast amounts of information, and it is possible to perceive only a small fraction of it. This paper examines the impact that limited perception has on economic decision-making. Limited perception can mean that it is hard for individuals to accurately assess the value of an individual good. Individuals are often presented with multiple options, rather than a single good, so that it is also difficult to assess the differences between goods, or tell which is of higher or lower value. We refer to this throughout the manuscript as individuals' ability to *discriminate* between goods. The primary focus of this study is how individuals' behaviour changes when it is easier or harder to discriminate between goods.

There are examples of individuals' limited ability to discriminate between goods having significant economic consequences. A major scandal emerged in several European countries when various processed food products, labelled as containing meats such as beef and chicken, in fact contained horsemeat.[1] However, consumers had

[1]Source: http://www.bbc.com/news/uk-21375594 accessed 15/12/15.

apparently been eating such products for some time[2] without perceiving the difference between the adulterated products and the genuine article. It was only after DNA testing by regulatory bodies that the problem emerged. Another example is a British supplier of caviar, which mistakenly mislabelled its standard variety, costing around £40/kg., as Sevruga, which costs much more, around £1280/kg., for several months. No one noticed.[3]

The above two examples involve consumers interacting with profit maximizing firms. Although there was not necessarily any malice in either case, it is common for policy makers to be wary of firms taking advantage of consumers' perceptual limitations. Thus, for example, there are many laws against watering down alcohol, such as the US requiring beer to be within 0.3% ABV within the stated strength[4] and the EU setting various minimum strengths for spirits.[5] Hence it is not only important to study individuals' perceptual limitations in isolation, but also to study their impact in settings which feature strategic interactions.

When individuals with perceptual limitations meet profit maximizing firms in a market, it is easy to imagine that firms will be able to exploit consumers' limitations and benefit from them. Although the exploitation of consumers is intuitive, this might not necessarily be the case in practice. In Akerlof (1970)'s model of a market for lemons, consumers are unable to discriminate between high and low quality sellers. This results in the high type of firm being harmed due to its inability to differentiate its product. Taneva (2015) constructs a model in which a buyer finds it optimal to maintain limited perception of a good, to the detriment of the seller, even though she has the option of perceiving its value perfectly.

We studied the individual as well as the strategic dimension of perceptual limitations in two experiments which mirrored a setting in which consumers have to evaluate and choose between different goods. We did so using novel experimental goods that allowed how easy it was to discriminate between them to vary, while the underlying values were held constant. The individual dimension of perceptual limitations was studied using an individual evaluation task (experiment 1), whereas the strategic aspect of perceptual limitations was studied in a market setting featuring two sellers and two heterogeneous buyers (experiment 2).

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[2]Source: http://www.independent.co.uk/news/uk/home-news/horsemeat-scandal-findus-leak-reveals-horse-in-beef-for-six-months-8486602.html accessed 15/12/15.

[3]Source: http://www.telegraph.co.uk/news/uknews/10067876/Supplier-investigated-after-top-grade-caviar-contained-cheaper-variety.html, accessed 15/12/15

[4]Source: http://www.ttb.gov/pdf/ttbp51008_laws_regs_act052007.pdf

[5]Source: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32008R0110

As a first step in our analysis, we designed experiment 1 to elicit participants' willingness-to-pay (WTP) for the goods which were later used in our market experiment (experiment 2). The market experiment (experiment 2) was deliberately designed in a way that gave the sellers some market power. Against the background of the above-mentioned existing literature, perceptual limitations might lead to countervailing effects in such a strategic setting. On the one hand, sellers might potentially utilise their market power to exploit the consumers with perceptual limitations. On the other hand, if consumers are less able to discriminate between goods, this could increase competition, eroding sellers' market power and profits. We chose the specific market setting on an exploratory basis, to allow the potential for either of the two countervailing effects described above to occur.

Thus, our overall goals with this study were primarily (i) to introduce novel experimental goods and see whether it was possible to influence individuals' perceptions using these good, and (ii) to investigate the potential consequences of this manipulation in a strategic market environment in which perceptual limitations might potentially have countervailing effects on market outcomes. Over and above the economic interpretations of our results, our analysis can thus also be seen to a certain extent as a proof of concept, developing an experimental paradigm which could be used in future studies for theory testing.

In both of our experiments, goods are represented as pictures depicting matrices of coloured squares, with colours worth different amounts to subjects. By varying how coherent and organized the matrices are, the ease of discriminating between them is also varied (see examples in Figure 2.). The goods are also easy for subjects to comprehend and are not over-reliant on their cognitive or mathematical skills.

As said above, our ultimate goal was to examine perceptual limitations in a market environment, and as a preliminary step our first experiment investigated individual decision-making. We investigated how varying how easy it was to discriminate between goods impacts people's willingness-to-pay (WTP) for these goods. Results indicated that the perceptual manipulation in our first experiment was successful. WTP changed depending on the visual presentation of the goods, with WTP for goods becoming more similar the more difficult it was to discriminate between them. The more visually similar pictures became, the more similar individuals' WTP for the goods were.

Against the background of the successful perceptual manipulation in experiment 1, we studied a market setting in experiment 2. Specifically, we examined how the perceptual limitations identified in experiment 1 affected the outcome of a posted offer market. The posted offer markets consisted of two sellers and two buyers, with heterogeneous preferences among buyers which gave the sellers market power.

We sought to see how behaviour was influenced by how easy it was for buyers to discriminate between goods, whether it affected their willingness to enter the market, and what they purchased if they did enter. We also looked at how perceptual limitations affected whether they took the optimal action, and their final payoff. For sellers, we wanted to see how they would react when buyers found it more difficult to distinguish between rival sellers, and whether prices and profits were affected.

The results of experiment 2 revealed that buyers were less likely to enter the market when it was more difficult to distinguish between goods, and are also more likely to make a mistake by not buying the good offering the greatest consumer surplus. Despite these differences in how buyers acted, sellers did not significantly change their behaviour: the prices they set and the profit they earned did not change according to how difficult it was to perceive product differences. Lastly, comparing experiments 1 and 2, there is evidence that the market mechanism caused buyers to form their WTP in a different way compared to the subjects performing the valuation task, and there is some indication that using this different strategy was beneficial to the buyers.

A theoretical underpinning of the current paper is provided by Rubinstein (1988), building on work by Luce (1956) and Fishburn (1970). He provides an axiomatic treatment of choice in which individuals are unable to distinguish between sufficiently similar components of a choice set, so that the usual economic assumption of transitivity no longer holds. The experimental goods used in this paper attempted to partially operationalise this notion of similarity and inability to discriminate. However, it is important to note that Rubinstein treats discrimination as binary: either individuals are able to perfectly perceive two attributes as distinct or treat them as completely homogeneous. Here, a more continuous definition of similarity was employed, specifically normalized cross-correlation (NCC), a measure taken from the vision and image matching literature (see e.g. Simpson et al. (2013, 2003)).

Our operationalisation of similarity and ease of discrimination has much in common with the discipline of psychophysics. Commonly psychophysical studies measure how far apart two stimuli (light, heat, sound, etc.) must be in order to detect a difference between them with a given accuracy (Falmagne, 2002). The less similar the stimuli, the more reliably individual can discriminate between them.

Kalayci and Potters (2011) present the results of a market experiment. They introduced experimental goods for which the degree of complexity could be altered while the underlying value was held constant, thus making it more difficult for subjects to discriminate between them. Complexity was operationalised by having the value expressed as a sum of increased length. This introduced a much greater interdependence with subjects' cognitive and mathematical abilities compared to altering the visual appearance of goods, as is done here. It is common for consumers to use visual perception in everyday purchases. Thus, our experimental set up provides insights into how perceptual limitations impact consumer choice environments in which the visual representation of goods is important. The market in Kalayci and Potters also had many differences to the one presented here (homogeneous buyers, vertical as opposed to horizontal differentiation, different choice variables for sellers who are asymmetric, robot buyers for one treatment, etc.).

Kalayci and Serra-Garcia (2015) showed that complexity in goods' costs drives subjects to choose goods based only on their benefits. However, there was no analogous effect of choosing based only on cost with complex benefits. Spiegler (2016) presented a general framework in which to study the effect of choice complexity on market structure and Crosetto and Gaudeul (2012) showed experimentally that consumers prefer choices between simple goods to complex ones.

All the above studies varied perception of their goods by expressing their value as a mathematical formula of varying difficulty of calculation. One other study that did use a visual representation, albeit not for valuation or markets, is Ruud et al. (2014). That study they used a colour band of varying brightness, with subjects trying to estimate the position of the brightest part in order to investigate how their estimates were rounded. The greater the variation, the easier it was to pinpoint the target.

Compared to the economic literature, the visual perception of goods has often been studied in the marketing literature. For example, Walsh and Mitchell (2005) attempted to measure how susceptible consumers are to treating heterogeneous goods as similar. Chandon and Ordabayeva (2009) examined how changing the dimensions of a product influenced consumers' perception of its volume holding the actual volume constant. Kwortnik et al. (2006) looked at the effect of labelling on consumer choice, and similarly Nilufer and Krishna (2011) found that semantic cues from a label could influence the perceived size of a good. Lamberton and Diehl (2013) studied how retailers' physical arrangement of products influenced the similarity of consumers' perceptions of goods.[6]

In Section 2, we describe the experimental goods used. Section 3 reports the procedures and results from the first experiment, in which subjects individually stated their willingness-to-pay for goods, and section 4 details the second experiment, in which subjects traded goods in a market. We discuss the findings of both experiments in section 5 and conclude in Section 6.

2 Experimental goods

Our two experiments used pictures as experimental goods, each of which was a 10×10 matrix, with every cell having a value to subjects of between 1 to 9 points. We set the value of a whole picture as the sum of values over all cells. The value of a cell was represented by a colour, so that each picture formed a "heat map". In both experiments we assigned subjects to one of two groups which we label red and blue. In the red group, subjects valued red cells more highly than blue, whereas in the blue group, subjects valued blue cells more highly than red. An example picture is shown in Figure 1, along with a scale showing the value of squares to participants in the red group. The scale for the blue group was the reverse of this, so that the blue square furthest to the left had value 9 and the red square furthest to the right had value 1.

In both experiment 1 and 2, we presented the experimental goods, i.e. pictures in pairs to the subjects. We generated 30 picture pairs, with 10 pairs consisting of "block" pictures and 20 pairs consisting of "scrambled" pictures. Cell values for the scrambled pictures were randomly generated. Block type picture pairs, however, only differed by a block of cells in the top left-hand corner, with all other cells having a value of 5. The dimensions of this block were the same for both pictures in a pair, with the block on one picture consisting of cells of value 4 and the other of cells of value 6. Examples of both block and scrambled pictures are shown in Figure 2.

