Predictive context using arbitrarily linked stimuli: The influence on dominance during onset binocular rivalry

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1 Summary

There are many theories about how predictive context influences onset binocular rivalry. As this previous research has focused on links between stimuli that are already present in the brain, it is interesting to see what happens when we do these experiments with arbitrary, taught associations between stimuli. it is hypothesized that there would be no difference between arbitrary and non-arbitrary predicitive context during rivalry. Participants were instructed to learn this association by means of a search task, in which a cue was linked to a colour. They were then later instructed to report which colour was dominant during onset binocular rivalry after having shown one of the used cues. The results show that the learned predictive context had little to no influence on dominant colours during the rivalry task. This is a rejection of our hypothesis, but in line with the proposed theory that dominance during onset binocular rivalry is settled in simple circuits in cortical and subcortical areas, instead of top-down and higher-order knowledge. More research is needed to further support this theory.

2 Introduction

2.1 Predictive context

Have you ever looked at a broken escalator and had the feeling that it was moving anyway? The brain has a clever way of decreasing computation time by filling in information that it does not have yet, but seems the most likely option. Your brain expects an escalator to be moving, so you will perceive it as moving, until the visual stimuli are properly processed and the brain is forced to retract its earlier judgement about the stairs. [10] This phenomenon, described first by von Helmholtz in 1860, is known as predictive context. [11]

The belief that the brain makes predictions about incoming stimuli has a growing support base, thanks to much research done since the 1950's [8], [13], [15], [16]. It has been proposed that predictive coding is the main neurocomputational principle for the brain's perception and in learning. [11]

In their paper *Olfaction modulates visual perception in binocular rivalry* [19], Zhou et al investigated whether olfactory cues had influence on the dynamics of binocular rivalry. Participants viewed a composite image of a rose and a marker pen through red and green glasses, while being subjected to either the smell of a rose or that of a marker pen (butanol). Each run had a duration of 60 seconds, in which participants were continuously smelling one of either scents. They were instructed to press a button whenever the dominant image switched. They found that the image congruent with the presented scent dominated perception significantly longer than the incongruent image. With the help of continous flash suppression, in the second experiment participants were asked to press a button as soon as they saw the image of a rose or a marker on their screen. Binocular CFS is a technique in which one eye is presented with a target image and the other is shown a mask of rapidly changing images. This mask is used to draw attention away from the target image. It is used to test awareness and at which point the target image will break through suppression. The aim of the second experiment was to see whether the image would break through faster if participants were presented with the congruent odor. Again, a significant correlation was found between the olfactory cue and the congruent image breakthrough times. This gives reason to believe that visual perception is influenced by olfactory perception. It gives us evidence for the idea that the brain is creating a hypothesis and uses this to predict (visual) perception.

In a different paper, *Voluntary action influences visual competition* [14] by Maruya et al, two experiments were performed to investigate whether voluntary movement had influence on dominance during binocular rivalry. During the first phase, participants were presented with rivaling images of a threedimensional rotating sphere and a circular stationary grating. They were instructed to move their mouse in order to move the sphere for as long as the sphere was present (in the dominant sphere trials) or as long as the grating was present (suppressed sphere trials). In half of the trials, movement of the mouse did in fact influence the movement of the sphere. In the other half, movement was automated and mouse movements were useless. It was found that when focusing on the sphere (dominant sphere trial), this image was significantly longer dominant than when participants were focusing on the grating. It was also found that, relative to the suppressed sphere trials, dominance was even more persistent when the sphere was manually moved around, as opposed to the automated movement. The results from this study indicate that a conflict between two incompatible stimuli is solved in favour of the motor control of the observer viewing the stimulus. The conflict resolution takes into account the motor movements of the viewer and their actual outcome. It is expected that a certain movement will have an effect on the sphere, and thus the brain will try to find this outcome somewhere in the stream of incoming stimuli.

More interesting research has been done by Denison et al [7], by proposing that Bayesian models of predictive coding could be an underlying process for choosing the perception with the highest probability. Using both current data and past experiences, the brain would determine perceptual selection. This idea has been explored by several research groups. For example Alink et al have done a fMRI study testing what happens when an expected stimulus is being processed versus an unexpected stimulus. They found that because the brain is anticipating, expected stimuli are being processed with less neural activation in the V1 cortex than unexpected stimuli are, which is in line with earlier research done by McKeefry et al [12], Harrison et al [9] and Bartels et al [3]. These findings provide evidence for the idea that the visual cortex anticipates its input and therefore detects expected stimuli much faster than unpredictable stimuli.

