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Coloured overlays and precision-tinted lenses: Poor repeatability in a sample of adults and children diagnosed with visual stress

Catherine Suttle, John Barbur and Miriam Conway

Division of Optometry and Visual Science, School of Health Sciences, City, University of London, UK

Running title: Repeatability of coloured overlays and lenses

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Abstract

Purpose: Visual stress consists of perceived distortions or discomfort while reading. It is claimed that these symptoms are alleviated by viewing through coloured lenses or overlays, with a specific colour required for each individual. This has been explained on the basis of altered visual cortex excitation as affected by the spectral content of the viewing light. If symptoms are indeed alleviated by a particular colour that has an impact on the individual's visual system, we would expect that selection of the most beneficial colour would be repeatable. The aim of this study was to determine whether this is the case.

Methods: Twenty-one participants (mean age 26 years (range 8 to 55 years); 12 female, 9 male) with visual stress and no other uncorrected ocular or visual anomaly were recruited. Each participant selected the colour most beneficial in alleviating their symptoms from a standard set of 10 coloured overlays, and underwent intuitive colorimetry in which the most beneficial of a wide range of chromatic illuminance settings was selected. Without prescribing an overlay at the first appointment, this process was repeated on a second occasion at a mean of 25 days later.

Results: About half of the participants (n=10) chose the same (n=7) or similar (with one common colour in both choices; n=3) coloured overlay on the two occasions, while 11 participants chose a completely different overlay colour. Across all participants, the colorimetry setting shifted by, on average, 9.6 just noticeable differences, indicating that the colours were perceptually very different.

Conclusion: These findings suggest that people with visual stress are unlikely to find exactly the same colour to be optimal on different occasions, and raise questions about the need for precise colour specification in tinted lenses for visual stress.

Introduction

Visual stress, also termed Meares-Irlen syndrome or scotopic sensitivity syndrome, consists of perceived visual distortions and/or discomfort when reading, which are alleviated by viewing through coloured overlays or lenses.[1] At least two hypotheses have been proposed to explain the symptoms and the potential benefit of coloured filters, both of which are based on modification of visual neural activity.[2-4] Wilkins and colleagues[5] report that the chromaticity of the lenses required to optimise reading speed is specific to each individual. To reflect this, the lenses have been termed 'precision tinted lenses' or 'precision ophthalmic tints'.

The coloured overlays and tinted lenses are individually prescribed on the basis that the colour is beneficial for that particular individual, and as such it should be highly repeatable. Repeatability of the choice of coloured *overlay* has been tested by comparing the colour chosen by children on two occasions separated by three months.[6] The difference between the two colours was smaller than expected by chance, but this may be due in part to the fact that the child had used the first overlay during the three month period and remembered the colour.

Questions about the effectiveness of coloured overlays and precision tinted lenses have been addressed by systematic reviews which have concluded that there is a lack of evidence to support their use,[7] that their use cannot be endorsed[8] or that the balance of evidence suggests that they can alleviate symptoms in people with visual stress.[9] Thus, the use of coloured overlays and lenses and the need for precise tinting is controversial. Since the need for such lenses is based on the concept that the colour is precisely appropriate for alleviation of visual stress symptoms in the individual, it is important to establish whether the same colour overlay or lens is optimal for that individual on different occasions. The aim of this study was to address this question.

Methods

The research was approved by City, University of London's School of Health Sciences ethics committee. The participant consented after being provided with full written details of the research procedures.

The City, University of London optometry clinic has offered assessment and management of visual stress. Over a two-year period, all patients attending for this purpose were invited to participate in the study. Potential participants were told in an information letter that "Some people with visual stress find that reading through coloured filters is helpful. However, it is not known whether the optimal colour filter is consistent over time." Prior to participation, all potential participants had undergone (outside of this study) a full eye examination including symptoms and history, vision, cover test, ocular motility examination, near point of convergence, assessment of accommodation, stereopsis, motor fusion, refraction, fundus examination and other tests where appropriate. Colour vision was not tested, as this is not part of the criteria for intuitive overlay or colorimetry testing (see Discussion). Binocular vision anomalies were treated if appropriate. Potential participants with uncorrected ocular or visual anomalies were not invited to participate in the study. Participants were asked whether they had been diagnosed by an educational psychologist with dyslexia, since previous research suggests that colour may be more helpful (at least in terms of rate of reading) in dyslexia than in controls .[10] Only reported formal (not suspected) diagnosis was recorded as such.