[6]There is also a large amount of research on visual attention in psychology. For an introduction to this literature, see Findlay and Gilchrist (2003).

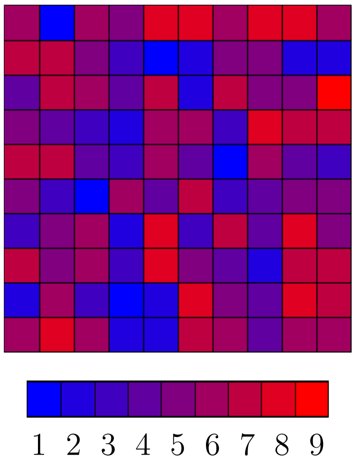


Figure 1. An example picture and the value scale for the red group.

We generated the pictures such that the values of each picture pair would sum to 1000. We introduced product differentiation by subtracting a given value from one picture and adding the same value to the other pair. The degrees of product differentiation used in both experiments are given in Table 1. The value difference between picture pairs ranged from 0 to 54, with a step of 6. The pictures we used thus ranged in value between 473 and 527. We informed the subjects that all pictures had a value between 460 and 540, and so their responses when stating WTP were restricted to be this range.

We measure the visual similarity of a picture pair by the normalized cross correlation (NCC), given by

$$NCC = \frac{1}{N\sqrt{\sigma_1^2 \sigma_2^2}} \sum_{i=1}^{N} \left(v_{1i} - \bar{v}_1\right)\left(v_{2i} - \bar{v}_2\right) \tag{1}$$

where v_{ji} is the value of cell i in picture j, v_j and σ_j^2 are the mean and variance of j and N is the number of cells in a picture, i.e. 100. NCC is a standard measure of visual similarity in image and vision research (Simpson et al., 2013, 2003) and takes values between -1 (very dissimilar) and 1 (identical). Block pictures all[7] had an NCC of -1 and scrambled pictures were constructed so that for each value difference, one pair had an NCC close to 0 and another pair had an NCC close to 0.9. For full details see Table 1.

[7]The exception is the (500, 500) pair. The 500 value block pictures consisted entirely of cells worth 5, and thus had 0 variance, and since calculating NCC requires dividing by the variance of both pictures, NCC was undefined. However, we treat it as if it had an NCC of -1.

Table 1. Picture pair values

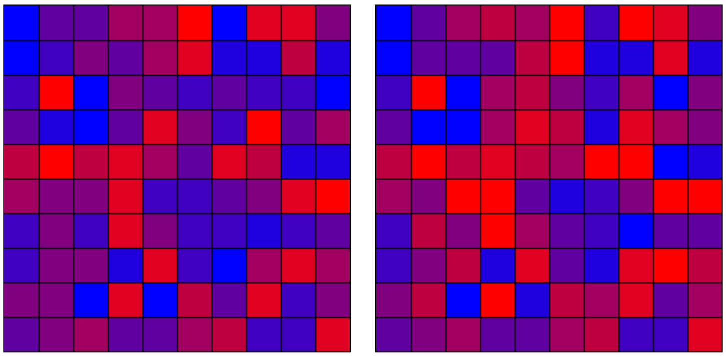
	Value difference									
	0	6	12	18	24	30	36	42	48	54
Picture 1 value*	500	503	506	509	512	515	518	521	524	527
Picture 2 value*	500	497	494	491	488	485	482	479	476	473
NCC (block)	—	-1	-1	-1	-1	-1	-1	-1	-1	-1
NCC (scrambled)	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.01
	0.90	0.91	0.90	0.91	0.91	0.91	0.91	0.91	0.91	0.90

Note. *Values shown are for participants in the red group. For the blue group, the values of a picture pair were reversed.

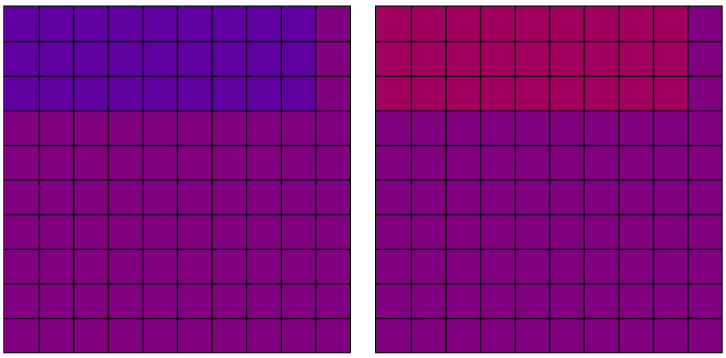
A total of 30 picture pairs were used in the experiments, two scrambled pairs and one block pair for each picture pair difference.

Figure 2. Picture pairs with values 473 and 527.

(a) Scrambled pictures



(b) Block pictures



We hypothesised that it would be easiest to discriminate between products for block pictures, followed by low NCC scrambled pictures, and then high NCC scrambled pictures.

Block pictures are qualitatively different to scrambled pictures, as they have only two colours rather than nine, and those two colours are grouped together. The reason for using block pictures, rather than for example images similar to scrambled pictures but with an NCC close to -1, was to include a condition in which we were as sure as possible that subjects could accurately discriminate between goods. Block pictures provided an appropriate baseline against which to judge the effects of perceptual limitations.

3 Experiment 1

As stated above, the overall aim of our study was to investigate whether and how manipulating the visual similarity of two goods would influence how they were traded in a market. As a preliminary step, we designed experiment 1 to elicit participants' willingness-to-pay (WTP) for the goods which were later used in our market experiment (experiment 2). The goods were presented in pairs to mirror how they would be presented in experiment 2, and to examine how WTP might be influenced by a context in which it was easier or more difficult to perceive differences between the goods.

Experiment 1 consisted of three different parts. In part 1, participants stated their WTP for a series of pairs of experimental goods. Parts 2 and 3 respectively consisted of eliciting subjects' risk preferences and evaluation skills.

3.1 Experimental procedures

In part 1, we elicited subject's WTP for the pictures over 30 periods. In each period, we showed a picture pair to the subjects and asked them to indicate the maximum price (in points) that they would be willing to pay for each. The Becker-DeGroot-Marschak (BDM) mechanism (Becker et al., 1963) determined the subject's payoff: For each picture, a randomly generated price between 460 and 540 points was drawn. If the randomly generated price was below, or equal to, a subject's WTP for a picture, the subject would buy it, so that the difference between its value and the random price was added to the subject's earnings. If the randomly generated price was above the subject's stated WTP, she would not buy the picture. Subjects had 30 seconds to enter their WTP. If they did not submit their WTP in time, they earned 0 for that picture. Figure A.1 shows a sample trial from the valuation task.

To avoid possible order effects, we presented the picture pairs in random order on a subject basis. We also chose at random which picture of a given pair to show on the left-hand side and the right-hand side of the screen.

In part 2, we elicited subjects' risk preferences using a task adapted from Eckel and Grossman (2002). Subjects had to choose one gamble they preferred from a list of gambles (see table B.1 for details). For each gamble there was a 50/50 chance of winning a high or low payoff, but as the list goes down the high payoff increases and the low payoff decreases in such a way that the expected value goes up but the guaranteed payoff goes down. Hence choosing a gamble lower on the list implies a subject is more risk seeking.[8]

In part 3, we presented subjects with six new scrambled picture pairs, two pairs each with the values (497,503), (485,515) and (473,527). Here, subjects estimated the values of the pictures, rather than their WTP, and their choices were rewarded using a scoring rule: They earned 80 points minus the absolute difference between their estimate and the picture's true value. The reward function here was different from part 1, and meant that the subject's incentive compatible response was to give their point estimate of a picture's value, rather than WTP. WTP could for example be lower than point estimates due to risk aversion. In this way, we also obtained a measure of how skilful the subjects were at perceiving pictures' true values.

Before beginning the experiment, we gave the subjects instructions to read on paper. To continue to the experiment, the subjects had to answer two control questions to ensure that they had understood the BDM mechanism correctly. Instructions can be found in appendix B. At the end of the experiment, the final payoffs were paid out in money using the exchange rate 10 points = 1 DKK. The average payment was DKK 205 (approximately US$30).[9]

[8]Note that this risk elicitation task which has also successfully been used in other studies (see e.g. (Dave et al., 2010; Reynaud and Couture, 2012)) was mainly chosen by us due to its simplicity and easy understandability.

[9]Buyers could theoretically make a loss over the course of the experiment by repeatedly buying pictures at a price higher than their true values. In the case that a participant made a loss overall they were informed that in this unlikely event they would have to work on a real effort task in order to earn back their show-up fee. No subject made an overall loss, and so none performed the real effort task.

Experiment 1 was implemented using zTree Fischbacher (2007). 95 subjects were recruited using ORSEE, Greiner (2015) and the experiment was carried out at the Laboratory for Experimental Economics (LEE) at the University of Copenhagen. 53 and 42 subjects participated in the red and blue group, respectively. In the invitation to take part, it we stated that colourblind individuals would not be able to participate. However we cannot guarantee that no participant was colourblind.

Intuitively, we expected that subjects would have greater difficulties in assessing picture value and in discriminating between goods when the goods were more visually similar. Firstly, we used NCC as a measure of visual similarity, and thus we hypothesized that the difference in WTP between pictures would be greater for block picture pairs than scrambled. Second, we hypothesized that the difference in WTP would be greater for scrambled pairs with low NCC than scrambled pairs with high NCC. We would judge the manipulation of subjects' perception as successful if these intuitive predictions could not be rejected.

3.2 Results

For each individual subject, we calculated the mean WTP for each of the three types of picture, and we used these subject-level observations for statistical testing. (Subject-level observations were used in a similar way throughout the analysis.) In Table 2 we show overall mean WTP (i.e. the average of the subject-level observations) for each of the three types of picture. WTP was highest for block pictures, then low NCC pictures, then high NCC pictures.