Going back to Denison et al, based on the assumption that Bayesian models are the underlying framework for predictive coding, they tested whether perceived smooth motion had preference over static images during binocular rivalry. They hypothesized that a bottom-up signal coming from an unexpected stimulus (non-smooth apparent motion) would be inhibited over a more expected stimulus (smooth apparent motion), as it would be less consistent with the first presented apparent motion pattern. Results were in favour of their hypothesis, as participants reported seeing a continuation of the perceived movement significantly more often than seeing a motion complementary to the apparent movement shown before the binocular rivalry task.

The main difference between the research discussed above, ([2], [7], [14], [19]), and the research done in this paper is the link between the stimuli used. In existing research, stimuli are almost always not arbitrarily linked. The smell of a rose has already been semantically linked to the picture of a rose in the brain. It is interesting to consider whether an already present bias provides the same predictive context as a newly learned bias. In this paper we attempt to recreate the same effect proved in the research above, this time using an arbitrary link between two stimuli.

2.2 Binocular rivalry

Our eyes are continuously seeing different images. Usually, our brain combines this information and uses it to create a threedimensional representation of the world around us. Stereoscopic vision helps us see depth. However, what happens if these two images are very different from each other? What if we showed a car to the right eye and a cat to the left eye? Intuition might tell us that we could see a car/cat hybrid, but actually this is not the case. [4]

First studied by Wheatstone [18] in 1938, binocular rivalry occurs when each eye views incompatible images at the same retinal location. [1] If we present very different visual stimuli to each eye, the images will not fuse together to create a hybrid between the two. One of the images will dominate awareness, while the other will be suppressed. Dominance will typically switch every few seconds, creating a pattern of perceptual alternations. This phenomenon is very useful when investigating brain processes involved in visual perception and awareness. Stable input leads to patterns in alternating awareness, which makes it very useful to research, for instance, how the brain resolves competition between stimuli and how it chooses a dominant stimulus. [4]

Binocular rivalry typically has two stages. The initial period of dominance, onset binocular rivalry, has different underlying processes than following switches in dominance. [6] According to Carter and Cavanagh (2011), images presented during a short period of time were highly susceptible to bias, whereas longer periods of exposure were much more stable and did not seem to be influenced by the viewers' bias. Images dominated for equal amounts of time. During a short exposure time, eg 1 second, participants reported seeing the same image over many trials. They therefore concluded that onset binocular rivalry is independent from sustained binocular rivalry.

The idea that onset binocular rivalry is susceptible to visual bias makes it a very helpful technique in the experiment proposed, as the aim is to discover a bias towards a learned association between a colour and a symbol. In 2014, Attarha and Moore [2] have carried out a series of experiments in order to find out what factors have influence on onset binocular rivalry. Their research is partly a replication of the experiments by Denison et al [7], but also tested for semantic information and predictive patterns of motion. It was found that predictive signals break down very early in visual processing. Onset rivalry was influenced by apparent and smooth motion patterns, but was not susceptible to top-down and semantic information. This is consistent with earlier research and the view that onset rivalry is not likely to be influenced by high-level information beyond the visual system.

2.3 Hypothesis

How does predictive context affect perception? In the literature discussed in the introduction, we have seen that predictive context arises when testing within a non-arbitrary context. We aim to investigate whether an arbitrary association between stimuli will elicit the same response among participants as seen in the aforementioned research. By letting participants discover the relation between a cue and a colour on their own, we hope to find that a cue will elicit a strong bias towards the corresponding colour, influencing binocular rivalry. It would follow from the research already conducted that colour perception in the binocular rivalry trials will skew towards congruation with the given cue. We therefore predict that an arbitrary predictive context will not yield a different result during binocular rivalry than a non-arbitrary predictive context.

3 Context within AI

Making decisions about perception is a rapid process in the human brain. Human perception is not without faults, but the fluency in which the brain predicts and corrects mistakes in perception has not been replicated by artificial intelligence. By constantly finding out more about perception and the way this works in humans, we pave the way for groundbreaking research in machine learning. Predictive context in humans is an efficient way of checking hypotheses. Researching the mechanisms behind predictive context might give us new ideas how to model intelligence and advance the field of robotics.
But not only does this research have its purposes in computer science, it also helps us better understand human-machine interaction. Knowing how people perceive, creating machine interfaces that are intuitive and helpful to people will become easier.