Diagnosis or confirmation (in participants who had previously been diagnosed) of visual stress was conducted by author MC. Participants were considered to have visual stress if they reported one or more symptoms of visual discomfort or distortion while reading, *and* they reported alleviation of symptom(s) with a coloured overlay. Wearing their current refractive correction for reading (if needed), the participant was asked to look at the text provided with the Intuitive Overlays (http://www.ioosales.co.uk/html/practice/eye05D.html),[11] and to report whether any of the following were experienced: discomfort, pain, blurring, doubling, shapes/lines, colours, movement, flicker, wobble or glare. If any of these were reported, the participant was then asked to observe the text through each of the ten Intuitive Overlays, individually and in combinations of two of these following the procedure previously described.[11] It has been noted that no standard diagnostic criteria are available for visual stress.[9] Previous studies on the benefits of coloured overlays or tints for reading have questioned participants about any

perceptual distortion they experience while viewing text[12,13] or about preference, ease and comfort while viewing or reading text.[14] Recently (after our data were collected), a set of diagnostic indicators has been published and these state that at least three of the above symptoms are required for diagnosis.[15] This would suggest that the criteria used in the present study and previous studies were generous and may have over-diagnosed visual stress. This point is discussed later (see Limitations).

The ten single overlay colours were presented according to the online instructions for use (http://www.essex.ac.uk/psychology/overlays/) which state that presentation should begin with the Rose colour. No evidence is given to support this requirement, however, and previous publications on this method have not discussed order of presentation[6,11] so it is not clear whether order is important. The participant chose an optimal coloured overlay by viewing text provided with the Intuitive Overlays kit consisting of two identical sections of monosyllabic words not formed into meaningful sentences. A coloured overlay was placed on one section, and this was compared by the participant with the other section viewed through no overlay, or through a comparison overlay. Combinations of two related coloured overlays (e.g. blue + blue; blue + purple) were included in the range as described elsewhere.[11] Through a process of elimination, the participant selected the overlay(s) through which symptoms were most alleviated. Visual stress and coloured overlay tests were carried out in a clinic room with the same ambient lighting throughout, but light levels were not measured.

Following an established method,[16] intuitive colorimetry involved the participant sitting at the Intuitive Colorimeter (http://www.ceriumoptical.com/vistech/colorimetry.aspx) in a darkened room and indicating whether each of 12 hue settings made text any more or less comfortable to read than with white light, and to compare against each other any hues found to lessen symptoms. The saturation of the preferred hue was then adjusted to find the least saturation at which symptoms were minimised. Brightness was also adjusted to find the optimal level. This process resulted in estimates of hue, saturation and an 'attenuation' value (indicative of the preferred luminance level). When taken together, these parameters describe the properties of the spectacle tint offering most symptom relief. In total, there are 288 possible lens colour settings.[16]

No overlay or tint was prescribed at the first appointment. The above procedures were repeated at a second appointment. The two appointments were intended to be one month apart, but due to the participant's availability the time period ranged from 2 to 57 days (mean 25 days). On each of these two occasions the optimal coloured overlay(s) and the hue, saturation and attenuation (brightness) of the coloured tint were noted using the published protocols.[8,9,11,16,17]

On the first occasion only, the Wilkins' rate of reading test (WRRT; http://www.ioosales.co.uk/html/practice/eye05F.html) was administered with and without the optimal overlay according to the published protocol including the use of an ABBA design.[13,18] This test was carried out with only the first choice of optimal overlay (on the first occasion) to assess whether a chosen overlay was associated with increased reading speed.

Data analysis

In order to compare the overlay colour chosen on each occasion, the two choices of coloured overlay were categorised as the same, similar or different.[19] If exactly the same colour or colour pair was chosen on each occasion, the choice was the *same* (e.g. blue on each occasion). If the colour choices on the two occasions were not the same but included one common colour the choice was *similar* (e.g. blue on the first occasion and blue + purple on the second occasion). If the two colour choices included no common colours the choice was *different* (e.g., blue on the first occasion and purple on the second occasion).