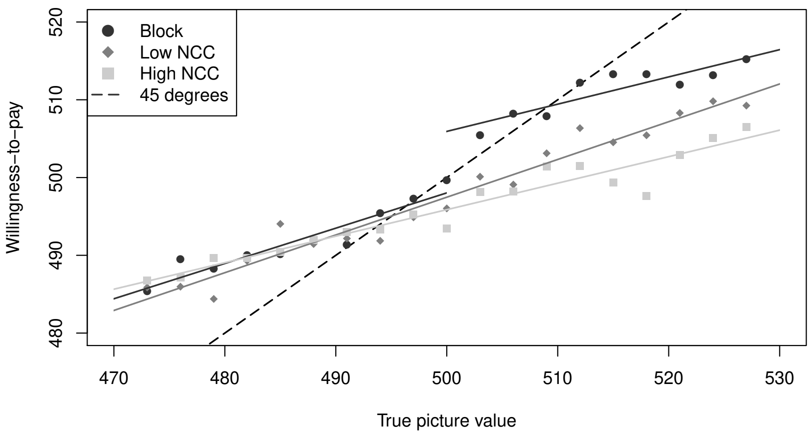
Disaggregating these results, Figure 3a shows the difference between true value and WTP as a function of pictures' true values. Subjects' tended to overpay for low valued pictures and underpay for high valued pictures, with the point at which they switch from one to the other coming somewhat below 500, the midpoint of the pictures' true values.

We show the results of fixed effects and pooled regressions with log WTP as the dependent variable in Table 3. The coefficient for ln value is the elasticity of WTP with respect to picture value, and was below 1. The interactions between ln value and picture type were significantly negative, indicating that the elasticity was lower for low NCC pictures compared to block pictures and lower still for high NCC pictures.

Summarizing the above:

Figure 3. Relationship between willingness-to-pay and true picture value

(a) Willingness-to-pay



(b) Difference in willingness-to-pay for a picture pair

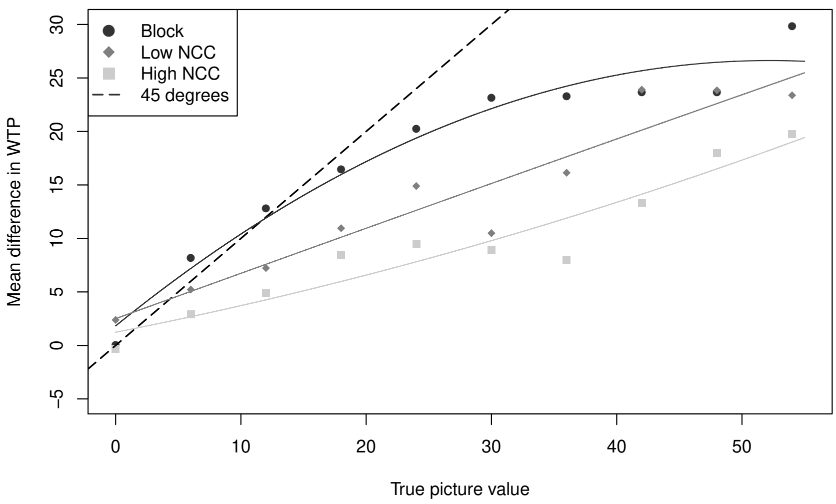


Table 2. Mean willingness-to-pay and mean difference in willingness-to-pay for a picture pair

	Block	Scrambled	
		Low NCC	HighNCC
WTP	501	497	496
Kruskal-Wallis p	0.001***		
WSR Test vs. Block p		0.003***	<0.001***
WSR Test vs. low NCC p			0.040**
Difference in WTP for a picture pair	18	14	9.29
Kruskal-Wallis p	<0.001***		
WSR Test vs. Block p		<0.001***	<0.001***
WSR Test vs. low NCC p			<0.001***

Note. WTP = willingness-to-pay; NCC = normalised cross-correlation; WSR = Wilcoxon signed-rank; *** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level, significance adjusted for Wilcoxon signed-rank tests using Holm's sequential Bonferroni correction (Holm, 1979). N=95.

Result 1. *(i) Subjects' average WTP was lower when picture pairs had a lower NCC.*

(ii) Subjects' average WTP was above picture value for low value pictures, and below picture value for high value pictures.

(iii) The elasticity of the WTP with respect to picture value was below 1, and the elasticity was lower for pictures with lower NCC.

In Table 2 we also summarise the mean differences in subjects' WTP for each picture of a pair, i.e. the differences between WTP for the higher valued of the pair and the lower valued of the pair. Differences in WTP were smaller for low NCC compared to block pictures, and smaller again for high NCC pictures. This can also be seen in Figure 3b, which shows difference in WTP as a function of picture pairs' value difference.

With Table 4 we report the results of regressions with WTP differences as the dependent variable. It confirms what is shown in Figure 3b: WTP differences were increasing in value differences, but at a declining rate.[10] In line with Table 2, the dummies indicating low and high NCC pictures were both significant and negative

[10]The quadratic functional form is preferred to a logarithmic one due to the large number of non-positive observations.

Table 3. Regression results with ln willingness-to-pay as dependent variable.

	(1) Fixed effects	(2) Pooled
ln value	0.609***	0.609***
	(0.000)	(0.000)
Low NCC	0.748***	0.756***
	(0.001)	(0.001)
Low NCC × ln value	-0.121***	-0.121***
	(0.001)	(0.001)
High NCC	1.65***	1.66***
	(0.000)	(0.000)
High NCC × ln value	-0.266***	-0.266***
	(0.000)	(0.000)
Period	0.000104	6.81E-05
	(0.235)	(0.443)
Skill		2.36E-05
		(0.966)
Gamble choice		0.00389***
		(0.008)
Gamble choice × low NCC		-0.00213
		(0.242)
Gamble choice × high NCC		-0.00496***
		(0.007)
Buyer type		-0.00478
		(0.257)

*Note.*NCC = normalised cross-correlation; subject fixed effects in model (1); standard errors clustered on subjects; p-values in parentheses; *** indicates significance at 1% level, ** indicates significance at 5% level, * indicates significance at 10% level; N=2850.

Table 4. Regression results for difference between willingness-to-pay for the lower and higher valued picture of a pair as dependent variable

	(1) Fixed effects	(2) Pooled
Value difference	0.608***	0.600***
	(0.000)	(0.000)
Value difference^2	-0.00298***	-0.00276**
	(0.009)	(0.016)
Low NCC	-3.48**	-4.87
	(0.012)	(0.133)
Low NCC × value difference	-0.0249	-0.0282
	(0.609)	(0.561)
High NCC	-5.41***	-6.71**
	(0.000)	(0.011)
High NCC × value difference	-0.118***	-0.124***
	(0.004)	(0.003)
Period	0.184***	0.179***
	(0.000)	(0.000)
Skill		-0.549***
		(0.000)
Gamble choice		-0.42
		(0.499)
Gamble choice × low NCC		0.386
		(0.590)
Gamble choice × high NCC		0.367
		(0.558)
Buyer type		1.81
		(0.134)

Note. NCC = normalised cross-correlation; subject fixed effects in model (1); standard errors clustered on subjects; p-values in parentheses; *** indicates significance at 1% level, ** indicates significance at 5% level, * indicates significance at 10% level; N=2850

in the fixed effects regression. In the pooled regression, both coefficients were again negative, but only that for high NCC pictures was significant. In neither regression did the coefficients differ significantly from each other (p-value 0.149 for fixed effects regression, p-value 0.597 for pooled regression).

This leads to the second set of results.

Result 2. *(i) The differences in subjects' WTP for picture pairs were lower for pairs with a lower NCC.*

(ii) WTP difference were increasing in value differences.

To conclude, experiment 1 showed that we could manipulate the subjects' perception of the experimental goods by changing the goods' visual similarity. This manipulation could be done while holding the underlying values of the pictures constant. The difference in subjects' WTP between the two goods was largest when the pictures were least visually similar (block pictures with NCC $= -1$), and lowest when the pictures were most visually similar (scrambled pictures with NCC ≈ 0.9).

3.3 Discussion

With experiment 1 we present a methodological contribution. The results showed that it was possible to manipulate individuals' perception of the experimental goods and that NCC was a useful measure of the goods' visual similarity that correlated with subjects' actions. The difference between subjects' WTP for the higher-valued and lower valued goods of a pair was greatest when the pictures were least visually similar (NCC = -1). When the goods were most visually similar (NCC$\approx$0.9) and it was most difficult to discriminate between them, there was less difference between subjects' WTP for each good in a pair.

Experiment 1 also provided insights into the way individuals valued the experimental goods. The value 500 appeared to be a salient focal point. This finding was not too surprising, as it was not just the only value with two zeros in the set of picture values shown to participants, but was also the midpoint.[11] This can be seen in Figure 3a, in which subjects tended to overpay, stating WTPs above true value for picture values below 500. However, the subjects tended to underpay by stating WTPs below true value for picture values above 500, although the point at which the lines of best fit cross the x-axis is somewhat below 500 (possibly due to loss or ambiguity aversion). Thus the greater the distance of true value from the focal point of 500, the greater the distance between true value and stated WTP. These results were suggestive of subjects using an anchoring and adjustment mechanism when constructing valuations. They anchored their valuation, and then adjusted, but not sufficiently, either up or down.

[11] Note that this holds both for the range of picture values actually presented and the range of possible values given to subjects in the instructions.

The elasticity of WTP with respect to a picture's true value was lower the more visually similar pictures were. This may have been due to caution in not wishing to overpay for pictures whose value was harder to assess, at least for pictures with values above 500.

Differences in subjects' WTP for a picture pair increased with value differences, as was expected, but at a declining rate, shown in Figure 3b. For block pictures, this may have been due to subjects being able to perform the relatively simple calculations to find the true value for pairs with low value differences, yet struggling with the more complicated calculations for higher value differences. (For example, with values (497, 503) subjects needed to count 3 squares of value 4, then subtract 3 from 500 and count 3 squares of value 6 then add 3 to 500. For values (473, 527) they needed to count 27 squares of value 4, 27 squares of value 6, then respectively add and subtract 27 from 500). This explanation could not have held with scrambled pictures though, as it was unfeasible to calculate their true values in the time allowed. This may then, as an alternative to the aforementioned anchoring and adjustment explanation, have been due to a diminishing sensitivity to the magnitude of the difference. Such a diminishing sensitivity has previously been found in psychological studies of individuals' sense of numerosity (Dehaene et al., 2008).

4 Experiment 2

Having established a set of experimental goods that people evaluated differently depending on their appearance and visual similarity, we could continue to examine what effect limited perception would have in a strategic market setting. In order to do this, we introduced the experimental goods of experiment 1 into a market environment in experiment 2.

We argued in the introduction that it is difficult to form a clear intuition as to the effect perceptual limitations can have on a market. On the one hand, sellers with some market power could exploit perceptual limitations to increase profits. On the other hand, if consumers are less able to discriminate between goods, this could increase competition, eroding sellers' market power and profits. We chose the specific market setting on an exploratory basis, to allow the potential for either of the two countervailing effects described above to occur. Each market had two sellers, which allowed for competition between them. The markets also featured two buyers, who were heterogeneous (one red type and one blue type). This allowed each seller to have some market power by attracting the buyer type to whom her good was worth more.