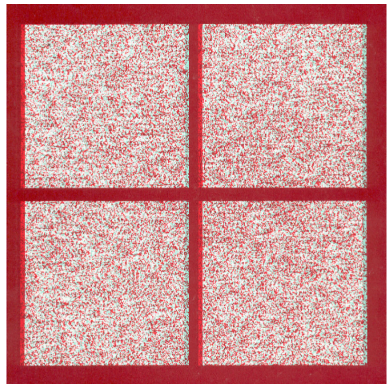

Figure 1: Stimulus for determining stereopsis. Looking through 3D glasses with stereoscopic vision, participants perceived shapes lying on top of the dotted background.

4 Methods

This experiment is divided into two goals. The first goal is to teach the participants an association between a cue and a colour (green — percent sign, red — hash sign), by means of a search task. The second goal is to test whether this association has effect on what participants perceive during a binocular rivalry task. Participants were encouraged to find the relation between cue and colour themselves and were not told what it was.

4.1 Participants

A total of eight participants took part in the experiment, four women and four men, all university-level students. Age ranged between 18 and 25. All participants had normal or corrected-to-normal and stereoscopic vision. Participation was voluntary, participants were not rewarded with money.

4.2 Determining stereopsis

Participants were checked for stereopsis with the help of the TNO test for stereopsis. Participants were instructed to look at the pictures (figure 1) and report what they saw. If a participant had stereoscopic vision, then they would see four differently orientated Pacman shapes, lying on top of the background. If a participant did not have stereoscopic vision, they would simply see the background without any shapes arising.

4.3 Determining luminance of green targets

To prevents participants from favouring one colour over another, it was made sure that both red and green would appear of equal brightness. A test was given to determine the relative luminance of green against the luminance of red. This was done for each participant separately, as there exist individual differences in luminance perception. The luminance of green was measured against that of red, which was set at 27 cd/m^2. A coloured square was presented on a background, alternating between red and green at 60 Hz. Participants were instructed to increase and decrease the luminance of green until they found no difference between red and green anymore. This test was done ten times per participant, to ensure that the mean luminance was meaningful, and the result was used during the entire experiment.

4.4 Stimuli and apparatus

Stimuli were presented on two Apple monitors linked to an Apple computer with a resolution of 2048 x 768 and a refresh rate of 85 Hz. A chin rest and a mirror setup at a distance of 75 cm from the screens ensured that each monitor was only presented to one eye. The experiment was constructed using Matlab, with addition of the PsychToolbox-3, v. 3.0.12.
Stimuli were presented on a gray background with a luminance of 72 $\mathrm{cd/m^2}$. The sinus gratings used in the experiment were presented at a visual angle of 0.4 degrees.

4.5 Procedure

Participants were instructed to place their head in the chin rest and focus on the fixation cross on the screen. They were first presented with a practice trial that consisted of only BR trials to ensure that they would not make any mistakes in pressing keys. This practice run consisted of only five trials, but participants were allowed to run it more times to get aquainted. After the BR trials, another practice run followed with only search tasks, also five per run. After every search trial, the participant received feedback on the given answer (true or false). After every trial, both BR and search, participants had to press the spacebar to continue to the next trial. This allowed for breaks during the runs, and were implemented to ensure that participants did not make mistakes due to the trials running too fast.

After the practice trials, four mixed trial runs followed. Each run had one hundred search trials and twelve BR trials. The BR trials were distributed evenly among the search trials, with an addition of a jitter function which made sure that after every six to fourteen search trials, a BR trial would follow. There were never two consecutive BR trials.
Participants had a short break after each run, until they felt confident enough to continue the next one. There was no set time limit on the breaks, but not

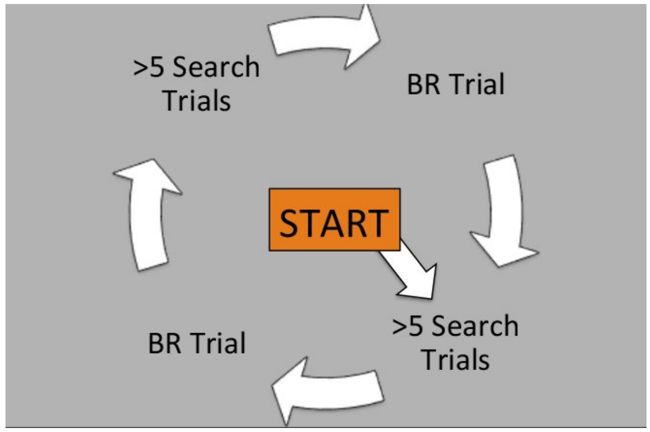

Figure 2: The basic cyclus of a block of 100 search trials and 12 binocular rivalry trials

one participant paused for more than five minutes before continuing.