As outlined above, Intuitive Colorimetry precision tinted lens colours are described in terms of their hue, saturation and attenuation. Difference in hue choice on the two occasions does not necessarily indicate significant difference in colour choice, because at low saturations both colours are close to a white point and may be very similar. For this reason, lens colour was specified on the basis of its position in the CIE (u', v') colour space and the difference between colours was specified by the chromatic displacement (CD) between the two settings, the distance in colour space between the first and second selected colour. For simplicity, this displacement or shift in colour within the (u', v') space was quantified by the

length of the line joining the locations of the colours the participant preferred on the two occasions.

To determine whether the shift in colour was significant, this was compared with the shift which would represent a just noticeable difference (JND), based on the mean threshold detection ellipses measured under similar conditions of light adaptation.[20] Since the colour threshold ellipses vary somewhat in size with the state of chromatic adaptation of the eye, an average displacement distance was obtained by averaging thresholds measured along the YB and RG axes at several locations over the area corresponding to the background colours generated in the intuitive colorimeter. This approach is not therefore expected to provide accurate estimates for small chromatic shifts, but displacements two to three times the computed threshold will undoubtedly be perceived as different colours and therefore become meaningful in the context of this study. The colour shift in each individual was divided by the mean chromatic displacement (JND) estimated in this way and expressed as multiples of this value.

Results

Twenty-five participants were recruited. At the first appointment, none of the participants reported that no overlay relieved their symptoms, so all selected an overlay. Data from one participant were excluded from analysis due to failure to attend the second appointment, and data from three participants were excluded because a symptom-relieving overlay colour was initially selected but the participant later reported no improvement in comfort compared to no overlay. Therefore data from 21 participants were included in analysis. Participants included 12 females and 9 males and mean age was 26 years (range 8 to 55). Monocular visual acuity was 6/7.6 or better in all participants. Just under half (n=10, 48%) of the participants reported having been previously diagnosed with dyslexia. Two-thirds (n=14) of the participants had previously been diagnosed with visual stress and had been using an overlay or tinted lenses for a period of months or years. A significant association was found between existing use of coloured overlays or lenses and a self-reported diagnosis of dyslexia (Fisher's exact test, p=0.004).

Table 1 shows the coloured overlays chosen by each participant on the first and second occasion, grouped according to their similarity. Seven participants (one third) chose the same combination of overlays on both occasions, three chose similar colours and 11 participants (52%) chose different colours. No significant association was found between similarity of overlay choice and a self-reported diagnosis of dyslexia (chi square 0.44, df=1, p=0.51) or a history of prior use of overlays (chi square 0.38, df=1, p=0.54)). The table also shows, for 17 of the 21 participants (data not collected in four participants), the reading speed with and without the first overlay, and the percentage change in speed. The median percentage increase overall was 16% (range 6 to 32%; no decrease in reading speed occurred), with 10% in participants without dyslexia and 17% in those with dyslexia. Neither the percentage increase (Mann-Whitney U=23, p=0.21) nor median reading speed without the overlay (Mann-Whitney U=33, p=0.77) were significantly different between participants with and without dyslexia. In addition, no significant difference in the percentage increase in reading speed was found between participants with or without previous use of coloured overlays or lenses (Mann-Whitney U= 21, p=0.38) nor between participants who chose the same or different coloured overlays (Mann-Whitney U=22, p=0.77; those who chose Similar colours were excluded due to their very small group, but when Same and Similar were combined for comparison with Different the result was also not significant (Mann-Whitney U=30, p=0.60). Participants who chose the same or different overlays on the two occasions did not have significantly different periods of time between the two appointments (Mann-Whitney U=28, p=0.88).

All participants chose an optimal colour using the colorimeter (none reported that colour in the colorimeter did not help). Table 2 shows the u'v' values of Intuitive Colorimeter chromaticity settings on each of the two occasions, the absolute difference between these and the corresponding chromatic displacement (CD) expressed in just noticeable differences (JNDs; see *Data Analysis* section) in participants who had previously chosen the same, similar or different overlays on the two occasions. The CD ranged from 3.1 to 23.8 (mean 9.6) JNDs. Figure 1 shows the chromaticity settings on both occasions and the CD (the line joining these points) for each participant who had previously chosen the same, similar or different overlays on two occasions. The mean CD in participants who had chosen the same or different overlays was 0.037 and 0.053 respectively and the difference was not significant (Mann-Whitney U=25, p=0.25). The corresponding mean number of JNDs in these subgroups was 8.0 and 11.4 respectively (Mann-Whitney=25, p=0.25). No significant difference (Mann-Whitney U=54, p=0.97) in CD was found between individuals with or without a self-reported diagnosis of dyslexia.