We aimed to explore the effect of visual similarity on, for buyers:-

(i) Whether they made a purchase or not.

(ii) Conditional on entering the market, whether they purchased the high or low value good.

(iii) Whether they made a mistake by failing to take the action which would give them the highest surplus.

(iv) Final payoff

For sellers, we aimed to explore the effect of visual similarity on:-

(i) Price set.

(ii) Final profit.

If sellers are able to exploit perceptual limitations, we expected that scrambled pictures would lead to higher seller profits and lower buyer surplus, in comparison to block pictures. Conversely, if buyers perceiving goods as more similar result in greater competition between sellers, we expected that scrambled pictures would lead to lower seller prices and profits and higher buyer surplus, in comparison to block pictures. Neither sellers exploiting consumers' perceptual limitations nor similar goods leading to increased competition gives a clear expectation of the effect of perceptual limitations on whether buyers purchase or whether they purchase the high/low value good.

4.1 Experimental procedures

Subjects took part in a posted offer market, where we assigned them a role as either a buyer or a seller. The subjects kept their role throughout the experiment, and buyers were also assigned to be either a red type or a blue type, which again they kept for the entire experiment. As in experiment 1, red buyers valued red cells more highly and blue buyers valued blue cells more highly.

Each market consisted of four people: two sellers, one red buyer and one blue buyer. Each seller could sell only one type of good, and buyers could choose to buy one unit from either seller, or not purchase. The good pairs used were the same as in experiment 1. Thus one seller could sell a good worth (weakly) more to the red type and one could sell a good worth (weakly) more to the blue type.

Each subject traded each good pair once, so that there were 30 market periods in all. In each session, approximately half of subjects traded the 10 block picture pairs first, with the other half trading the 20 scrambled picture pairs first. Within these sets of block and scrambled pictures we randomized the order of the good pairs, with the same order used for all subjects. We randomly re-matched with subjects with other subjects who saw the block and scrambled pictures in the same order every period, and this was common knowledge. Matching groups were between 8 and 16 in size, with a median of 12.

Each period had two stages. In the first stage, we informed sellers about the true value of their own picture to both buyer types as well as the values of the other seller's picture. Sellers then had 60 seconds to set a price for their picture. If they exceeded this limit they were prompted to make their choice immediately, but there were otherwise no other consequences for exceeding the time limit. In the second stage, buyers could choose between buying a picture from seller 1, or from seller 2, or to abstain from buying. Buyers had 30 seconds in which to make their choice. If they did not make a choice, they bought nothing that round.

If a seller sold a good to a buyer, the seller earned the price she set minus a fixed cost of 450 points. Sellers could not set prices below 450 and thus could not sell at a loss. If a buyer bought a good, she earned its true value minus the price set by the seller. After each period, we showed sellers a feedback screen informing them of the price they set, the price set by the other seller, and whether they sold zero, one or two goods. We did not give buyers any feedback about their payoffs between rounds. Figure A.2 shows example screens from stages 1 and 2.

Following the 30 market periods, we measured risk preferences by presenting subjects with the same gamble choice as in experiment 1. Afterwards, we asked subjects (both buyers and sellers) to estimate the values of six scrambled pairs, and then finally the subjects answered a questionnaire, as in experiment 1.

Subjects had the instructions available on paper and had to answer control questions correctly in order to continue. The instructions are reproduced in appendix B. At the end of the experiment the final payoffs were paid out in cash using an exchange rate of 10 points = 1 DKK. The average payment was DKK 230 (approximately US$35).[12]

We implemented Experiment 2 using zTree. We recruited 112 subjects using ORSEE, and the experiment took place at LEE at the University of Copenhagen. In the invitation to take part, we stated that colourblind individuals would not be able to participate, although we cannot guarantee that no subject was colourblind. One subject left part way through a session due to illness, and data from that session following her departure is excluded from the analysis.

4.2 Results

We present summary statistics for various variables of interest in Table 5.

Beginning with buyers, we observed differences in their behaviour across picture types: In markets with block pictures, buyers made a purchase 92.7% of the time, significantly higher than the equivalent rates of 85.3% for both high and low NCC scrambled pictures.

We show the results of a logit regression with whether a buyer made a purchase as the dependent variable in Table 6. There is confirmation that there was a significant difference between the purchase rate of block and scrambled pictures. For each picture pair there was one that has a (weakly) higher value and one that has a (weakly) lower value to the buyer. Denote the higher value picture as h and the lower value picture as ℓ. Increasing the price of h made buyers more reluctant to buy, however the coefficient on the price of ℓ was not significant. Although there was some price sensitivity, there was no strong evidence that there were differences in price sensitivity across picture types. None of the interaction terms of price with picture type dummies were significant at the 5% level. Furthermore, those which did achieve significance at the 10% level did not do so consistently over both regression specifications. Thus, we can highlight a first set of results.

[12] As in experiment 1, buyers could theoretically make an overall loss, however no one did.

Table 5. Summary statistics from experiment 2

	Block	Scrambled	
		Low NCC	HighNCC
Buyer purchases per period	0.927	0.853	0.853
Kruskal-Wallis p	0.007***		
WSR Test vs. Block p		0.022**	0.002***
WSR Test vs. low NCC p			0.759
Buyer purchases of h cond. on buying	0.823	0.753	0.815
Kruskal-Wallis p	0.010***		
WSR Test vs. Block p		0.011**	0.903
WSR Test vs. low NCC p			0.009**
Buyer mistakes per period	0.0964	0.171	0.146
Kruskal-Wallis p	0.001***		
WSR Test vs. Block p		0.005**	0.010**
WSR Test vs. low NCC p			0.509
Buyer profit per period	21.7	17.4	19.6
Kruskal-Wallis p	0.023**		
WSR Test vs. Block p		0.018*	0.182
WSR Test vs. low NCC p			0.049*
Seller price	490.2	491	489.9
Kruskal-Wallis p	0.718		
WSR Test vs. Block p		0.4	0.961
WSR Test vs. low NCC p			0.075
Seller profit per period	33.6	32.9	31.5
Kruskal-Wallis p	0.465		
WSR Test vs. Block p		0.273	0.245
WSR Test vs. low NCC p			0.173

p-values for tests of difference across picture type; WSR = Wilcoxon signed-rank; NCC = normalised cross-correlation; h = higher valued picture; *** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level, threshold values for significance adjusted for Wilcoxon signed-rank tests using Holm's sequential Bonferroni correction; N=56.

Table 6. Logit regression results for buyer purchase and choosing h conditional on purchasing

	Buyer purchase		Purchase h cond. on buying	
	(1)	(2)	(1)	(2)
	Fixed effects	Pooled	Fixed effects	Pooled
h price	-0.0412***	-0.0427***	-0.0537***	-0.0540***
	(0.007)	(0.001)	(0.005)	(0.001)
h price × low NCC	0.0134	0.0239	-0.0153	-0.00295
	(0.469)	(0.196)	(0.410)	(0.867)
h price × high NCC	0.0125	0.0219	-0.0331	-0.0226
	(0.566)	(0.199)	(0.139)	(0.262)
ℓ price	-0.0182	-0.0205	0.0914***	0.0737***
	(0.259)	(0.147)	(0.000)	(0.000)
ℓ price × low NCC	0.0289	0.0296	-0.0458	-0.0414
	(0.166)	(0.126)	(0.194)	(0.168)
ℓ price × high NCC	0.0280*	0.0312***	-0.00369	-0.0101
	(0.085)	(0.009)	(0.908)	(0.730)
h value	-0.0207	-0.0139	0.0768***	0.0678***
	(0.319)	(0.451)	(0.007)	(0.004)
Low NCC	-35.5***	-39.1***	0.545	-0.468
	(0.004)	(0.002)	(0.980)	(0.978)
Low NCC × h value	0.0268	0.0185	0.0556*	0.0406
	(0.344)	(0.487)	(0.064)	(0.111)
High NCC	-59.1***	-57.9***	-2.18	-2.27
	(0.004)	(0.001)	(0.925)	(0.919)
High NCC × h value	0.0745*	0.0586	0.0386	0.0358
	(0.063)	(0.104)	(0.312)	(0.254)
Period	0.0179	0.0164	0.0335**	0.0228*
	(0.137)	(0.165)	(0.032)	(0.054)
Order		-0.123		-0.376
		(0.658)		(0.124)
Skill		-0.0981*		-0.0208
		(0.098)		(0.405)
Skill × low NCC		0.153**		-0.0207
		(0.040)		(0.630)
Skill × high NCC		0.0867		-0.0508
		(0.255)		(0.272)
Buyer type		0.255		-0.0467
		(0.113)		(0.867)
Gamble choice		0.170*		-0.273***
		(0.055)		(0.005)
Gamble choice × low NCC		0.127		0.216
		(0.416)		(0.139)
Gamble choice × high NCC		-0.0828		0.0287
		(0.341)		(0.841)

Note. Subject fixed effects; standard errors clustered on matching groups and subjects; p-values in parentheses; NCC = normalised cross-correlation; h (ℓ) = higher (lower) valued picture; *** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level; N=1590 for buyer purchase, N=1391 for purchasing conditional on buying

Result 3. *(i) Buyers were more likely to purchase block than scrambled pictures.*

(ii) A higher price for h significantly reduced the probability of purchase, but the price of ℓ had no effect on the purchase probability.

(iii) Buyers' price sensitivity did not change over picture type.

Table 5 also summarises what buyers bought conditional on purchasing. With block pictures, buyers purchased h 82.3% of the time, significantly higher than the equivalent rate of 75.3% with low NCC pictures. It was also higher than the purchase rate of 81.5% for high NCC pictures, although not significantly so. However, these results are not reproduced in logit regressions for purchasing h conditional on entering the market, the results of which are given in Table 6. The dummies indicating picture type were not significant, and in the fixed effects regression, the coefficient on the dummy for low NCC pictures was even positive. The contradiction between the results in Table 5 and Table 6 was possibly due to some heterogeneity in the way buyers reacted to scrambled pictures. The precise effect of picture type on buyers tendency to purchase h was thus not clear.

It is, however, possible to see that buyers were more likely to purchase h when it had a higher value. With the particular set of goods used here, this also implies that buyers purchased h more frequently when the value difference between the two pictures was greater.