4.5.1 Search trials

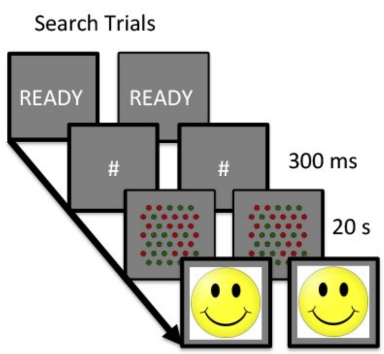

Figure 3: Procedure of one search trial.

A fixation cross was presented to each eye for 300 milliseconds. Following this, a cue was presented for 300 milliseconds (a hash sign or a percent sign). After this, a hexagonal field with 38 sinus gratings of 0.4 degrees visual angle each appeared, the same for each eye. A part of the dots was green, the other red, in three different configurations: 5/33, 19/19 and 33/5. The dots all had a sinus grating in sixteen different orientations.
Participants were instructed to remember the cue they received, as it gave information about what key to press if the target had been found. If a participant

got a hash sign cue, they had to press the right arrow key, if they got a percent sign, they had to press the left arrow key (after finding the target stimulus). Participants had 20 seconds to find the grating with the vertical orientation.
The goal of this task was to teach participants the association between cue and colour. They were instructed to look for a way to find their target faster, and they were told that it had something to do with the cue. If a hash sign was given, the target stimulus would always be green, and thus make it easier for the participant to find it because they could ignore all red distractors. If a percent sign was given, the target would always be red.
The aim of this experiment was to test whether participants had used the relation between cue and colour. If they used the cue, they would only search within either green or red, instead of the whole field of 38 gratings. This would give them an advantage, as it would strongly decrease the amount of distractors. Therefore, if participants used the cue, a strong effect of set size would be visible in the response times. If participants did not use the cue, they would constantly be searching through the whole grid of distractors, giving no effect of set size.

4.5.2 Binocular rivalry trials

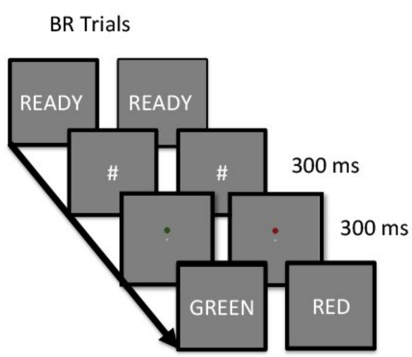

Figure 4: Procedure of one binocular rivalry trial.

A fixation cross was presented to each eye for 300 milliseconds, whereafter a cue was presented during 300 milliseconds (a hash sign or a percent sign). After the cue, during 300 milliseconds, on one side, a red dot (again 0.4 degrees) appeared, grated with black lines in a diagonal orientation, on the other side a green dot would appear, also with black diagonal grating. Afterwards, a message would appear on the screen, instructing the participants to press *f* if they saw a red sinus grating and to press *j* if they saw a green grating. If one of these keys were pressed, a new message appeared on the screen, instructing the participant to press spacebar to continue to the next trial.
The aim of these trials was to test whether the association between cue and

colour is visible during binocular rivalry.