Discussion

About half (n=11) of the participants chose a completely different overlay colour on the two test occasions, while others chose either the same (n=7) or similar (n=3) overlay colours. It is worth noting that there is a 1 in 38 chance of choosing the same combination on two occasions by chance: 9 individual colours, plus each of these with 3 colour combinations, plus grey or double grey. The 7/21 (one-third) choosing an identical colour is therefore considerably higher than chance. No association was found between similarity of colour choice and a diagnosis of dyslexia. Previously, Jeanes et al[6] found that children tended to choose the same overlay on two occasions. They tested a total of 152 primary and secondary school children. About half of the children found a coloured overlay beneficial and were given that overlay to try for a period of three months, after which they were asked to select again the most beneficial coloured overlay. The colours selected on the two occasions were found to be more similar than would be expected by chance. However, it seems likely that the child would know the overlay colour or combination of colours very well after using them for a period of three months, and their choice on the second occasion may be somewhat influenced by familiarity or even long term adaptation processes that favour the new spectral composition of the light. Colour names were not reported, but the average shift could represent a complete change in colour, such as from pink to green (see results in figure 2 of Jeanes et al[6]). Our findings may not differ notably from these but by reporting the colour names we can demonstrate a major change in colour choice in about half of our participants. The other half chose either the same or similar colours, so overlay colour choice was consistent. The period without an overlay between the two tests was intended to minimise the possibility that the participant would remember their choice, but it remains possible that the second choice was biased by the first since the overlay colours are distinctive and very easily discriminable.

Alternatively, it is possible that choice of the same or similar colours on the second test does not reflect bias but demonstrates consistent alleviation of symptoms with a specific overlay colour or combination. This would be consistent with the hypothesis that colour helps to alleviate symptoms by changing neural activation in the visual cortex, and that the spectral composition selected as most beneficial is specific to the individual.[4] Perhaps this applies in

the participants who made consistent colour choices, but again when overlay colour is chosen it is highly likely that memory of any previously selected overlay colour plays a part.

On average, for the 17 participants in whom reading speed was measured with and without the first chosen overlay, reading speed was increased by 16%. This is higher than some of the previously reported increases in reading speed with overlays in schoolchildren (e.g. 9% increase[21]) or adults (e.g. 12% increase[14]). The relatively high increase may reflect the fact that most (two thirds) of the participants had previously been diagnosed with visual stress and had been wearing coloured overlays or lenses for some time. They may, therefore, be people who experience relatively high alleviation of symptoms with overlays. However, participants with a history of using overlays did not have higher reading speed increases or more consistent choice of overlays than those without prior overlay use.

The choice of colour in the intuitive colorimeter is less likely to be subject to bias since there is a much wider range of possible colours, and the participant views the whole scene through that colour rather than seeing the colour against a white background and in simultaneous comparison with other colours. In our sample, all participants selected colours separated by more than 3 JNDs, and on average by more than 9 JNDs. At least two previous studies have investigated repeatability of choice of coloured overlays or lenses for reading difficulty. Jeanes et al[6] determined the separation of overlay colours chosen on two occasions in CIE UCS space, and found this to be smaller than would be expected by chance. Wilkins et al[12] found the separation between the optimal intuitive colorimetry setting (at which the colour is most beneficial) to the closest setting at which symptoms worsen to be about 6 JNDs on average, lower than the ~9 JND separation found in the present study. This is interesting, since it suggests that in the present study the optimal colour chosen on the second occasion is separated from the first optimal colour choice by more than the separation at which the colour is no longer likely to be beneficial. It should be noted, however, that threshold depends on a number of factors including age and luminance. The threshold (JND) used in the present study is based on data from young normal trichromats[20]; the threshold used by Wilkins was based on data from Hunt[22] and may not be directly comparable.

The present study suffers from several limitations. Two-thirds of the participants had previously used coloured overlays or lenses. In these cases, there was already some familiarity with a particular filter colour which may have biased the choice of overlay or lens colour. In addition, our approach was to give no overlay on the first occasion, so that the participant would not become familiar with the colour during the one-month interval between the two overlay tests. This is contrary to the approach used by Wilkins[12] and others in which the overlay is prescribed for a period of time to assess whether benefit is sustained, before colorimetry is carried out. It is possible that the one third of participants (n=7) who had not previously found overlays beneficial would not have found sustained benefit with the chosen overlay colour. However, it is worth noting that three of these returned later reporting sustained use of the overlay, so only four may not have found sustained benefit.