The price of h lowered its purchase frequency and the price of ℓ raised it. Again, there was little evidence that buyers' price sensitivity differed over picture type. None of the interactions of the price of h with picture type dummies were significant. The interaction of the price of ℓ with low NCC was significant, but only at the 10% level, and its interaction with high NCC was not significant.

This leads to the second set of results for experiment 2:-

Result 4. *Conditional on purchasing:*

(i) Buyers' were more likely to buy h when it had a higher value, or equivalently, when the value difference between the pictures was greater.

(ii) The probability of purchasing h was decreasing in the price of h and increasing in the price of ℓ.

(iii) Buyers' price sensitivity did not change over picture type.

We also examine whether buyers make "mistakes" when purchasing. We define a mistake as buying the picture which offered inferior surplus or as not buying when at least one picture offered a positive surplus. Table 5 shows that the mean mistake rates of 17.1% and 14.6% for high and low NCC scrambled pictures were both significantly higher than the mean mistake rate for block pictures of 9.6%.

In Table 7 we report the results of a logit regression with whether a buyer made a mistake or not as the dependent variable. The coefficient for the value of h was significantly positive, implying that for block type pictures, the probability of a buyer making a mistake increased as the value difference between goods increased. The reverse was seen for scrambled pictures: The coefficients on interactions between both scrambled dummies and the value of h. This is illustrated in Figure 4a.

A possible explanation for the above result is that the strategies the buyers used to evaluate the goods may have been different depending on the picture type. For block pictures, buyers may have been able to calculate the exact picture values and surpluses from buying. However, this strategy was more cognitively demanding for higher valued pictures. For scrambled pictures it was presumably always impossible for buyers to calculate the exact surpluses. However, with higher value goods, implying also a greater value difference between good pairs, it was easier to visually identify the highest value good (i.e. which of the goods seemed most red/blue).

From the regressions we see that the probability of making a mistake fell over the course of the experiment, possibly due to learning.

Summarising:

Result 5. *(i) Buyers were more likely to make mistakes with scrambled pictures than with block pictures.*

(ii) For block pictures, buyers were more likely to make mistakes when the value difference between goods was greater.

(iii) For scrambled pictures, buyers were less likely to make mistakes when the value difference between goods was greater.

Buyers earned an average payoff of 21.7 points per period with block pictures, compared to 17.4 per period for low NCC and 19.6 per period for high NCC pictures. The Kruskal-Wallis test indicates differences between the three picture types, although none of the pairwise tests achieves significance at the 5% level after adjusting for multiple testing.

Table 7. Regression results for buyer mistakes and buyer surplus

	Buyer mistake		Buyer surplus	
	(1)	(2)	(1)	(2)
	Fixed effects	Pooled	Fixed effects	Pooled
h price	0.0160*	0.0147	—	—
	(0.053)	(0.105)		
h price × low NCC	0.000573	-0.00347	—	—
	(0.964)	(0.795)		
h price × high NCC	-0.0158	-0.0144	—	—
	(0.196)	(0.156)		
ℓ price	0.000229	-0.000358	—	—
	(0.986)	(0.975)		
ℓ price × low NCC	-0.00928	-0.00459	—	—
	(0.664)	(0.802)		
ℓ price × high NCC	-0.0146	-0.00973	—	—
	(0.331)	(0.377)		
h value	0.0125	0.0121	0.230**	0.228**
	(0.567)	(0.574)	(0.040)	(0.043)
Low NCC	36.1**	34.9**	-119**	-130**
	(0.032)	(0.030)	(0.034)	(0.024)
Low NCC × h value	-0.0605**	-0.0573**	0.225**	0.233**
	(0.028)	(0.031)	(0.041)	(0.030)
High NCC	45.0***	39.7***	-204**	-203**
	(0.001)	(0.002)	(0.011)	(0.014)
High NCC × h value	-0.0574**	-0.0550**	0.394**	0.401***
	(0.033)	(0.032)	(0.013)	(0.010)
Period	-0.0344***	-0.0336***	0.396***	0.423***
	(0.001)	(0.003)	(0.000)	(0.000)
Order		0.288		5.53**
		(0.133)		(0.029)
Skill		0.054		-0.373*
		(0.106)		(0.080)
Skill × low NCC		-0.0597		0.555*
		(0.310)		(0.075)
Skill × high NCC		0.0151		-0.157
		(0.696)		(0.587)
Buyer type		0.0388		0.0654
		(0.816)		(0.957)
Gamble choice		-0.0474		0.0297
		(0.516)		(0.968)
Gamble choice × low NCC		0.0048		-0.204
		(0.964)		(0.793)
Gamble choice × high NCC		0.187**		-0.85
		(0.046)		(0.269)

Buyer fixed effects; standard errors clustered on matching groups and subjects; p-values in parentheses; NCC = normalised cross-correlation; h (ℓ) = higher (lower) valued picture; *** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level; N=1590.

In columns 3 and 4 of Table 7 we show the results of regressions with buyer surplus as the dependent variable. The dummies indicating low and high NCC pictures were both significantly negative, giving weight to the results in Table 5. Buyer surplus was increasing in the value of h.

Result 6. *(i) Buyer surplus was lower for scrambled than for block pictures.*

(ii) The difference in the surplus buyers earned from block and scrambled pictures was lower when the value difference between goods was greater.

Buyer surplus was lower with scrambled pictures, which is consistent with sellers being able to exploit perceptual limitation, and inconsistent with perceptual limitations benefiting buyers due to increased competition between sellers. However, no firm conclusions can be drawn without also examining sellers' behaviour.

Sellers set an average price of 490.2 for block pictures, 491 for low NCC scrambled pictures and 489.9 for high NCC scrambled pictures. A Kruskal-Wallis test p-value of 0.718 indicated that sellers did not adjust their behaviour across picture type. Sellers made an average profit of 33.6 points per period for block pictures, compared to 32.9 and 31.5 for low and high NCC pictures respectively. A Kruskal-Wallis test that sellers' mean profit per picture differs over picture type had a p-value of 0.465, indicating no significant difference. Table 8 shows the results of regressions of sellers' price setting behaviour and seller profit. In neither was a significant effect found of picture type. Seller price and profits are illustrated in Figure 5.
To summarise the findings for sellers:-

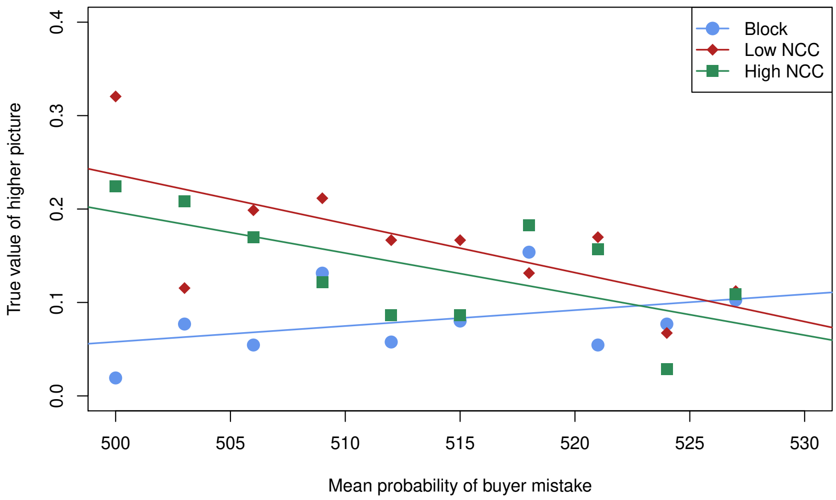
Result 7. *There was no significant effect of picture type on sellers' prices*

Result 8. *There was no significant effect of picture type on seller profit.*

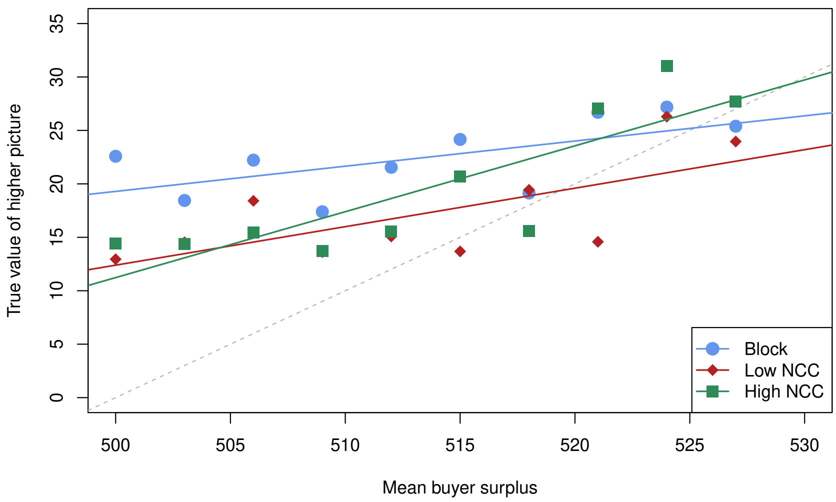
Seller prices and profits being the same for block and scrambled pictures implies that neither of the postulated countervailing effects of sellers exploiting buyers' perceptual limitations and perceptual limitations increasing seller competition was dominant.

Figure 4. Buyer behaviour

(a) Probability of buyer mistakes



(b) Buyer surplus



Note. NCC = normalised cross-correlation

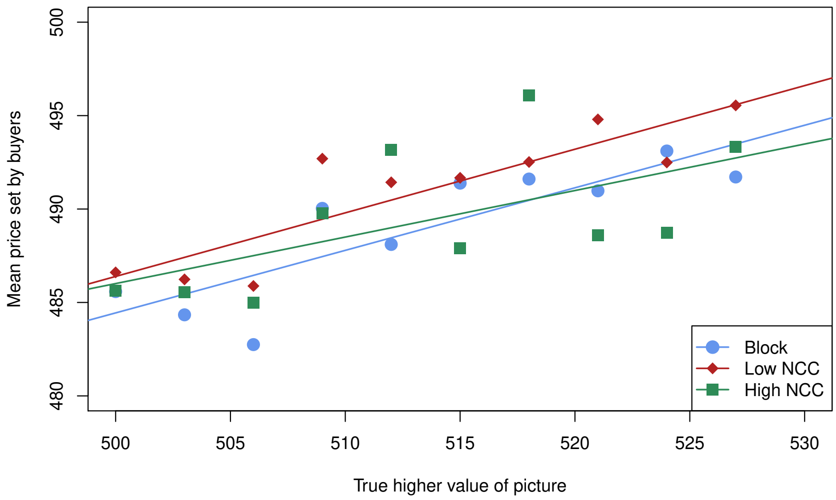
Table 8. Regression results for seller price and seller profit.