5 Results

5.1 Search task

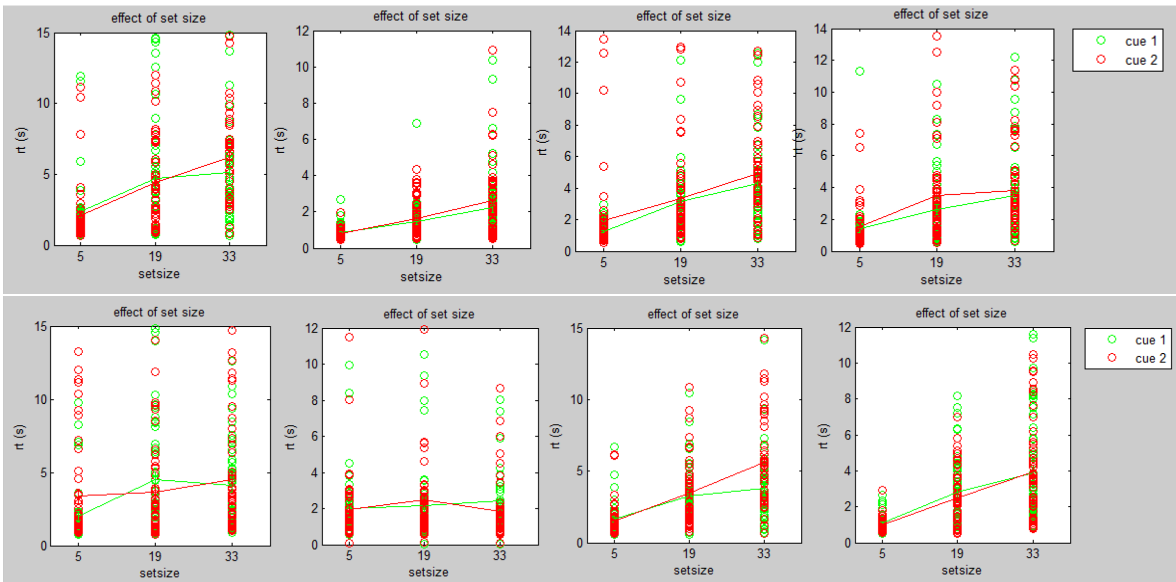

Figure 5: Effect of set sizes of red and green targets in search trials. Every graph depicts one participant and shows the reaction times with every ratio between red and green. If a participant had understood the relation between cue and colour, reaction times would be higher with an increase of the amount of distractors in the cued colour.

Below, in figure 5, we can see the effect of the set sizes in the search trials for every participant. It was expected that, if a participant had understood the link between cue and colour, they would only search for the target in the cued colour dots. Therefore with an increase in the amount of distractors in the cued colour, we would see longer reaction times. Six out of eight graphs show this increase very clearly. Although all participants reported having understood the relation between cue and colour, it is clear that participants five and six did not actually use the cue.

5.2 Binocular rivalry task

In figure 6, all binocular rivalry responses are depicted per participant. Any indication for colour bias can be seen here clearly. Participant 8, for instance, has a high percentage of congruence on cue 2 (the one for red), but a very low

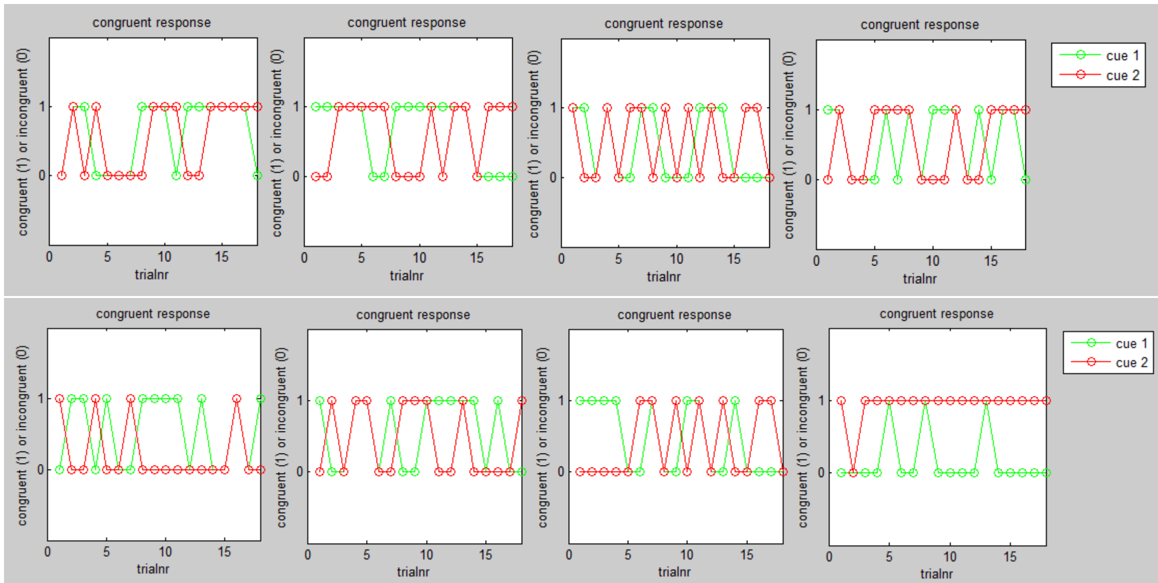

Figure 6: Congruent and incongruent responses in BR trials. Each participant is depicted separately. If a participant picked the colour in the BR trial associated with the given cue, this would be a congruent response.

one on cue 1 (green), which means that they have almost always chosen red regardless of the given cue.