Diagnostic indicators published after our data were collected[15] recommend that at least three symptoms (their table 4) should be part of a diagnosis of visual stress. This would suggest that some of our participants should not be considered to have visual stress. This would also be true of much of the previous work in this area since previous studies on the benefits of coloured overlays or tints for reading have questioned participants about any perceptual distortion they experience while viewing text[12,13] or about improvements in comfort or clarity of text[14] but have not required at least three symptoms. However, the authors of the new diagnostic indicators state that they should be interpreted flexibly.

We did not test colour vision in our participants, so it is possible that our sample included individuals with inherited (red-green) colour vision defects. These would arise rarely (about 0.4%) in females and more commonly (8%) in males.[23] In our sample of 9 males this would translate to less than one participant but remains a possibility. While colour vision has not usually been tested in studies on the use of colour filters for visual stress, it is an important consideration for future work. We also did not measure light levels, and while the same environment including room lighting (for overlay testing) was used throughout, we cannot be sure that lighting was exactly the same for all participants on both occasions. Our intuitive colorimetry findings are not likely to be affected by lighting, however, since colorimetry was carried out in a darkened room and using the same viewing conditions

throughout the study. Finally, our sample is small, limiting the extent to which our findings reflect repeatability in the wider population.

The above factors limit the extent to which conclusions can be drawn from our results. The findings suggest that participants with visual stress are unlikely to find exactly the same colour to be optimal on different occasions. This may indicate that the use of colour to alleviate discomfort or difficulty while reading is not a valid approach, or that the use of colour is valid but the colour does not need to be precise. Our study cannot discriminate between these possible conclusions, and a larger study is needed to establish more clearly whether individually specific and precise colours are beneficial for people with visual stress while reading.

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Figure and table captions

Table 1: Colour of overlay or combination of overlays chosen on two occasions. Same: identical overlays were chosen on both occasions; Similar: the two overlays include one identical colour and one different colour; Different: the overlays include no identical colours. Reading speed (wpm = words per minute) measured using the Wilkins Rate of Reading Test[18] is shown for two viewing conditions, with and without Overlay 1, and the change in speed as a percentage of the speed without the overlay.

Table 2: Columns labelled u'1, v'1, u'2 and v'2 each show coordinates of the preferred chromaticity settings on the first and second occasion. The chromatic displacement (CD) and the number of just noticeable differences (JNDs) are also shown.

Figure 1: The chromaticity shift (change in chosen colour between two colorimetry tests) is shown in CIE (u', v') colour space for all participants who had chosen the same (left panel), similar (centre panel) or different (right panel) overlays on the two different occasions. Filled red circles represent the colorimetry setting on the first occasion, and open circles on the second occasion. Filled grey circles on the centre panel show the chromaticity of highest saturation of hues at 60 degree intervals, to illustrate the extent of the colour space. The chromaticity of the background lighting (at zero saturation) is u' = 0.222 v' = 0.521. To illustrate the scale of the colour displacements, the horizontal black line on the left panel (from coordinates u' = 0.3, v' = 0.4) shows the extent of displacement equivalent to one JND.

Comparison	Overlay 1	Overlay 2	Reading speed (no overlay;wpm)	Reading speed (with overlay 1; wpm)	Reading speed % change
Same	Grey + Grey	Grey + Grey	-	-	-
	Grey + Grey	Grey + Grey	140	170	21
	Blue + Blue	Blue + Blue	73	81	11
	Aqua + Aqua	Aqua + Aqua	45	50	11
	Blue + Purple	Blue + Purple	106	117	10
	Aqua + Mint Green	Aqua + Mint Green	73	96	32
	Aqua + Mint Green	Aqua + Mint Green	-	-	-
Similar	Aqua	Aqua + Mint Green	-	-	-
	Lime Green + Lime Green	Lime Green + Mint Green	109	120	10
	Lime Green	Lime Green + Mint Green	146	185	27
Different	Purple	Orange	175	214	22
	Blue + Purple	Aqua	109	120	10
	Pink + Purple	Orange	108	116	7
	Blue + Blue	Lime Green + Mint Green	127	134	6
	Purple + Blue	Rose + Rose	126	147	17
	Yellow + Yellow	Orange	90	113	25
	Rose	Orange	193	227	18
	Grey	Orange	49	53	9