	Seller price		Seller profit	
	(1)	(2)	(1)	(2)
	Fixed effects	Pooled	Fixed effects	Pooled
Good value†	0.302***	0.304***	0.333**	0.336**
	(0.004)	(0.004)	(0.021)	(0.019)
Low NCC	8.62	14.6	34.2	38.1
	(0.856)	(0.761)	(0.707)	(0.670)
Low NCC × Good value†	-0.0167	-0.0239	-0.0693	-0.0797
	(0.858)	(0.798)	(0.696)	(0.651)
High NCC	28.7	29.3	-8.92	-8.07
	(0.560)	(0.553)	(0.929)	(0.935)
High NCC × Good value†	-0.0567	-0.0611	0.0119	0.00345
	(0.558)	(0.532)	(0.951)	(0.986)
Period	-0.286***	-0.313***	-0.148*	-0.187**
	(0.000)	(0.000)	(0.084)	(0.029)
Order		-6.78***		-5.19***
		(0.004)		(0.002)
Skill		-0.121		-0.505
		(0.749)		(0.105)
Skill × low NCC		0.0663		0.0882
		(0.819)		(0.797)
Skill × high NCC		0.0198		0.434
		(0.941)		(0.239)
Seller type		2.44		3.40**
		(0.280)		(0.049)
Gamble choice		0.886		0.0607
		(0.328)		(0.936)
Gamble choice × low NCC		-0.698		0.308
		(0.362)		(0.719)
Gamble choice × high NCC		0.532		-0.238
		(0.503)		(0.809)

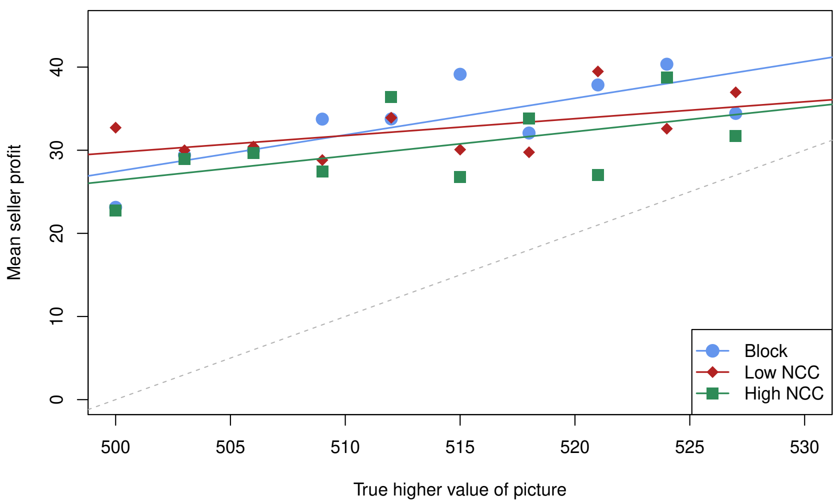
Seller fixed effects; standard errors clustered on matching groups and subjects; p-values in parentheses; †value to whichever buyer type valued it more; NCC = normalised cross-correlation; h (ℓ) = higher (lower) valued picture; *** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level; N=1590.

Figure 5. Seller behaviour in the market

(a) Price set



(b) Seller profit



Note. NCC = normalised cross-correlation

Summing up experiment 2, we found that buyers' propensity to purchase was higher for block pictures than for scrambled pictures when it was more difficult to discriminate between them. This is consistent with the finding that buyers were more likely to make a mistake when the market featured scrambled pictures, compared to block pictures. We also found that sellers did not attempt to exploit buyers' perceptual limitations, as the prices they set and the profits they earned did not significantly differ by picture type.

4.3 Discussion

Buyers' propensity to buy was lower for scrambled pictures. This reluctance can be explained by the fact that they were much more likely to make mistakes when the market featured scrambled pictures. it can be seen in Figure 4a that buyers' propensity to make mistakes was increasing in the value of h for block pictures, but for scrambled pictures it was decreasing. This convergence may have been due to it being more difficult to calculate the value of block pictures as their values increased, leading to more errors. However, for scrambled pictures it became easier to distinguish which picture has the greater true value when the value difference between them was greater, and thus mistakes were rarer.

It is possible to examine the role buyers' skill in perceiving the true value of pictures plays.[13] There was a correlation between skill and buyers' actions, with more skillful buyers being more willing to purchase, possibly as they were surer of earning a positive surplus. They were also less likely to make mistakes. However, there was no significant correlation between skill and buyers' payoffs.

While buyers' actions changed depending on picture type, those of sellers did not. Neither the prices set nor profits earned differed between block and scrambled picture types.

Sellers set a higher price for goods which were worth more (at least to one of the two buyers), indicating that they posses some market power. However, the coefficient in the fixed effects regression was below 1, indicating the market power was not full. Despite this, they were not able to exploit buyers' perceptual limitations. Nor did sellers' market power appear to be reduced by buyers finding it more difficult to discriminate between goods.

[13]Note that since the measure was constructed as the mean absolute difference between true values and a subject's estimates of true values, a lower number indicates greater skill.

One possible explanation for this result is that sellers found the market structure too complicated and confusing, and thus were unable to work out how to make a greater profit from scrambled pictures. However, evidence against this explanation is the fact that all sellers were able to answer control questions to verify that they understood their environment. In addition, they were able to exercise market power, indicating that sellers had some strategic knowledge of the market institution.

The greater propensity for buyers to make mistakes was consistent with the intuition that sellers may be able to increase profits by exploiting buyers' perceptual limitations. For example, in the limit when buyers have a mistake rate so high they effectively choose at random, sellers' optimal action is to set the highest possible price.

On the other hand, buyers were more reluctant to enter the market with scrambled pictures: many buyer mistakes took the form of "leaving money on the table". Furthermore, results indicated that buyers' propensity to purchase was price sensitive, giving sellers had an incentive not to increase prices. A potential interpretation of the observed pattern of results is that sellers' ability to exploit perceptual limitations was counterbalanced by buyers' reluctance to enter the market, perhaps due to fear of being exploited. There are interesting implications of this interplay, in that the willingness of individuals to enter a market may depend on their outside option. When individuals' outside option is poor, the exploitation of perceptual limitations becomes more likely. Future research could investigate whether sellers would increase the price of scrambled pictures if they knew that buyers would have to purchase a good.

5 General discussion

This article is an example that moving beyond individual choice biases is important, as the impact of perceptual limitations on market and strategic interactions can be complex and non-intuitive.

We did not have a clear intuition as to whether buyers in this market institution would be helped by perceptual limitations increasing competition or hurt by sellers exploiting perceptual limitations. It is clear that the market did not eliminate the impact of perceptual limitations entirely, as buyers made less surplus from scrambled than block pictures. However, it is also not clear that they were hurt by the market mechanism either: Sellers did not appear to exploit buyers' perceptual limitations as they made no greater profit from scrambled pictures compared to block pictures. In fact, there was some evidence that buyers were helped by interacting in a market: Buyers' surplus in experiment 2 was significantly greater than predicted by willingness-to-pay stated in experiment 1 at the 10% level. There were many differences between experiments 1 and 2, but the goods buyers were presented with were the same. The differences, for example being given prices rather than being asked to state WTP, may have prompted buyers to use a different strategy, which was certainly not harmful, and was possibly beneficial.

The range of values we chose for the goods in this study was narrow, with the maximum value difference being only around 10% of the value of each good. On the other hand, the fixed cost imposed in experiment 2 meant value differences were a greater fraction of sellers' potential profits.

There was a significant effect of period on almost all variables of interest. The goods we used were unfamiliar to subjects, and the environment may have been somewhat confusing, with the value of the traded goods changing each period. Thus the time the markets take to adjust is long, and there was some evidence that the adjustment is still going on at the end of 30 periods. A future avenue of research might hence be to see the results when a market with perceptually limited buyers has adjusted fully, either by allowing for more periods or by simplifying the environment.

Comparing our experimental goods used here with the assets expressed with varying degrees of mathematical complexity used by Kalayci and Potters (2011) and others, we suggested in the introduction that the goods we used might possess greater external validity. This arguably is the case when the situation modelled is consumer choice, in which visual appearance is a large component in individuals' decision-making. Visual attention is a neglected aspect of choice in economics, and should be considered more. On the other hand, for many goods, e.g. insurance and other financial products, individuals' cognitive abilities are arguably more important in choice, in which case a mathematical representation of goods may have greater external validity. A comparison of the relative efficacy and appropriateness of the visual and mathematical representations of goods would be a useful subject for future research.

6 Conclusion

In this study we contribute to the literature on the importance of perceptual limitations on markets by introducing novel experimental goods. We were able to vary the visual similarity of the goods while holding their underlying values constant. The experimental results showed that subjects were able to understand the concept of the goods, that the manipulation of subjects' perception was successful and that NCC was a useful measure of visual similarity.

Furthermore, our analysis showed that when individuals found it difficult to perceive the degree of product differentiation, their willingnesses-to-pay for goods become closer together. In addition, perceptual limitations increased buyer mistakes in a market, thus lowering their payoff, although there were indications that the market institution aided buyers relative to individual choice.

In this paper we intentionally took an exploratory path, with no specific hypothesis tested and there is much further work possible using our framework. There are many different ways that markets can be structured, and the selection of any particular market rules in this study would inevitably have been to a certain extent arbitrary.

Future research could usefully explore the effect of perceptual limitations in other environments. For example, a standard Bertrand game with no product differentiation where the equilibrium is price at marginal cost. It could be examined whether making it harder for participants to discriminate between goods allows sellers to set prices above marginal costs and make positive profits. In our experiment, firms were restricted to competing on price, and could not choose whether to sell block or scrambled pictures. Future experiments could allow firms the choice of what picture type to sell, similar to the literature on firms selling shrouded or unshrouded goods (Spiegler, 2014; Wenzel, 2014; Chioveanu and Zhou, 2013; Gabaix and Laibson, 2004).