In the table below, the fraction of congruence can be found for each participant. It shows us that 4 out of 8 participants have scored a fraction more than 0.5000. Another thing that stands out is that the participants that did not show a correlation between set size and reaction times, also have not scored above 0.5000 in this table.

Participant	fraction congruent
1	0.5833
2	0.6389
3	0.4722
4	0.5556
5	0.3889
6	0.5000
7	0.4167
8	0.5556

5.3 Statistical analysis

To determine whether congruence is significantly higher than 0.5 in the binocular rivalry task, the results in the table above have been used in an unpaired t-

test. We compare the results against a null hypothesis of $P(congruence) = 0.5$, meaning that giving a cue has no effect on perception during binocular rivalry. If results show that this null hypothesis is very unlikely ($p < 0.05$), we may conclude that predictive context in the form of a given cue does indeed have influence on perception during binocular rivalry.
A one-tailed t-test was used. It is expected that the chance that congruence will decrease under the influence of preditictive context will be very small, as 5 out of 8 participants scored at least 0.5000 congruence.
Applying the t-test to the group, we found $t(7) = 0.4606, p = 0.6591$, which means it is not nearly significant enough to reject our null hypothesis.

6 Discussion

The results of the experiment are not in favour of our hypothesis. However, this does not necessarily mean that the hypothesis is untrue. Five out of eight participants did have a score of at least 50% congruency. A point of criticism is the number of participants. We have observed at least two people who did not show an effect in set size on the search tasks. With a larger pool of data, these outliers would have had a much weaker effect on the overall statistic or could simply be excluded from analysis.

Secondly, we could omit unsuccessful search tasks altogether by telling participants beforehand what the relation was between cue and colour. While there is a certain merit to the idea that the association would be stronger and more ingrained if discovered individually, it could actually make no difference at all.

Another thing that has already been observed is the bias for colour that was present in some participants. Determining luminance for green for each person individually cannot eliminate innate preferences for red or green. It is useful to restrict testing to participants who do not show a strong bias to either colour. With a larger pool of participants, excluding people who show this bias would have much less impact on the total number of participants.

It has also been mentioned that between each run of trials there was an optional break for participants. Fatigue and loss of concentration may very well be a factor in performance on both the search and binocular rivalry task. By making short breaks mandatory, we would have made it easier for participants to keep concentrating on the tasks.

Lastly, participants reported having trouble with the binocular rivalry task. It was difficult and often they were not sure what colour had exactly appeared. Varying the exposure of the coloured dots could make a difference in responses by participants. The exposure time in this experiment was 300 milliseconds, which could arguably have been too short.

Replicating the experiment with these alterations may bring us results more in favour of our hypothesis. Not only are there possible alterations to the experiment, another sign that our hypothesis may still be viable is the success of other researchers in the same field, as mentioned in the introduction. The experiments in the papers by Maruya et al and Zhou et al have not made use of binocular rivalry, but have nonetheless found evidence for the existence of predictive context.

When assuming, however, that these alterations would not change the outcome of the experiment, the results differ from what was expected according to the set hypothesis. Looking at Attarha and Moore [2], we see that they have provided an alternate explanation for the results found by Denison et al [7]. Denison et al proposed that prior knowledge could influence dominance during onset rivalry, which also lies at the basis of the hypothesis in this paper. If knowledge of a link between cue and colour had influenced rivalry, non-arbitrary and arbitrary links between stimuli should have had the same effect on the rivalry task. As this is clearly not the case, we move to Attarha and Moore's interpretation of Denison et al's research. Building on these experiments, Attarha and Moore have added three extra experiments involving semantic and pattern knowledge to investigate whether it is prior knowledge that influences rivalry, or if it is another mechanism that is the underlying framework. Based on their results, they propose another theory, namely that simple circuits between early cortical and subcortical areas may underlie the selection bias during onset binocular rivalry.

Learning a new link between a cue and a colour falls in an entirely different category than local motion signals. The experiments by Attarha and Moore have proven that higher-order knowledge and top-down information have had no influence on onset rivalry during their experiments. Counting having to learn a new arbitrary association between stimuli as higher-order knowledge, the results taken from this experiment is more of a confirmation of Attarha and Moore's theory than a rejection of the hypothesis itself.

Given the criticism given above on the experiment, more research is needed to fully reject or embrace the idea that arbitrary predictive context has the same influence on onset binocular rivalry as non-arbitrary predictive context has.

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