Yellow + Lime Green	Rose	92	103	12
Yellow + Lime Green	Purple + Pink	100	127	27
Rose	Yellow	-	-	-

Overlay Similarity	u'1	u'2	v'1	v'2	CD	Number of JNDs
Same	0.183	0.210	0.540	0.540	0.027	5.9
	0.239	0.196	0.529	0.481	0.064	13.8
	0.209	0.200	0.530	0.519	0.015	3.1
	0.197	0.218	0.532	0.541	0.023	4.9
	0.203	0.187	0.526	0.475	0.054	11.5
	0.257	0.253	0.474	0.491	0.017	3.7
	0.209	0.190	0.530	0.472	0.061	13.0
Similar	0.194	0.192	0.477	0.518	0.041	8.8
	0.208	0.192	0.530	0.517	0.020	4.4
	0.253	0.230	0.523	0.498	0.034	7.2
Different	0.184	0.261	0.540	0.544	0.077	16.5
	0.237	0.255	0.475	0.492	0.024	5.1
	0.202	0.206	0.520	0.503	0.018	3.8
	0.236	0.299	0.474	0.518	0.077	16.5
	0.158	0.261	0.441	0.484	0.111	23.8
	0.212	0.285	0.510	0.533	0.076	16.3
	0.245	0.230	0.523	0.529	0.016	3.4
	0.213	0.282	0.528	0.520	0.069	14.7
	0.224	0.249	0.544	0.538	0.026	5.5
	0.234	0.261	0.540	0.504	0.045	9.5
	0.268	0.271	0.521	0.474	0.047	10.1
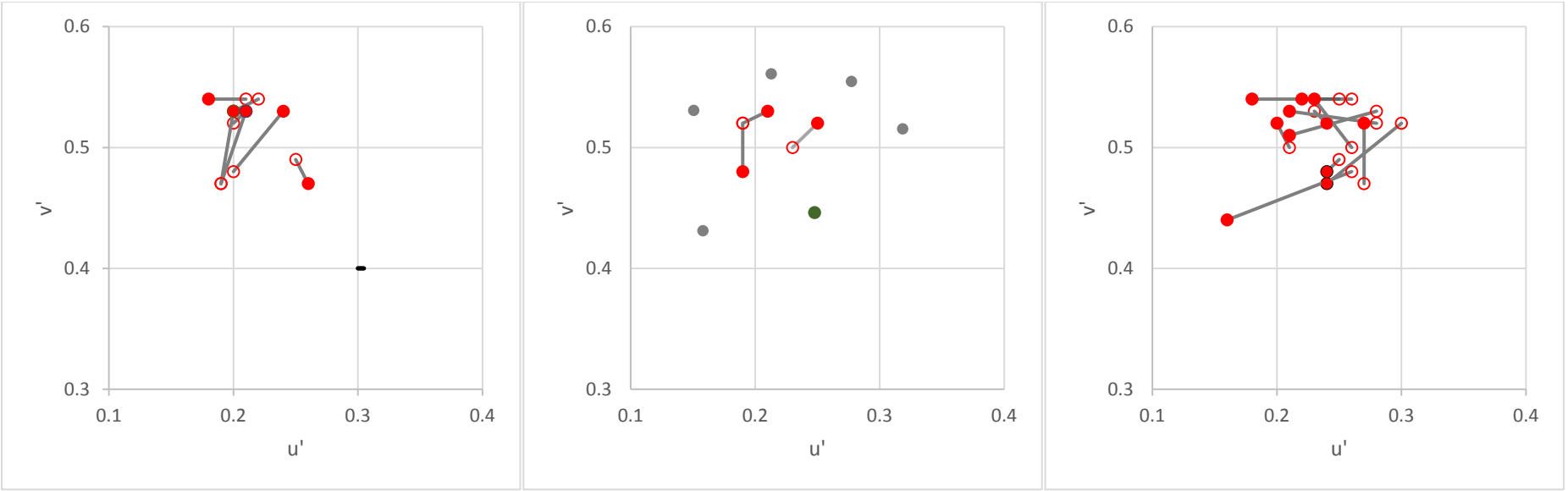
Figure 1