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Appendices

A Screenshots

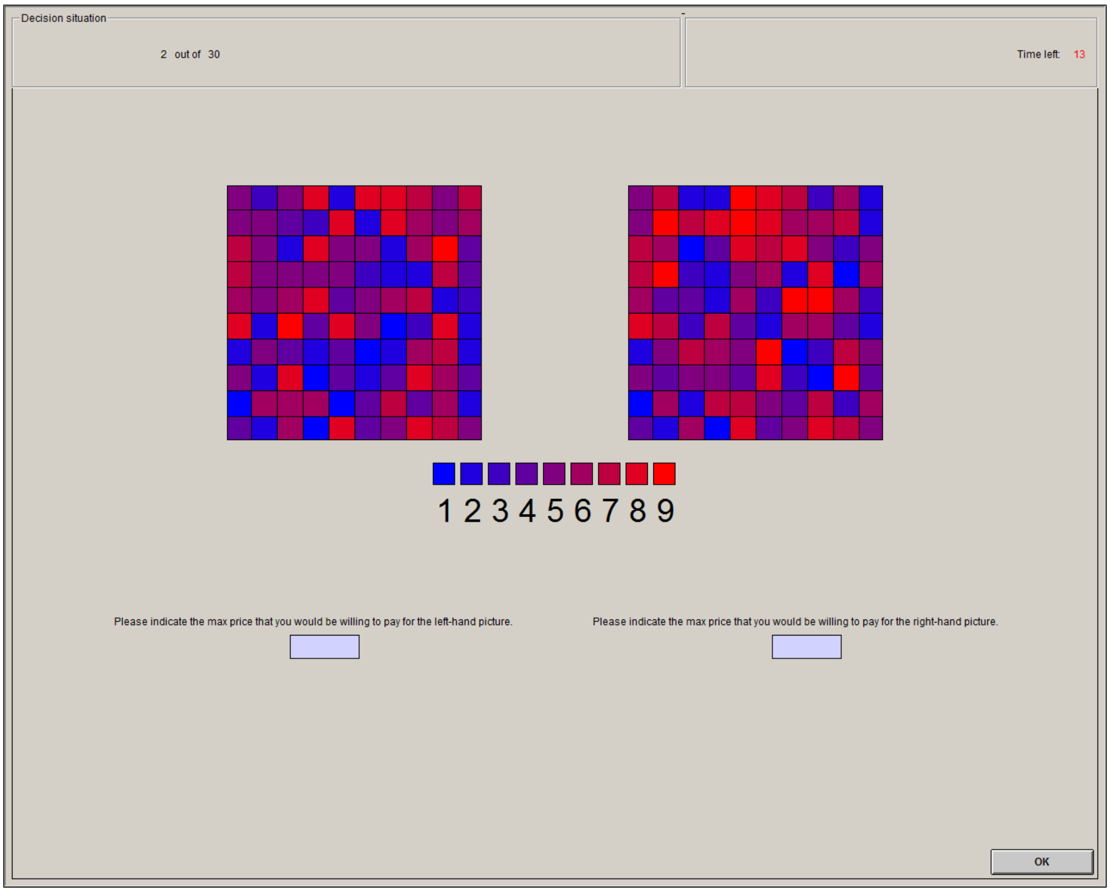
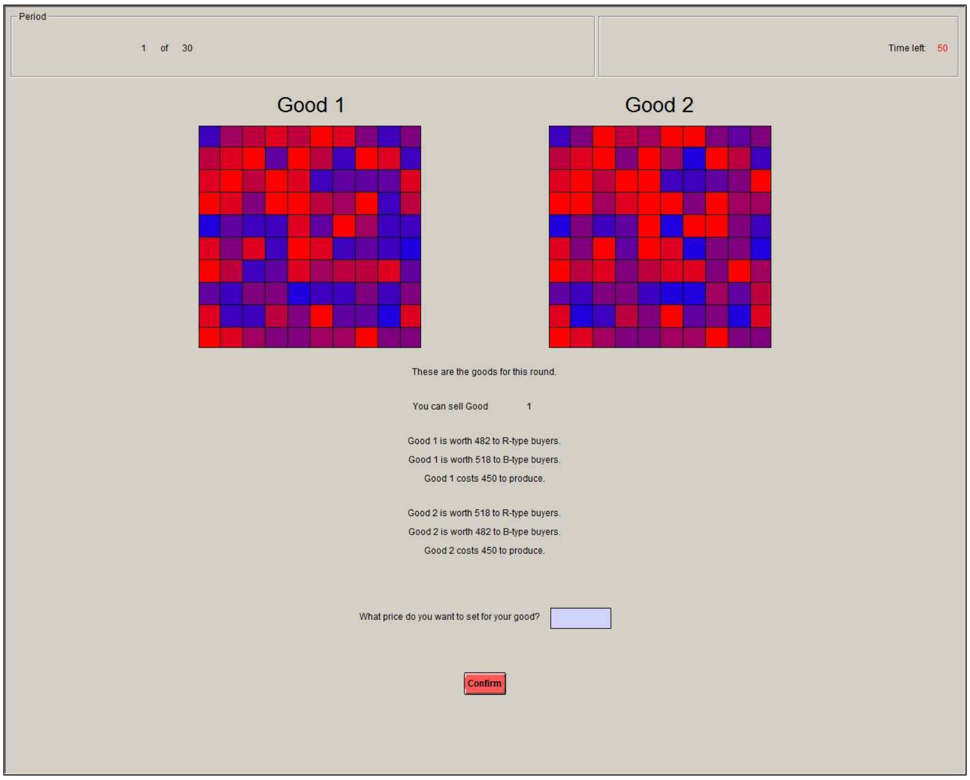


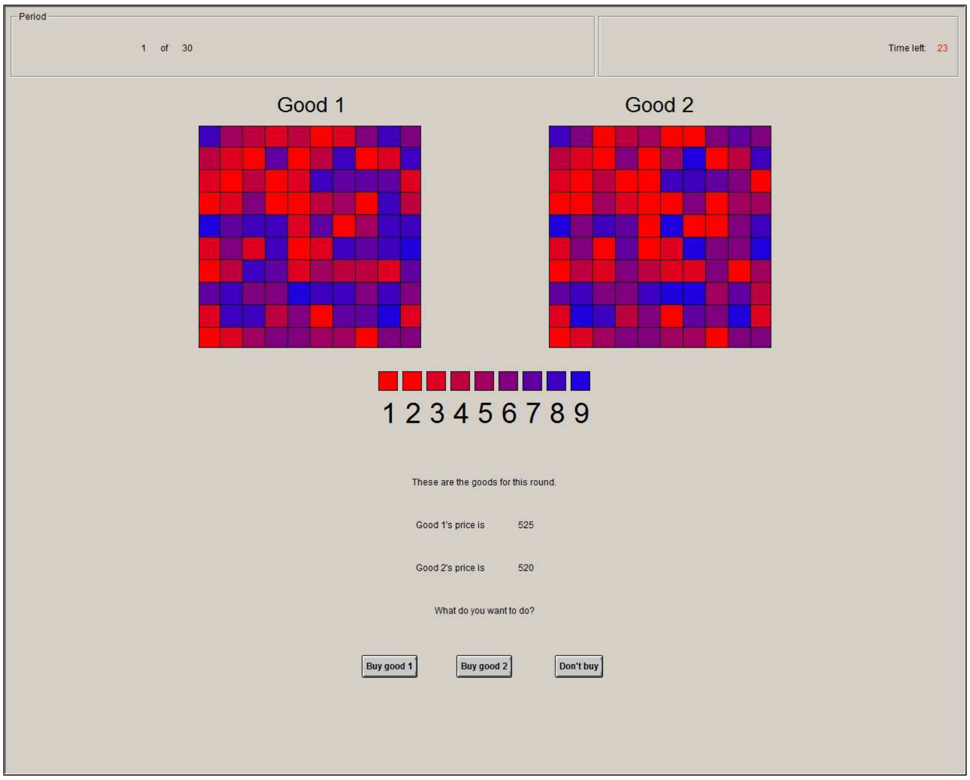
Figure A.1. A subject's view of the valuation task (experiment 1)

Figure A.2. Screenshots of stage 1 and 2 (experiment 2)

(a) Stage 1 (seller screen)



(b) Stage 2 (buyer screen)



B Instructions

B.1 Experiment 1

Welcome!

This experiment is part of a research project undertaken by researchers from the University of Copenhagen.

It is important that you read the instructions carefully before the experiment starts.

There are three parts to this experiment, of which the first is the longest.

By participating in this experiment, you can earn money. Your payment for all three parts will be added together. In the theoretically possible but extremely unlikely event of you making a loss overall, we have a task to do at the end to make good the loss. (The amount of the loss determines how long you have to work at it.)

Your earnings, plus the show-up fee of kr. 50, will be paid in private at the end of the experiment.

During the experiment you will be confronted with a sequence of decision situations. In each situation you will be asked to make decisions about two pictures, which each have a value between 460 points and 540 points.

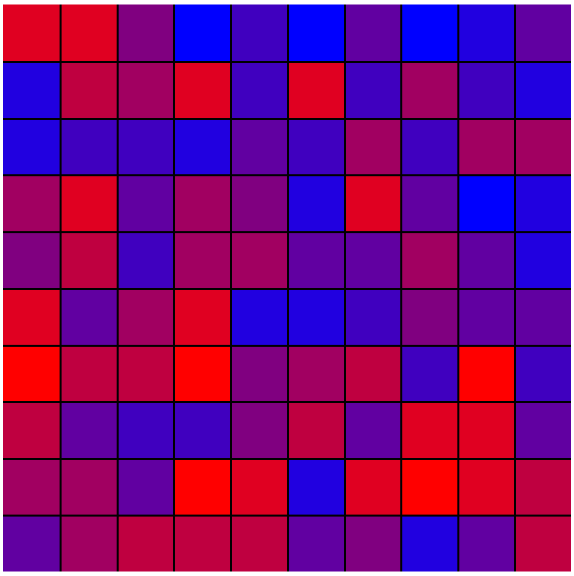
Decision situation

You will be presented with two pictures.

Your task for each is to indicate the max price (in points) that you would be willing to pay for the picture. Notice that the value of the picture implies that your willingness to pay should range between 460 points and 540 points.

Note: There is a time limit of 30 seconds for each decision situation. If you haven't entered anything by the end of 30 seconds, the experiment will move on and you get nothing from that decision stage.

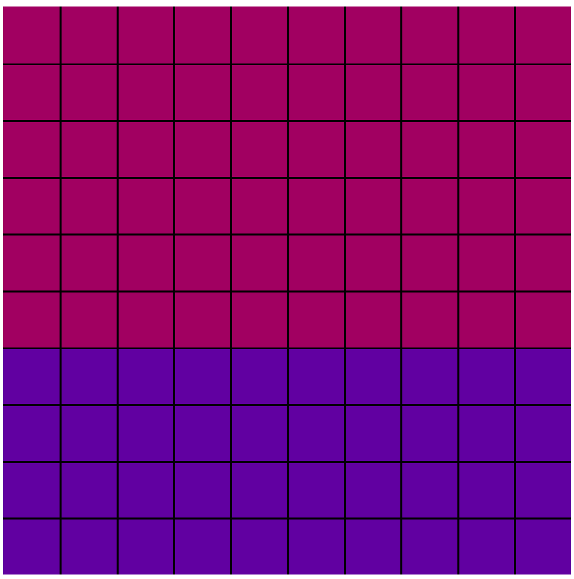
An example of a picture is:



Picture Value

How is the value of a picture determined? Each picture consists of 100 squares. Each square has a colour and each colour has a value. The total value of a picture is the sum of the points over all squares.

Example:



A square like this  is worth 6 and there are 60 of them in the example, giving a total of 360.

A square like this  is worth 4 and there are 40 of them in the example, giving a total of 160.

The value of this picture is then 360 + 160 = 520.

Your Earnings

How is your payoff calculated? The mechanism we use to determine your payoff is explained below. It has one important feature: it is in your best interest to truthfully indicate the max price you would be willing to pay for a picture. You can never do better by indicating a lower or higher price.

The payoff mechanism is as follows:

For each of the shown pictures, we will randomly draw a selling price between 460 and 540 points. The random selling prices are completely independent of the picture's value.

- First, if the random selling price is **lower** than, or equal to your stated willingness to pay, you will **'buy'** the picture. 'Buying' the picture means that the value of the picture is added to your earnings and the random selling price is subtracted.
- Second, if the picture's random selling price is **higher** than your stated willingness to pay, you **do not buy** the picture. Not buying the picture means that nothing is added and nothing is subtracted from your earnings.
- Your earnings (in points) from this experiment will be the sum of your payoffs from all decision situations.

Remember that if you fail to make an enrty within 30 seconds, the experiment will move on and you will earn nothing from that decision stage.

At the end we will convert your earnings in points to money using the following exchange rate: 10 points = 1 DKK.

Detailed payoff examples will be shown on the next page.

	Left hand picture	Right hand picture
Value	520	495
Your willingness to pay	500	490
Random selling price	465	510

Payoff Examples

Example 1

Suppose the underlying values of the pictures, your willingness to pay and the randomly drawn prices were as in the table. You buy the left hand picture, as its randomly drawn price is less than your willingness to pay for it. You don't buy the right hand picture, as its randomly drawn price us higher than your willingness to pay for it. Your payoff is then

$$
\begin{aligned}
\text{Payoff} &= \text{left hand value} - \text{left hand random selling price} \\
&= 520 - 465 \\
&= 55
\end{aligned}
$$

Example 2

	Left hand picture	Right hand picture
Value	525	485
Your willingness to pay	500	480
Random selling price	520	500

Suppose the underlying values of the pictures, your willingness to pay and the random selling prices were as in the table.

For both the left hand and right hand picture, the randomly drawn price is higher than your max willingness to pay for them, so you buy neither of them. Your payoff is simply 0.

Example 3

	Left hand picture	Right hand picture
Value	525	485
Your willingness to pay	525	480
Random selling price	520	470

Suppose the underlying values of the pictures, your willingness to pay and the randomly drawn prices were as in the table.

For both the left hand and right hand pictures, the randomly drawn price is lower than your max willingness to pay for them, so you buy both pictures. Your payoff is then

$$\begin{array}{lccccccccc} \text{Payoff} & = & \begin{array}{c}\text{left hand}\\ \text{value}\end{array} & - & \begin{array}{c}\text{left hand}\\ \text{random selling}\\ \text{price}\end{array} & + & \begin{array}{c}\text{right hand}\\ \text{value}\end{array} & - & \begin{array}{c}\text{right hand}\\ \text{random selling}\\ \text{price}\end{array} \\ & = & 525 & - & 520 & + & 485 & - & 470 \\ & = & 20 & & & & & & \end{array}$$

After the experiment has finished you will be able to collect your earnings, plus the show up fee of kr.50, from the experimenter.

In a moment when the experiment starts you will be asked some control questions before the task begins.

The instructions for the other two shorter parts of the experiment will follow later.

B.2 Experiment 2

Welcome!

This experiment is part of a research project undertaken by researchers from the University of Copenhagen.

It is important that you read the instructions carefully before the experiment starts.

There are three parts to this experiment, of which the first is the longest.

By participating in this experiment, you can earn money. Your payment for all three parts will be added together. In the theoretically possible but extremely unlikely event of you making a loss overall, we have a task to do at the end to make good the loss. (The amount of the loss determines how long you have to work at it.)

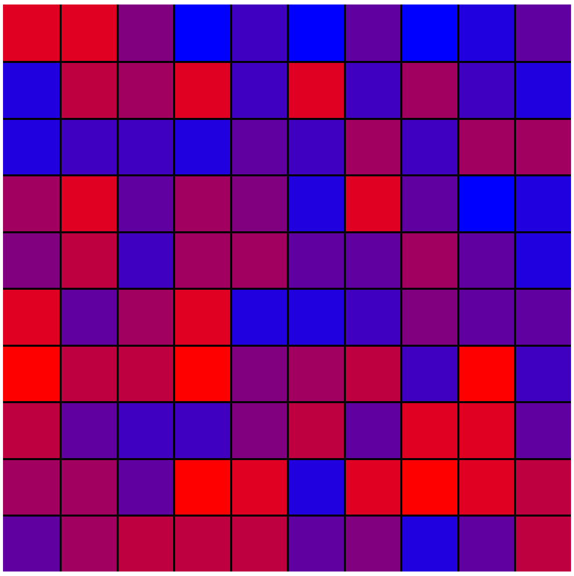
Your earnings, plus the show-up fee of kr. 50, will be paid in private at the end of the experiment.

In this experiment you will be either buying or selling goods in a market. There are two different kinds of roles in this experiment, buyers and sellers. In addition, as will be explained in more detail below, there are two different types of buyers.

In a moment you will randomly be selected into a role and type. That is, we will randomly determine whether you are buyer or seller, and if you are selected to be a buyer, we will randomly determine whether you will be a type R buyer or a type B buyer.

You will keep the same role and type for the whole experiment.

The goods that you will be buying or selling (depending on your role) will be pictures like the one below:

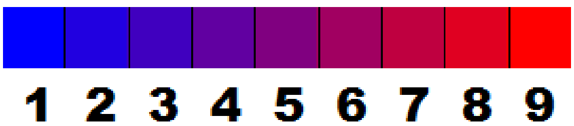


Picture Value

Each picture consists of 100 squares. Each square has a colour and each colour has a value. The value of a picture is the sum of the points over all squares.

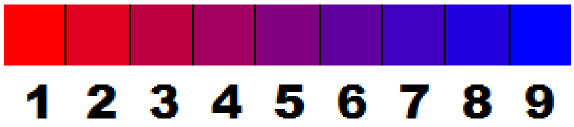
Importantly, however, the different colours have different values for the two different kinds of buyers in the experiment.

R-type buyers value the colours of the different squares according to the following scale:



so they value “redder” colours more than “bluer” colours.”

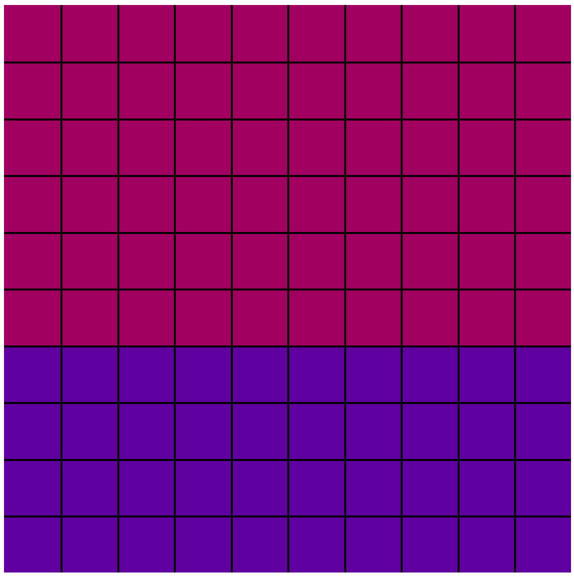
B-type buyers value the colours of the different squares according to the following scale:



so they value "bluer" colours more than "redder" colours.

This implies that the same picture has a different value for R- and B-type buyers in this experiment.

Example



For R-type buyers, a square like this  is worth 4 and there are 40 of them in the example displayed above, giving a total of 160.

For R-type buyers, a square like this  is worth 6 and there are 60 of them in the example, giving a total of 360.

Thus, the value of this picture to R-type buyers is $160 + 360 = 520$.

On the other hand, for B-type buyers, a square like this  is worth 6 and there are 40 of them in the example, giving a total of 240.

For B-type buyers, a square like this  is worth 4 and there are 60 of them in the example, giving a total of 240.

Thus, the value of this picture to B-type buyers is $240 + 240 = 480$.

As mentioned above sellers as well as R- and B-type buyers interact with each other in a market.

Market

There will be 30 market periods in which two sellers and two buyers, one R-type and one B-type, are matched to each other. A single market period works like this:

(1) Sellers are shown the two pictures being traded, told their value to R-type and B-type buyers, and they are informed about which picture of the two they can sell.

(2) Sellers set a price for their picture, without knowing what price the other seller sets. There is a time limit of 60 seconds for this task.

(3) Buyers are shown the pictures (but not told their values) and decide which picture of the two to buy, or not to buy at all. Buyers have 30 seconds to decide. If they haven't entered anything by the end of 30 seconds, the experiment will move on and they get nothing for that period.

After each period we will randomly select a new set of people you interact with in the market, i.e. you will not interact with the same people each time.

Your Earnings

Sellers: For each picture sold a seller earns the price that was paid by the buyer minus a cost of 450.

Seller Earnings = Price – A cost of 450

Buyers: For each picture bought, buyers earn the value of it minus the price they paid.

Buyer Earnings = Value to the buyer − Price

Remember, the 'Value to the buyer' for each picture depends on the type of the buyer.

At the end we will convert your earnings in points to money using the following exchange rate: 10 points = 1 DKK.

In a moment when the experiment starts, you will be assigned your role, and then you will be asked some control questions before the market begins.

The instructions for the other two shorter parts of the experiment will follow later.

B.3 Gamble choices

Table B.1. Risk preference elicitation task, gamble list

Choice (50/50 Gamble)	Low payoff	High payoff	Expected return
1	28	28	28
2	24	36	30
3	20	44	32
4	16	52	34
5	12	60	36
6	2	70	36